MEASUREMENT OF TOOTH SIZE AND SHAPE IN SUBJECTS WITH HYPODONTIA AND A CONTROL GROUP USING A NEW IMAGE ANALYSIS TECHNIQUE

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Measurement of tooth size and shape in subjects with hypodontia and a control group using a new image analysis technique

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Abstract

The literature referred to here provided information concerning the epidemiology of hypodontia and its association with other developmental anomalies. Current research with the major developments in molecular biology has focused on the genetic component of the aetiology mainly on animals. Limited information has been gained from human studies concerning the morphology of different teeth in hypodontia. The present research is both methodological and investigative in nature.

The aims of this study were to measure crown morphology of the permanent dentitions for hypodontia subjects divided according to severity of hypodontia into mild, moderate and severe groups and a control group, and then to compare the measurements of groups.

All subjects were of white Caucasian origin and were unrelated. The study groups were balanced for size (N = 40), gender (N = 20) and age. The effect of both severity of hypodontia and gender were examined. The total study population was N = 161.

A new measurement system using image analysis and new measurement index for tooth taper were developed, validated and then utilised in the main study. The image analysis technique and tooth taper measurement were validated against the classical manual measurements and subjective scoring respectively. The errors of measurements were assessed by duplicate measurements to determine the intra- and inter-observer reproducibility. It was found that measurements for all study variables were repeatable without systematic error and with small method error.

Comprehensive measurements (N = 15) were obtained from both the buccal and occlusal views for the following dimensions of tooth crowns: The principal mesiodistal (MDb and MDo) and buccolingual (BL), proportional mesiodistal (MD25, MD50 and MD75) and buccolingual (BLm and BLd), occlusogingival (OG), perimeter (Pb and Po), area (Ab and Ao) and the distance between MDb and occlusal level (Db) and between MDo and buccal border of tooth crown (Do). A number of indices (N = 5) to evaluate tooth crown morphology were also calculated: Tooth taper determination index (MD50/MD75), crown indices of buccal morphology (CIBM1 and CIBM2 i.e. MDb/OG and Db/OG respectively) and crown indices of occlusal morphology (CIOM1 and CIOM2 i.e. MDo/BL and Do/BL respectively).

Two-way analysis of variance followed by multi-comparison tests with Bonferroni adjustment for the significance levels were employed in the main study.

The results of the main study revealed significant differences between hypodontia groups and control subjects for the following measurement variables: MDb, Db, OG, Pb, Ab, MD25, MD50, MD75, tooth taper, CIBM2, MDo, Do, BL, Ao, Po, BLm and BLd. Hypodontia subjects demonstrated significantly smaller measurement values than controls except Db, tooth taper and CIBM2. The severity of hypodontia affected the degree of difference in tooth morphology; for many variables the more severe the hypodontia the greater the difference from controls. There were only a few significant differences between hypodontia and control groups for the variables CIBM1, CIOM1 and CIOM2.

Gender differences (within groups) indicated that males tend to show larger measurements than females although few findings reached statistical significance.

The symmetry of right and left measurements (MDb and tooth taper), the number of cusps in the premolar and molar teeth and the intermaxillary ratios were investigated. The findings suggest that asymmetry in bilateral measurements appeared to be increased in hypodontia subjects. Descriptive data also suggest that all the intermaxillary ratios tend to be larger in hypodontia than the control group. There was a tendency for the reduction in the number of cusps for hypodontia subjects than controls. Again, these findings were related to severity of hypodontia.

Thus, variation in tooth morphology in patients with hypodontia was clearly established. The differences were related to the severity of the condition. However, there were also variations in the measurements between individuals with hypodontia of the same severity group. A possible explanation is the multifactorial aetiology of the condition. In certain groups, especially with severe hypodontia, the small numbers of some tooth types which developed may also have influenced the results.

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Dedication

To my parents, may wife and my three children (Hunidel, Hanan and Manal). This work is also dedicated to my brothers, sisters, relatives and all friends.

Declaration

This thesis is the original work of the author using the help and guidance indicated in the acknowledgements.

Mohammad Hunidel Al-Sharood

Abbreviations And Notations

Abbreviation	*Interpretation*
1^{st}	First
2^{nd}	Second
3^{rd}	Third
M	Male
F	Female
U	Upper or maxillary
L	Lower or mandibular
Notation of Study Groups:	
0	Control
1	Mild hypodontia
2	Moderate hypodontia
3	Severe hypodontia
Notation of Genders:	
0	Male
1	Female
Notation of Study Subgroups:	
M0	Male control
M1	Male mild hypodontia
M2	Male moderate hypodontia
M3	Male severe hypodontia
F0	Female control
F1	Female mild hypodontia
F2	Female moderate hypodontia
F3	Female severe hypodontia
Tooth Notation:	
U1	Upper (maxillary) central incisor (11 is the right and 21 is the left tooth)
U2	Upper lateral incisor (12 the right and 22 the left tooth)
U3	Upper canine (13 the right and 23 the left tooth)
U4	Upper 1^{st} premolar (14 the right and 24 the left tooth)
U5	Upper 2^{nd} premolar (15 the right and 25 the left tooth)
U6	Upper 1^{st} molar (16 the right and 26 the left tooth)
U7	Upper 2^{nd} molar (17 the right and 27 the left tooth)
L1	Lower (mandibular) central incisor (31 is the left and 41 the right tooth)
L2	Lower lateral incisor (32 the left and 42 the right tooth)
L3	Lower canine (33 the left and 43 the right tooth)
L4	Lower 1^{st} premolar (34 the left and 44 the right tooth)
L5	Lower 2^{nd} premolar (35 the left and 45 the right tooth)
L6	Lower 1^{st} molar (36 the left and 46 the right tooth)
L7	Lower 2^{nd} molar (37 the left and 47 the right tooth)
i.u.	Intra-uterine
N (n)	Number
Y	Year
M	Month
MM (mm)	Millimeter
ICC	Intra- or inter-class Correlation Coefficient
2-way ANOVA	Two-way Analysis of variance
SD (Std Deviation)	Standard deviation
Sig	Significant or significance
P	Probability
P1	Significance level of multi-comparison tests (before final adjustment)
P2	Significance level after final adjustment
=	equals to
+	Plus
−	Minus
±	Plus and minus

/ or (÷)	divided by
x	Multiplied by (times)
$<$	Less than
$\leq$	Less than or equals to
$>$	Greater than
$\geq$	Greater than or equals to
Min	Minimum
Max	Maximum
mg	Milligram

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Chapter 1

Introduction

1.1. INTRODUCTION

Orthodontics is a branch of dentistry that is concerned with growth and development of the human face and dentition, the development of dental occlusion and correction or prevention malocclusions. Functional occlusion, improved appearance and a stable result are the main objectives of contemporary orthodontic management. The maxillary and the mandibular jaws, together with the facial soft tissues and the dentition, are the major components of the human dentofacial complex. The developmental anomalies of this complex result from disturbances of the normal mechanisms of growth and development. The morphology and position of the dentition has a critical role in the performance of some of the functions of the mouth such as chewing, swallowing and speech, as well as the appearance of the face. For good occlusion therefore, the teeth must be proportional in morphology.

Accordingly, malocclusion of the dentition is any form of teeth interdigitation that has undesirable effects in the appearance and function of dentofacial complex. The World Health Organisation includes malocclusion under the heading of Handicapping Dentofacial Anomalies. These have been defined as: "An anomaly which causes disfigurement or which impedes function and which requires treatment if the disfigurement or functional defect is, or is likely to be, an obstacle to the patient's physical or emotional well being" (WHO 1962). Slazmann (1968) maintains that, a handicapping malocclusion is one, which negatively affects function, aesthetics and speech. Hypodontia (Figures 1-5), supernumeraries, ectopic tooth positions and craniofacial deformities are examples of developmental anomalies, which may cause dental malocclusions, and are of a prime concern to dental researchers and clinicians. All dental surgeons, not only orthodontists, are concerned with the aetiology of malocclusions to set a realistic treatment plan and predict prognosis.

There had been a particular emphasis, in this century, on growth and development of the human dentition. The predominant influences in this development are genetic and environmental factors (Garn et al. 1980, Brook 1984, Berdal et al. 1987, Townsend et al. 1988, Heikkinen et al. 1994, Thesleff and Aberg 1997, Alvesalo 1997, Tucker and Sharpe 1999, Sarkar and Sharpe 2000, Sew and Wan 2000).

The study of hypodontia relates to problems of diagnosis and treatment planning. It is fairly common to find a history of hypodontia in a family during clinical examination. On some occasions, malformation of teeth is seen in persons with no congenital absence of teeth, but with a family history of hypodontia. Certain teeth e.g. the 3rd molar, 2nd premolar and maxillary lateral incisor teeth are more affected by hypodontia than the rest of dentition. Moreover, females are more frequently affected by hypodontia than males. Sometimes, hypodontia is seen as a manifestation of more generalised syndromes such as ectodermal dysplasia and cleft lip and/or palate (Redpath and Winter 1969, Shapira et al. 2000). The clinician may face a problem with regard to space management. This fact is due to the general effect on the size and shape of the remaining teeth (Figures 1-5). A common example is the maxillary lateral incisor teeth that may appear as tapered in shape or microdont, unilaterally or bilaterally (Alvesalo and Portin 1969, Foster and Van Roey 1970). Alterations in tooth morphology appear to be related to hypodontia.

The orthodontist, restorative and paediatric dentists and general practitioner may all be involved in the clinical management of these patients. It is generally agreed that the more severe the hypodontia the more complex is the management. In severe cases, the facial morphology may be adversely affected due to reduction in the alveolar process dimensions and lip protrusion and/or retroclination of the anterior teeth (Sarnas and Rune 1983, Nodal et al. 1994, Ogaard and Krogstad 1995). Occasionally, masticatory function is reduced and psychological concerns caused by poor dental aesthetics are also of importance (Graber 1978, Hobkrik and Brook 1980). Therefore, hypodontia needs careful diagnosis and an appropriate management.

To aid the diagnosis of developmental anomalies of tooth number and morphology, various techniques are used to analyse clinical records. For example, classical manual measurements, radiographs and tables have been used to estimate the size and shape of patient's teeth. Researchers and clinicians still encounter difficulties in planning treatment and predicting results and stability. One problem is the availability of an accurate and valid technique to analyse the records.

Previous studies pointed out that there is a need for more information with regard to understanding the aetiology of hypodontia. It has been clear that the comprehensive measurement for tooth morphology is missing in the literature to further explain the link between hypodontia and alterations in dental morphology. There is also a shortage of knowledge concerning determination the patterns of hypodontia according to severity, gender and location. No such studies have been done before.

The main aim of this study is to investigate the crown morphology of permanent teeth from study casts of hypodontia patients with different categories of severity and compare them with a control group of subjects with normal complement of permanent dentitions, and taking into account the factor of gender. The study also aims to investigate the use of a new image analysis technique to obtain measurements.

This investigation is described in a series of chapters. The following chapter (Chapter 2) presents the survey of the literature that has been divided into several sections and subsections. The statement of the problem, aim, objectives and hypotheses of the study are presented in the Chapter 3. Chapter 4 describes the study population, materials, and methodology. Assessment the accuracy of the new image analysis system and measurement methods is divided into two chapters: Chapter 5 shows reliability of part of measurement variables and validation of the new measurement technique. Chapter 6, on the other hand, discusses determination of tooth taper and reliability of the other part of measurement variables. The results are demonstrated in Chapter 7. The discussions and conclusions are reported in Chapter 8, which are followed by some recommendations for further work.

Figure 1: Clinical picture for dentition with mild hypodontia. The figure shows hypodontia of both permanent maxillary lateral incisor teeth.

Figure 2: Clinical picture for dentition with moderate hypodontia. This case illustrates hypodontia of five premolar teeth.

Figure 3: Clinical picture for dentition with severe hypodontia. The figure shows multiple absence of different permanent teeth.

Figure 4: Clinical picture for dentition with severe hypodontia. Many permanent teeth are absent.

Figure 5: Clinical picture for dentition with severe hypodontia. Multiple permanent teeth are absent.

Figures 1-5 demonstate a range for the severity of hypodontia. These also present dental malocclusions that are manifested by the absence of different tooth types, abnormal morphology and displacement of the erupted teeth and interdental spacing.

1.2. TERMINOLOGY USED IN THE STUDY

1.2.1. Hypodontia

Hypodontia is the congenital absence of one or more teeth. In the permanent dentition studies often exclude the third molars. For the purpose of this study, a classification is suggested to describe the congenital absence of teeth, taking into account the use of only two terms as well as the severity of the condition affecting the permanent dentitions (Table 1). This also holds with definitions given in previous research (Wisth 1974a, Hobkrik and Brook 1980, Burzynski and Escobar 1983, Schalk-van der Weide 1992).

Table 1: A classification and definitions of the congenital absence of teeth (3^{rd} molars are excluded).

TERMINOLOGY	DEFINITIONS
HYPODONTIA	***Hypodontia*** indicates the congenital absence of one or more teeth. ***Hypodontia/S;*** is the congenital absence of one or more teeth with evidence of associated syndrome. Three categories are used to describe the severity of hypodontia: 1. ***Mild hypodontia:*** The absence of one or two teeth. 2. ***Moderate hypodontia:*** The absence of three to five teeth. 3. ***Severe hypodontia:*** The absence of six and more teeth.
ANODONTIA	***Anodontia*** refers to complete congenital absence of the dentition. ***Anodontia/S;*** defines congenital absence of the whole dentition when the anomaly is part of a syndrome

1.2.2. Dental Morphology

In this study, the morphology of a tooth indicates its size and shape.

1.2.3. Dental Dimension

Dental dimension refers to any measurement variable of a tooth. For instance, the mesiodistal dimension refers to the mesiodistal diameter, tooth width, breadth, etc.

1.2.4. Tooth taper

Tooth taper is the convergence of the proximal surfaces in the direction of the occlusal surface (incisal edge). This refers to the anomaly of tooth morphology and the incisor teeth are measured in this study. It covers the so-called peg-shaped, conical, pointed and malformed incisors, etc. Tapered incisors could show small or large mesiodistal and/ or occlusogingival dimensions.

Chapter 2

Review Of The Literature

This review of the literature briefly covers the overall development of the human dentofacial complex. However, the main emphasis will cover abnormalities of the human dentition particularly those including a reduced number of teeth as well as abnormalities of tooth size and shape.

2.1. OVERVIEW OF FACIAL DEVELOPMENT

Cytology, growth and genetics are interrelated sciences concerned with cell formation and the multiplication of cells as well as transferring the features of the identity of the living organism. Human growth and development involves all those factors that affect initial cell formation and zygote development and divisions. There have been several documented studies that have particular emphasis on the development and growth of the human face although; it has not yet been completely defined. The literature shows that, this is a series of complex processes involving the interaction of genetic and environmental factors (Hellman 1927, Brodie 1953, Bjork 1955, Enlow 1966, Sperber 1967, Moss and Salentijn 1969, Nanda 1975, Poole 1975, Gullikson 1975, Sarnas and Solow 1980, Hook 1981, Mills 1985, Ginsburg et al. 1991, Heikkinen et al. 1994).

It is generally accepted that, the overall growth and development of the human face occurs in two interrelated phases the prenatal and postnatal phases. This overview briefly outlines the main concepts of development, the events that take place and their significance to orthodontic diagnosis and management.

2.1.1. Prenatal Growth and Development

The initiation of human development occurs at the union of male and female gametes to form a highly specialised single cell called a zygote which contains units of genetic information (chromosomes) that are derived from both parents. Each cell contains 46 chromosomes as demonstrated by Tjio and Levan in 1956 (cited by Cohen 1975). The human X and Y chromosomes carry determinant components (genes) that affect development and influence final body shape and skeletal and dental development.

The prenatal or the intrauterine (i.u.) life is the first phase of human growth and development, which occurs during the whole period of pregnancy until the moment of delivery. This phase lasts, on average of 40 weeks. It is divided into two main stages; the embryonic and foetal stages. Embryonic development commences with zygote development and ends at the end of the 8th week of gestation. It involves differentiation and organisation, which are the most significant stages of embryogenesis.

It has been pointed out that the embryo is a genetically predetermined structure that may be affected by teratogenic effects of many environmental factors during pregnancy (Yamazaki et al. 1954, Sever et al. 1965, Axrup et al. 1966, Gullikson 1975, Nanda 1975, Poole 1975, Ciola 1975, Garn et al. 1980, Hook 1981, Sperber 1989, Ginsburg et al. 1991, Moore and Persaud 1993, Heikkinen et al. 1994, Proffit 2000). A teratogen is an agent, such as a drug, infection or irradiation that produces or raises the incidence of congenital abnormalities. Adverse results from this may be growth deviation in the form of tissue malformation, suppression and morphologic changes, or embryonic death.

Foetal life extends for seven months and starts as a continuation from the embryonic period and ends at the birth of the neonate. It is characterised by rapid growth, reproportioning of body components, maturation of functions and increase overall growth of the foetus. The human face takes its initial shape in the 4^{th} month i.u., and the size of the body increases and develops more rapidly than the head in foetal life (Sperber 1989, Moore and Persaud 1993). As a result, a change of the head size occurs from about half of body size at the beginning of the foetal phase to about one-third at the 5th month and one fourth at delivery.

2.1.2. Postnatal Growth and Development

Postnatal growth and development is the second phase of development. It involves several growth periods such as, infancy, childhood, pubertal growth spurt, adulthood as well as late growth changes. The literature indicates that the tissues and organs grow at different rates as well as achieving proportional harmony. Another concept is that of variability in which growth has a range of normal pattern. Considerable dentofacial variations exist between different racial backgrounds, and even among people of the same community (Hellman 1927, Harris 1975)

Several theories and concepts have been proposed to describe dentofacial development. The implant studies demonstrated the concept of growth rotations (Bjork 1955, 1963, 1969, Bjork and Skieller 1972). During growth, both jaws rotate and move in various directions. The maxilla grows mainly in a forward and downward direction, while the mandible may presents different rotations, various facial profiles and dental occlusions are therefore, expected.

Bone, suture and cartilage, together or separately, may be the prime indicators of craniofacial growth and development (Enlow 1966, Mills 1985). The nasal septum and the condyle of the mandible are examples of cartilage sites. Bones undergo comprehensive processes of remodelling (resorption, deposition and translocation). The suture and bone system may be responsible for some congenital deformities, such as, craniofacial synostosis e.g. Crouzon syndrome (Kreiborg and Bjork 1982).

In the functional matrix theory (Moss and Salentijn 1969), the soft tissues are the determinants, while bone and cartilage grow in response to the functional need of the soft tissue. The classic examples are the enlargement of the nasal, oral and orbital cavities for the functional needs of breathing, mastication and sight. The teeth provide the functional matrix for the alveolar bone growth.

A mechanism of dental compensation i.e. the tendency of the alveolar bone in both jaws to normalise the arch relationship in cases with jaw malrelationships has been discussed (Brodie 1953, Solow 1980). The adverse effects of airway obstruction may result in abnormal facial growth and the development of malocclusions (Subtelny 1954, Linder-Aronson 1975, Linder-Aronson et al. 1993). The equilibrium theory of tooth position and its surroundings has also been proposed (Proffit 1978, Moss 1980).

Most of human growth is completed in the postpubertal spurt period, the facial bones retain the potential for further apposition growth in adult life i.e. late growth (Brodie 1953, Sarnas and Solow 1980). An increase in mandibular prognathism, facial height, and lower anterior teeth crowding are some examples of adult changes.

2.1.3. Developmental Disorders

Birth defects and congenital deformities or anomalies are similar terms used to describe developmental disorders that occur in prenatal life and present at/or after birth. The severity of these disorders ranges from minor to very major clinical significance. Several congenital facial deformities have been reported in the literature as potentially occurring during embryonic life. For example, Poole (1975) and Sperber (1989) pointed out that it is at this period of life that clefts of the lip and/or palate occur. Proffit (2000) reported on other conditions: Treacher-Collins syndrome or mandibulofacial dysostosis may result from a mesenchymal tissue deficiency manifested by mandibular and maxillary underdevelopment. Hemifacial microsomia or unilateral tissue lack or deficiency typically involves the tissues of the external ear and the ramus of the mandible. During the foetal stage, the craniofacial synostosis such as, Crouzon's syndrome and Apert's syndrome are defects that may occur. These are the result of the premature fusion of the craniofacial sutures. There have been several factors suggested in the literature to be involved in the aetiological mechanism of these developmental disorders.

2.1.3.1. Genetic Factors

Genetic factors may be the most important element in the aetiology of most of the congenital anomalies. Carter (1969) described and divided the genetic disorders into these caused by chromosomal abnormality, mutant genes, maternal-foetal incompatibility, and those by extremes of normal variation caused by alleles at many gene loci. Many syndromes have been reported to demonstrate congential tooth anomalies such as hypodontia. Hall (1983) listed 56 syndromes having congenital tooth absence as part of the syndrome; 34 general syndromes and 22 of the 55 clefting syndromes. The cleft of the lip and/or palate is the commonest deformity affecting the head and neck region. The cleft lip and/or palate conditions are related to hypodontia and discussed below (section 2.5.2.2.).

Ectodermal dysplasia consists of a large number of conditions, which are characterised by disturbances in the formation and function of ectodermally derived structures, maily hair, nails, teeth and sweat glands. The relationship between this anomaly and the congential absence of teeth is also discussed below (section 2.5.2.1.). Rieger syndrome is another condition that is linked to hypodontia (section 2.5.2.3.).

Chromosomal abnormalities may involve either the number or structure of chromosomes. The anomaly may affect sex and/or autosomes. The prevalence of chromosomal disorders is not little. Individuals with such anomalies have characteristic phenotypes. Down's Syndrome (trisomy 21) is commonest chromosomal defect occurs once in every 1,400 births in mothers aged 20-24 years and once in 20-25 births in mothers aged 45 years or more (Hook 1981, Moore and Persaud 1993). Many physical, facial as well as oral characteristics have been reported including hypodontia, tooth size and tooth structure anomalies and occlusal disturbances. Moreover, sex chromosomes (Klinefilter and Turner syndromes) have been demonstrated to influence tooth size. This is discussed in a section to follow (section 2.6.3.1.).

The morphology of teeth may be influenced by genetic factors. The relationship between these parameters is discussed below (section 2.2.2., 2.3., 2.4.4.5, 2.4.4.6., 2.5.1.1., 2.5.1.2.)

2.1.3.2. Environmental Factors

Teratogens are environmental factors, which usually act during the active stage of differentiation of the tissue or organ. The precise mechanism by which these factors interfere with the early stage of development and cause defects has not been clearly defined. The survey of the literature suggests that if an environmental agent is given at a significant dosage and at a specific stage of embryonic development, it may adversely affect or disturb normal growth and development.

Teratogenesis has been demonstrated by many clinical as well as experimental studies. Experimental studies demonstrated that the maximal incidence of cleft palate does happen when a teratogenic drug has been given during the cell differentiation and mobilisation stages (Nanda 1975, Sperber 1989). It has been estimated that between 7% to 10% of human birth defects result from adverse actions of drugs, viruses and other environmental factors (Moore and Persaud 1993).

The role of maternal condition (physiological and pathological) has been pointed out by many clinical and experimental observations. The incidence of congenital malformations increases in the pregnancies of older mothers. Down's syndrome is an example in which incidence is related to maternal age (Hook 1981).

The quality and quantity of the diet might have an effect on embryonic development. Evidence has been reported in which a low caloric diet given to pregnant mice increased the teratogenic action of cortisone (Nanda 1975). Many investigators claim that maternal health and low birthweight are associated with delay in dental development and reduction in tooth dimensions in children (Bailit and Sung 1968, Garn et al. 1980, Sew and Wan

2000).

Social habits of the mother e.g. alcohol intake, smoking and also climate are other suggested factors (Ginsburg et al. 1991, Heikkinen et al. 1994). Alcohol consumption during pregnancy is a risk factor for developmental damage which ranges from spontaneous abortion, growth retardation, abnormal facial and head structures to behavioural abnormalities Ginsburg et al. (1991). The estimated prevalence of foetal alcohol effects ranges from 24 to 29 per 1,000 births compared with 1 to 3 per 1,000 births in the general population births. It can affect nearly every organ system in both humans and animals and is responsible for about 5% of all congenital anomalies.

The effect of maternal smoking during gestation on dental development has been investigated by Heikkinen et al. (1994) in 2,159 pregnancies. They found a trend of size reduction in the 1^{st} molar and incisor teeth and concluded that smoking may affects overall development and dental development at some specific sensitive period i.e. 24^{th} to 28^{th} gestational weeks.

Diabetes and blood pressure disturbances have also been demonstrated as factors, which affect the blood flow through the placenta and the normal fluid exchanges between the mother and her embryo (Nanda 1975, Garn et al. 1980). The effects of diabetes, hypothyroidism and hypertension have been tested by Garn et al. (1980) who found a relationship between these conditions with deviations in the size of tooth crowns and birth weight of the offspring. The sample involved 870 individuals at age 7 to 8 and findings revealed that, diabetes, hypothyroidism, prolonged gestation, high birth weight and large size at birth were associated with greater than average tooth size, and the opposite was found with hypertension, short gestation and lower birth weight and length.

Infection during pregnancy might have an effect either by disturbing the normal physiology of the body or by the secondary effect of drugs taken to control infection, or by both. Nanda (1975) noted that 70% of mothers who contracted German measles (Rubella) during the first trimester had birth defects in their offspring. These findings were in an agreement with other reports (Sever et al. 1965, Gullikson 1975). Untreated maternal syphilis may cause deafness and abnormal teeth and bone (Moore and Persaud 1993).

The relationship between drugs and developmental malformations has also been demonstrated (Nanda 1975, Moore and Persaud 1993). An antibiotic such as tetracycline may disrupt the development of the permanent dentition from 18 weeks to age 16, while streptomycin may cause deafness. Corticosteroids and imipramine hydrochloride have a similar teratogenic effect. A single dose of 50 mg of a sedative such as thalidomide when taken by pregnant women in the 4^{th} to 7^{th} weeks of gestation, may result in 20% of babies having skeletal malformation, typically cleft palate, absence or dysplasia of the eyes and ears (Axrup et al. 1966). The dental anomalies reported are hypodontia, enamel hypoplasia and small crown size (Nanda 1975). Anticonvulsant drugs such as diphenylhydantoin was reported to be implicated in the cause of cleft palate and cardiac malformation in some offspring of mothers who had taken such drugs during pregnancy (Nanda 1975). Moore and Persaud (1993) added that trimethadione may case growth retardation, clefts and limb defects and large doses of salicylates at an early stage of pregnancy might have a teratogenic effect.

The adverse effects of irradiation on the normal development have also been demonstrated. Yamazaki et al. (1954) reported deformities in the babies of women who were pregnant at the time of the atomic explosions in Hiroshima and Nagasaki. Niswander (1975) suggested similar findings. Weyman (1968) reported failure of tooth development in a case exposed to irradiation. Nanda (1975) pointed out that an exposure to 100 roentgens of radiation in the 9th day of rat embryo development resulted in many malformations for most subjects. Malformations were fewer when the exposure was on the 10th day and no malformation were noticed when the x-ray exposure was on the 11th day of gestation. Ciola (1975) pointed out that the possible genetic effect of irradiation results from the production of chromosomal aberrations and gene mutations.

Further discussion will be shown (section 2.3., 2.4.4.3., 2.4.4.4., 2.6.3.1.)

2.2. OVERVIEW OF DENTAL DEVELOPMENT

There have been several studies carried out to investigate dental development (odontogenesis) and all were in agreement that the process is complex and highly organised and involves interactions of various factors. Fortunately, a tremendous revolution in molecular biological techniques in the past 10 years has provided valuable insight and better understanding for this phenomenon.

2.2.1. Anatomy of Tooth Morphogenesis

The dentition is derived from the ectoderm and mesoderm, with a contribution from the neural crest (Figure 6). The ectoderm gives rise to the tooth enamel, while the neural crest tissue provides material for the formation of dentine and pulp as well as the cementum. The periodontium, on the other hand, is derived from both mesoderm and neural crest materials (Kollar 1975, Bazen 1985, Sperper 1989, Thesleff et al. 1995, Thesleff and Aberg 1997, Thesleff and Sharpe 1999, Ferguson 1999). Classically, dental development is divided into the bud, cap, bell, calcification and eruption stages (Figure 7).

Tucker and Sharpe (1999) described three interrelated processes (initiation, morphogenesis and patterning) to be involved in early odontogenesis. The initiation is the process that determines the sites in the developing jaws where teeth will develop in which a number of signals or molecules e.g. Fgf-8 (Fibroblast growth factor-8) were involved as part of a genetic cascade which sets up the whole tooth initiation. The source of initiating signals is the oral epithelium but, the mechanisms which restrict the expression of signals is yet unknown. The next step includes determination of how the oral epithelium will thicken and then produce the correct tooth germs in the correct position along the oral surface, i.e. morphogenesis (formation of different tooth shape) and patterning (correct locations of teeth in the jaws).

The first morphological evidence for human odontogenesis is the formation of a primary thickening of the oral epithelium around the lateral margins of the developing oral cavity, which then buds into the underlying mesenchyme (Figure 7). This takes place as early as the 4th week i.u. (Bazen 1985, Sperber 1989, Alvesalo 1997) or the 6th week i.u. (Kollar 1975). The free margin of this epithelium gives rise to two processes that invaginate into the underlying mesenchyme. The outer process (vestibular lamina) will form the vestibule

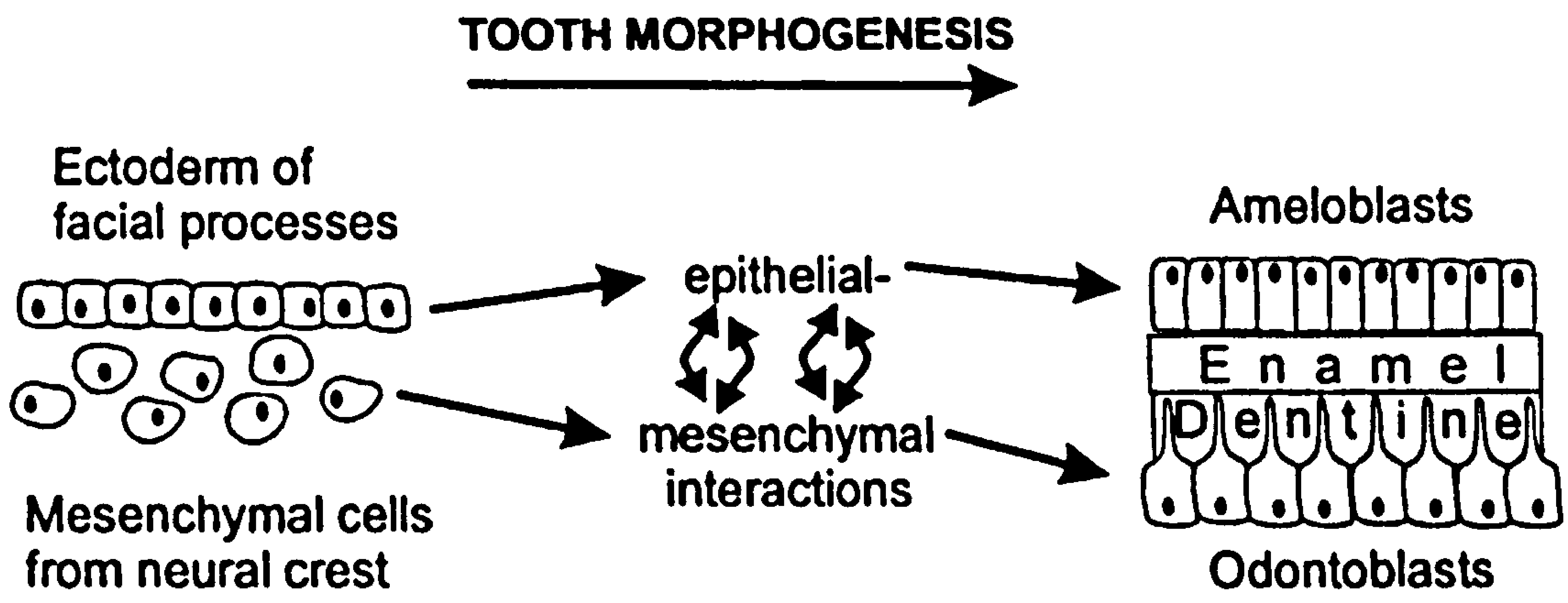


Figure 6: Dental development: Schematic representation of the differentiation of the ameloblasts and odontoblasts at the interface between epithelium and mesenchyme, which is linked to mechanism of tooth morphogenesis during various developmental stages (bud, cap and bell stages). The ectoderm of the facial process gives rise to the formation of ameloblasts, and the underlying neural crest-derived mesenchymal cells to formation of odontoblasts.

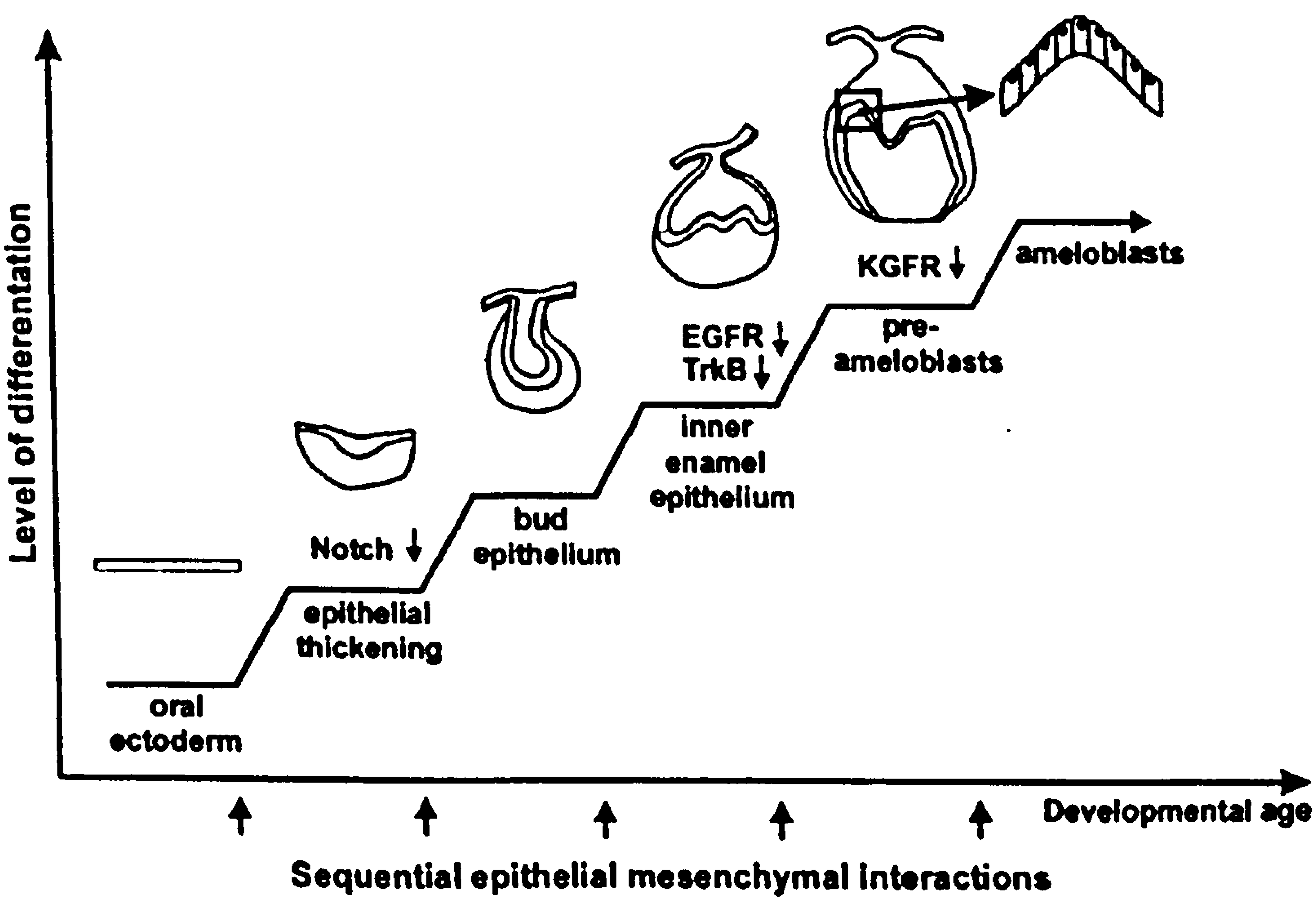


Figure 7: Dental development: Schematic representation for the differentiation of ameloblasts and the tooth morphogenesis. A chain of epithelial-mesenchymal interactions regulates the differentiation of the ameloblasts and down-regulation of several signalling receptors occurs at various stages of development e.g. Notch receptor before the bud stage, epidermal growth factor receptor (EGFR) and fibroblast growth factor receptor (KGFR: keratinocyte growth factor receptor) at the bell stage.

* *Figures 6 and 7 have been reproduced from Thesleff and Aberg (1997) with permission.*

that demarcates the cheek and lip from the tooth-bearing regions. The inner one (dental lamina) from which the tooth buds form. Then, discreet swellings of the dental lamina form the enamel organs that differentiate through the bud, cap and bell stages. In addition, condensations of neural crest-derived ectomesenchymal cells occur locally to form the dental papilla and peripherally around the enamel as the dental follicle. All of these developing tissues are known as the tooth germ. As the dental papillae are formed, the number of teeth is determined.

The initiation of a tooth germ depends on interaction between the proliferating dental epithelium and its underlying mesenchyme. A chain of inductive interactions exists between the two tissues, which controls both tooth morphogenesis and cell differentiation (Ruch 1985, Thesleff and Aberg 1997, Thesleff and Sharpe 1999, Sarkar and Sharpe 2000). Thus, the differentiation of the tooth-specific cell types (the mesenchymal odontoblasts, cementoblasts and epithelial ameloblasts) is tightly linked to tooth morphogenesis. They analysed the expression of many signals in different growth factors in developing teeth from the time of initiation to the stage of completed crown morphogenesis and found that the expression is down-regulated relatively early in the ameloblast cell lineage (Figure 7). The mesenchymal cells condense around the bud and during the cap and bell stages the epithelium undergoes folding morphogenesis, resulting in the determination of the tooth-crown form.

The tooth germs of the deciduous incisor, canine, and 1st molar teeth develop by the 6th week i.u. and the 2nd deciduous molar tooth germs start to form in the 7th week. Whereas the tooth germ of the permanent 1st molar begins at the 16th week i.u. and the 2nd and 3rd molars after birth (Sperber 1989). The maxillary dentition is formed from four sites of origin of odontogenic epithelium at the borders of the frontonasal prominence, whereas the mandibular teeth develop from four initial sites of development in the mandibular arches, two in each side. The primary tooth germs are ten in each jaw while the tooth germs of the permanent teeth develop lingually to their predecessor tooth germs (Sperber 1989, Ferguson 1999). The distal extension of the dental lamina gives rise to the primordia of the primary 2nd molar as well as the permanent molar teeth. Each tooth germ is composed of an enamel organ and dental papilla surrounded by a dental sac (follicle) which becomes ossified forming a bony crypt in which the tooth develops and later erupts.

Hertwig's epithelial root sheath is formed by the inner and outer enamel epithelia and by enclosing the dental papilla, the epithelium root sheath outlines the root of the tooth. The root sheath subdivisions determine the number of roots of a tooth. The inner enamel epithelium of the root sheath induces odontoblast differentiation to form dentine, which precedes enamel formation by the ameloblasts. The dental sac lays down cementum over the root. The dental papilla differentiates into the dental pulp and the peripheral cells into odontoblasts. At this time, the periodontal ligament begins to form. The ameloblasts of the inner enamel epithelium and the adjacent odontoblasts form a bilaminar membrane, which is believed to be under genetic control (Kollar 1975, Sperber 1989, Ferguson 1999). Its differing folding, dictated by unknown factors, determines the shape of each individual tooth cusp and their number.

Tonge (1969) investigated the time-structure relationship of tooth development of 31 human embryos and found a sequential appearance of tooth differentiation relative to the general embryonic processes. As a result three phases have been suggested, namely, potentiality (0-22 days), interaction (23-32 days) and specificity of individual structural formation (32-48 days). In animals, Slavkin and Bavetta (1968) investigated the odontogenic epithelial-mesenchymal interaction in 240 upper and lower incisors of 20-day embryonic rabbits. The epithelium or mesenchyme has no potential to develop into a tooth germ in isolation. They suggested that, the potential for tooth morphogenesis is determined prior to the 20th day of gestation in the rabbit incisor.

Kollar (1975) also confirmed the role of the enamel organ and the mesenchymal papilla in tooth formation. When an embryonic tooth germ is cut into two similar pieces, the formation of two small teeth was demonstrated. Sperber (1989) argues that, because there are branches of alveolar nerves growing into the jaws and adjacent to the sites of ectomesenchymal condensation, a neural inductive influence for odontogenesis may exist. His experimental evidence was in amphibia in which ablation of neural crest tissue resulted in absence of tooth formation.

The chronology of the initial mineralization or calcification of the deciduous dentition showed variations (Moorrees et al. 1963, Garn et al. 1970, Lunt and Law 1974, Sunderland et al. 1987). Lunt and Law (1974) reviewed the literature back to 1861 and reported the sequence of calcification in the deciduous teeth to be; central incisors, 1st molars, lateral incisors, canines, and 2nd molars. They suggest ranges instead of fixed values to reflect developmental variations. Moorrees et al. (1963) used intraoral radiographs (for 48 males and 51 females) and lateral or oblique jaw radiographs (for 136 males and 110 females) and demonstrated 14 different stages of tooth development, and pointed out some gender differences.

Garn et al. (1970) used histological sections of 52 first trimester human embryos (22 males and 33 females), to test the use of tooth formation as a prenatal reference standard. They suggested that there was a gender variation with higher tooth stage and body size correlation for females than for males. Sunderland et al. (1987) evaluated serial sections of the jaws of 121 human foetuses aged 10 to 26 weeks post-menstrual and concluded that none of the deciduous teeth exhibited mineralization earlier than 15 weeks. Findings have shown that, the first mineralised dentine in the deciduous central incisor teeth was at 15-19 weeks, while in lateral incisors, canines and 1^{st} and 2^{nd} deciduous molars mineralised dentine first appeared at 16-21, weeks, 19-22 weeks, 16-19 weeks and 20-22 weeks respectively.

2.2.2. Molecular Biology of Odontogenesis

Current investigations have focused attention on the impact of certain elements on tooth development at the cellular level. With recent advances in genetic techniques and contribution of various specialities that are concerned with human development, more information has been provided about the early communication between the epithelial and ectomesenchymal cells, genes and structural proteins. The mouse was commonly used to study the mammalian development due to its suitability for both embryological and genetic manipulation.

The genetic pathways that control morphogenesis are established between the transition from bud and cap stage. Certain controlling molecules called growth factors, receptor molecules and transcription factors were found (MacKenzie et al. 1992, Vainio et al. 1993, Satokata and Maas 1994, Thesleff and Sharpe 1997, Davideau et al. 1999, Tucker and Sharpe 1999, Sarkar and Sharpe 2000). For instance, some growth factors like bone morphogenetic protein (BMP2 and BMP4), Wnt proteins or fibroblast growth factor (FGF-3 and FGF-4), may function as signals or regulators for initiation of tooth development as well as crown shape morphogenesis.

Transcription factors are DNA-binding proteins that control the activity of other genes. These constitute several groups such as the homeobox genes, which are highly conserved molecules and are important molecules for the development of the craniofacial complex and tooth morphogenesis (Thesleff et al. 1995). Specific combinations of these genes expressed in the neural crest cell may control tooth type and patterning (Thesleff and Sharpe 1997). The homeobox gene Msx2 was found to be expressed in the enamel knot, septum and naval. This and many other genes such as Msx1 show a complex interaction that suggests a possible link between cusp development and bud initiation (MacKenzie et al. 1992).

If transgenic mice are lacking any of these functional Msx1 (also known as Hox 7) and Msx2 genes (Hox 8), tooth development does not occur (Satokata and Maas 1994). Similarly, in experimental work on mice embryos, the epidermal growth factor (EGF) and epidermal growth factor receptor (EGFR) have been implicated to play a role in the early odontogenesis.

The enamel knot is a transient population of non-dividing epithelial cells that can be seen in sections of tooth buds as a dense population of cells at the early cap stage and disappeared by the late cap stage (Thesleff and Sharpe 1997, Tucker and Sharpe 1999). It acts as a signalling centre that directs cusp morphogenesis i.e. regulating tooth shape development by remaining non-proliferating while stimulating the proliferation of surrounding cells. The future of tooth germ, therefore, is already determined to be incisor, canine, premolar or molar tooth in the upper or lower jaw.

The DLX homeogenes that encode transcription factors are suggested to be involved in the patterning of orofacial skeleton derived from neural crest cells. Davideau et al. (1999) investigated the expression of DLX5 genes in human embryos that was detected in the mandible at 6 weeks and then in the maxilla. They pointed out that its expression became restricted to progenitors cells of developing tooth germs, bones and cartilage of mandible and maxilla. Moreover, asymmetric expression of DLX5 in the dental epithelium and mesenchyme during odontogensis from bud to cap stage would contribute to complex patterning of tooth shape.

Evidence has been shown concerning the role of some elements in the early stages of odontogenesis. Berdal et al. (1987) investigated the histology and microradiography of early post-natal molar tooth development in vitamin-D deficient rats in comparison with those of vitamin-D replete controls. The cytodifferentiation of odontoblastic cells was inhibited and the number of mineralised cusps was significantly lower in deficient group so teeth tend to be flat. Accordingly, vitamin-D deficiency disturbs mophogenesis and histodifferentiation of both epithelial and mesenchymal tissues. Parvalbumin (calcium-binding protein) also has a relationship with the biomineralization of ameloblasts and odontoblasts during tooth development (Davideau et al. 1993). It could contribute to membrane plasticity during differentiation and could buffer calcium producing mineralised enamel and dentine during the later stages of tooth development. Vitamin D-dependent calcium-binding proteins known as Calbindins-D are also expressed in rat mineralised tissue and appear to have phenotypic role in mineralised tissue cells (Berdal et al. 1996).

2.2.3. Clinical Perspectives

Understanding the types and roles of these controlling molecules is a very important achievement. They, therefore, should be considered to have significant roles in the aetiology of many dental and craniofacial anomalies (Ranta 1986, Ivens et al. 1990, Murray et al. 1992, Thesleff and Aberg 1997, Arte et al. 1996, 1997, Goldenberg 2000, Sarkar and Sharpe 2000).

Ranta (1986) suggested a mutation in Msx1 to be included in cases having cleft palate as well as hypodontia. Ivens et al. (1990) pointed out that in some patients with Wolf-Hirschhorn disease, the Msx1 gene is deleted. On the other hand, mutation of the human Msx2 gene was responsible for some type of cryniosynostosis. In Rieger syndrome, the epidermal growth factor in chromosome 4 has been implicated (Murray et al. 1992). While the gene defect in ectodermal dysplasia has been localised to Xq13-21 (Arte et al. 1996). A recent study by Sarkar and Sharpe (2000) suggested that inhibition of Wnt proteins signalling has led to retardation in tooth development and formation of smaller teeth.

The relationship between these genes and the developmental absence of teeth has been discussed in section on the aetiology of hypodontia (section 2.4.4.5, see also 2.5.2.).

2.2.4. Tooth Eruption

Eruption is the process by which the tooth emerges from its site of formation through the alveolar bone and the gum into the oral cavity to achieve the occlusion. A process of bone resorption and deposition creates eruption space for them. The literature indicates that, teeth have a longer chronological development period than any other organ in the human body. The sequence of eruption appears to be under genetic control, while variation in the age of eruption may be caused by hormonal, nutritional and/or disease conditions (Sofaer 1975, Stewart and Poole 1982).

The exact eruptive force of the mechanism of tooth movement has not been fully defined, as a result, several theories have been proposed to account for this (Sperber 1989, Sandy 1992, Ferguson 1999). The force may be produced by the pulp, blood pressure around the root of tooth, cementum deposition on the tooth root, the remnants of the attachment of the dental follicle and oral epithelium, activity of the functional matrix when the periodontal tissue permeability increased leads to fluid accumulation of periodontal tissue producing a tooth-bone separation movement, the contraction of the oblique collagen fibres of the periodontal membrane, or a combination of these factors.

The osteoclasts cause bone resorption, thus creating a path for a tooth to move or erupt. The evidence was based on studies on dogs (Marks et al. 1983) and rats (Wise and Fan 1991, Wise and Lin 1994) in which tooth eruption was prevented in osteopetrotic (toothless) rats because there was an absence or reduction for the number of the osteoclasts. There was also an influx of monocytes into the dental follicle in which the period of maximum activity coincides with active eruption (peak of the osteoclasts), 16 weeks post-natally for the 3rd premolars in dogs, and 3 days for the molars in rats. This monocyte influx then, decreases, as does osteoclastic activity. Wise and Lin (1995) pointed out that the connective tissue sac that surrounds the tooth prior to eruption (dental follicle) is the tissue required for tooth eruption. Their evidence for this was that, no tooth eruption occurred when dental follice is surgically removed.

The current view is to investigate the signal(s) responsible for the initiation of these cellular changes. Few studies have been carried out suggesting some interrelated molecules, known as the transforming growth factor-beta 1 (TGF-beta 1), colony-stimulating factor molecule (CSF-1), interleukin-1 alpha (IL-1 alpha) and the epidermal growth factor (EGF), as being possible candidates because of their ability to accelerate eruption, or their immunolocalization, or their gene expression and/or any combination of these abilities (Wise and Fan 1991, Wise and Lin 1994, 1995).

2.2.5. Development of Dental Occlusion

The development of occlussion involves various stages i.e. the deciduous occlusion, mixed dentition, and permanent occlusion. It had been noted that correct occlusion is not a fixed or particular anatomic state, but a changing functional process undergoing continual modification and adjustment during the whole life in both deciduous and permanent dentitions (Begg 1954, Clinch 1966, Moyers 1969). Unfortunately, there is little agreement on the concept of occlusion. In orthodontic practice, dental occlusion may be considered under two broad headings. The first one is based on the concept of the static occlusion, i.e., the position where the maxillary and mandibular teeth meet together in contact (Angle 1899, Andrew 1972, Gravely and Johnson 1974, Williams and Stephens 1992). Accordingly, different classifications of normal occlusion and malocclusion were proposed. However, none of these is considered ideal for clinical use and are maily used for description.

The second concept is the functional occlusion i.e. the occlusion of the dentition when the upper teeth are in contact with the lowers during the functional movement of the lower jaw in harmony with the temporomandibular joints and associated structures. This is known as the functional occlusion (Roth 1976).

Several interrelated determinants control the final picture of good occlusion such as, the presence of all the teeth, normal size and normal shape of the teeth. Any deviations may lead to the development of malocclusion. The positions of the teeth in their jaws as well as the anatomy of the individual teeth are the two most significant factors in the development of a correct occlusion (Begg 1954).

2.2.6. Development of Dental Malocclusion

Literature discussing the development of malocclusion has been extensive and indicated that the process is complex and the influence of genetic and environment factors in the aetiology has been a matter of debate (Hunt 1961, Mossey 1999, Cobourne 1999). According to Hixon (1971), malocclusions are not pathological processes but, cultural reactions to genetically normal variations in size and shape of the teeth and face. Malocclusion has been described as the disease of civilisation and some evidence has been presented from collected prehistoric data (Begg 1954, Corruccini 1984). A faulty occlusion might lead to functional problems, for instance, in the periodontal tissues or the temporomandibular joint system (Roth 1976, Burgett 1995, Okeson 1995).

Population, familial and genetic studies to investigate facial and occlusal features revealed racial variations, a person is very similar to his family as compared with the unrelated controls and a significant genetic variance was found for many features with a role for environment (Litton et al. 1970, Chung et al. 1971, Harris 1975, Townsend et al. 1988, Varrela and Alanen 1995).

2.3. OVERVIEW OF DENTAL ANOMALIES

Extensive studies in the literature reported on abnormalities affecting human teeth. The orthodontic significance of such abnormalities is the possible adverse effects in the occlusion as well as appearance of the patient's dentition and face. The present study focuses on the hypodontia and tooth morphology, which are discussed in detail (sections 2.4., 2.5. and 2.6. below). Other dental anomalies are briefly discussed.

2.3.1. Aetiological Factors

Both genetic and environmental factors have been implicated in aetiology of dental anomalies. The genetic role in the development of dental anomalies was shown in family, twins and prevalence studies (Thomsen 1952, Grahnen 1956, Sperber 1967, Alvesalo and Portin 1969, Woolfe 1971, Gravely and Johnson 1971, Alvesalo and Tigerstedt 1974, Brook 1974a, 1984, Suarez and Spence 1974, Chosack et al. 1975, Bailit 1975, Potter et al. 1976). Many of these investigations demonstrated more than one dental anomaly on examination of their samples. Some anomalies tend to have higher frequencies among relatives compared with the general population and demonstrate gender differences.

The role of environment in tooth development has also been reported (Sever et al. 1965, Axrup et al. 1966, Brook 1974b, 1984, Gullikson 1975, Maguire et al. 1987, Sew and Wan 2000). Pre- and post-natal environmental factors, discussed earlier, have been suggested as possible causes. More detail is shown (sections 2.1.3.1., 2.1.3.2. and 2.4.4.).

2.3.2. Anomalies of Tooth Number

Deviations from the usual number of the human permanent dentition (32 teeth, 16 in the upper jaw and 16 in the lower) or the deciduous dentition (20 teeth in both jaws) have been documented in the literature. When the total number of teeth is less than the normal complement of dentition, the condition is known as hypodontia (Detail in sections 2.4. and 2.5.). Supernumerary teeth, on the other hand, mean that more than 32 permanent teeth (or more than 20 deciduous teeth) exist in the patient's jaws. Many clinical studies pointed out that it usually occurs in the premaxilla. The permanent dentition is more often to be affected than the primary dentition, with a prevalence of 0.3% (Dolder 1937), 2.1% (Wisth et al. 1974a) and 1.5 to 3.5% (Brook 1974a) and males appear to be more frequently affected.

Supernumeraries take various forms (conical-shaped, tuberculates and supplemental teeth) that may affect the eruption or the position of the adjacent teeth (Winter 1966, Brook and Winter 1970, Howard 1978, Buenviaje and Rapp 1984, Humerfelt et al. 1985, Frame and Evans 1989, Mitchell and Bennett 1992, Becker et al. 1997). Cases with supernumeraries were more likely to be associated with larger teeth as compared with the general population teeth and may manifest some rare conditions such as cleidocranial dysplasia and Gardner's syndrome.

2.3.3. Anomalies of Tooth Size

Large tooth size (megadontia or macrodontia) as well as small tooth size (microdontia) may occur in human dentition. Abnormalities of tooth size have been reported in many populations. Review of the literature illustrated variations among different races and genders. The association between anomalies of tooth size and other anomalies have been reported particularly the association between microdontia and hypodontia and between macrodontia and supernumeraries (Rantanen 1956, Jacobsen and Alexandersen 1970, Lavelle et al. 1970, Brook 1974b, 1984). More detail is presented (sections 2.1.3.2., 2.4.4., 2.5.1.1. and 2.6.3.).

2.3.4. Anomalies of Tooth Shape

It has been indicated previously that final tooth shape (phenotype) is the product of its genetic directive (genotype) modified by the environment in which it develops. It is not uncommon to find the maxillary permanent lateral incisor, or any anterior teeth, to be small in size, tapered or abnormal in shape. This abnormality may be unilateral or bilateral. Many studies have reported an association between a peg-shaped tooth on one side and the absence of the contralateral tooth (Dahlberg 1945, Davies 1968, Alvesalo and Portin 1969, Foster and Van Roey 1970, Buenviaje and Rapp 1984, Lai and Seow 1989). A study to find out the inheritance pattern of peg-shaped upper lateral incisors revealed a hereditary cause, which may present as a weaker expression of the same gene behind the missing tooth (Alvesalo and Portin 1969). Further discussion is presented below (sections 2.4.4., 2.5.1.2. and 2.6.3.).

2.3.5. Other Dental Anomalies

Many other dental anomalies, which are not of the interest of the present study, have been reported and breifly outlined. Anomalies of tooth eruption: Investigation into the tooth eruption revealed variations in the eruption age, between genders and between different racial communities. Girls tend to have earlier skeletal and sexual development and their earlier tooth eruption is part of their earlier maturation. A difference has been found to be less for the 1st molar teeth than for canines (Bailit 1975). An inverted path of eruption has been documented (Keith and Midda 1989). Buenviaje and Rapp (1984) reported 0.08% of their sample to have such anomaly. Occasionally teeth are present in the mouth at birth (natal teeth) or may erupt 30 days after birth (neonatal teeth). Bazan (1985) noted that they have a familial pattern and the prevalence is 1 in 2,000-3,500 births. Sometimes syndromes may be present such as, Ellis-van syndrome. An association has been found between ankylosis and infraocclusion of primary molars and ectpoic eruption of teeth suggesting a genetic role (Kurol and Thilander 1984, Kurol and Olson 1991, Bjerklin et al 1992). Bailit and Sung (1968) discussed the role of environmental factors and pointed out that low birth weight appears to be associated with tooth eruption retardation. Transpositions of teeth have been also reported (Peck et al. 1993, 1998, Chattopadhyay and Srinivas 1996, Plunkett et al. 1998, Royer De Verbizier et al. 1999, Basdra et al. 1999).

Anomalies of tooth structure may be divided into those affecting the enamel and dentinal tissues that could result from genetic defects and/or as a result of some environmental factors. Amelogenesis imperfecta is a rare hereditary condition reported in the literature (Winter and Brook 1975, Witkop 1989). Dentinogenesis imperfecta is a hereditary defect that affects the dentin (Witkop 1975, Gage 1985). It may occur alone or be associated with a general condition affecting the skeleton (Osteogenesis imperfecta).

Anomalies of tooth form have been also reported in the literature including tooth gemination and fusion (Brook and Winter 1970, Foster 1987, Lai and Seow 1989, Aguilo et al. 1999), tooth dilaceration (Howard 1978, Davies and Lewis 1984, Lai and Seow 1989), Talon cusp (Davis and Brook 1985, Hattab et al. 1995) and dense evaginated odontome (Hill and Bellis 1984).

2.4. HYPODONTIA

The congenital absence of the human dentition has great interest to dental surgeons because it may produce malocclusion. For anthropologists, as well as geneticists, it represents one aspect of variation in humans. Numerous studies have been carried out to investigate the nature of this condition.

2.4.1. Terminology

Hypodontia may affect the primary dentition, or permanent dentition, or both. There is no agreement on its definition. The following are some terms which have been mentioned in the literature: Hypodontia, congenital absence of teeth, lack of teeth, agenesis of teeth, missing teeth, oligodontia, severe hypodontia, anodontia, partial anodontia, complete anodontia, deficient dentition, dental aplasia, defective dental development and dental hypoplasia.

Disagreement also exists regarding the appropriate term used according to the number of absent teeth. Hypo is a prefix that means deficient (Zwemer 1998). According to Jorgenson 1980 and Burzynski and Escobar 1983, it was defined as agenesis of one or more teeth. On the other hand, Rune and Sarnas (1974) used the term, advanced hypodontia for the absence of four or more teeth (excluding the third molar).

Absence of six or more teeth, excluding third molars, has been called severe hypodontia (Wisth et al. 1974a, Hobkrik and Brook 1980) or oligodontia (Schalk-van der Weide et al. 1993, Nieminen et al. 1995, Arte et al 1996). Oligodontia has been defined as the absence of a large number of teeth (Stewart et al. 1982) or the absence of several permanent teeth without associated systemic disorders (Goldenberg 2000). Oligo is from classical Greek root and means few. Accordingly, Jorgenson (1989) pointed out that; oligodontia may be defined as the developmental absence of a few teeth or the presence of a few teeth. Ogaard and Krogstad (1995) categorised the severity of hypodontia into mild for the absence of 2-5 teeth, moderate for the absence of 6-9 teeth and severe for the absence of 10 or more teeth.

Werther and Rothenberg (1939) used the term of partial anodontia for missing one or more teeth and total anodontia for complete absence of the dentition. Burzynski and Escobar (1983) suggested anodontia for the absence of all teeth and noted that it implies the lack of any of the accepted normal complement of 52 deciduous and permanent teeth. The investigator believes that the term, per se, is of a limited importance as long as the anomaly is clearly described and the case is properly diagnosed. A rare condition such as the congenital absence of all teeth should be distinguished from less severe conditions. A classification is, therefore, proposed which considers the severity and pattern of the anomaly (Table 1).

2.4.2. Clinical Implications

Hypodontia is of direct clinical importance. This is mainly related to problems of diagnosis, severity of tooth absence, general effect on the remaining teeth and dental occlusion and the management. Underneath two subsections summarise main points in the management of hypdontia patients. Other sections that cover main aspects of hypodontia follow these and all have direct relation to clinical dentistry.

2.4.2.1. Indications of treatment

The prime motivating factor for individuals seeking orthodontic treatment is aesthetics. However, hypodontia patients seek treatment to manage deteriorations of the appearance and/or function that cause psychological depression in some patients. Several investigations have been reported on the influence of hypodontia, with regard to personality and psychological factors of the patients (Graber 1978, Hobkrik and Brook 1980, Winstanley 1984, Schalk-van der Weide et al. 1992). Although, this is a rare situation, it should be considered seriously.

2.4.2.2. Considerations of management

Unfortunately, there is no such formal procedure to manage patients with hypodontia. Its management may neccesitate the help of many specialities. All authors are in agreement that management depends upon the severity of of tooth absence. The general principle in management is to deal with space of the dental arches i.e. a space closure in less severe case, while the prosthetic replacement as well as some orthodontic tooth movement is usually the case in extensive conditions. Different options and methods of treatment were suggested including orthodontic movement and/or restorative replacements in the form of dentures, crowns, bridges, auto-transplantation and endossous implant etc. (Oliver et al. 1975, Senty 1976, Hobkrik and Brook 1980, Asher and Lewis 1986, Odman et al. 1988, Scher 1990, Millar and Taylor 1995, Evans and Briggs 1996, Newman and Newman 1998, Levander et al. 1998). These papers suggested a number of important considerations that have to be evaluated before commencement of management. These include age of the candidate, the dental occlusion, soft tissue and skeletal patterns, number, colour and morphology of remaining teeth, location of absence, amount of alveolar ridge, oral hygiene, interest of the candidate, expectation of treatment, team-patient interaction and time as well as cost of treatment. However, it is not the purpose of this review to discuss the above-mentioned points in detail.

The facial morphology of hypodontia subjects should be taken into account before the commencement of treatment. Lack of alveolar bone growth may lead to the tendency of the facial profile to be concave and prognathism of the lower jaw to achieve occlusion (Broadbent 1937, Winstanley 1984, Ranta 1985). Apalsia or reduction of the alveolar bone has been demonstrated, particularly in the area of mutliple teeth missing (Oliver et al. 1975, Yamashiro et al. 1998). However, conflicting findings were reported. In a sample comprised hypodontia (6 males and 6 females) and control groups (16 males and 20 females), the morphology of the mandible had been investigated (Jamsa and Alvesalo 1980). No significant differences were found in the measurements between groups and the only exception found suggesting larger mandibular corpus (menton to gonion) in hypodontia than controls.

In a cephalometric study, Wisth et al. (1974b) investigated the craniofacial morphology in a sample comprising 24 males and 31 females with hypodontia of one or more teeth, aged 9 years. The individuals displayed less maxillary jaw prognathism and length and a greater proclination in the maxillary anterior teeth than control subjects. Out of this sample, 12 males and 18 females were re-examined to investigate facial changes at age 16 years (Roald et al. 1982). The main finding indicated a shorter maxilla in hypodontia subjects than in controls and with little effect on the individuals' general growth pattern. The investigators therefore noted that treatment of hypodontia patients should follow the same guidelines in orthodontic management as other patients. Yuksel and Ucem (1997) also carried out a cephalometric study and found little effect of hypodontia on the dentofacial morphology. A total of 74 subjects (33 males and 41 females) were investigated but no information was indicated regarding the severity of absence.

The association between the severity of hypodontia and the pattern of craniofacial morphology was also investigated. Sarnas and Rune (1983) studied the soft and hard tissue facial profile in subjects with hypodontia of four or more teeth (59 males and 82 females). They found slight maxillary retrognathism and greater incisor tooth uprighting than controls, which would have no effect on the lip position and/or facial aesthetics. Hypodontia subjects (N = 118 males and females) with absence of more than 12 teeth demonstrated greater ($P<0.05$) mandibular prognathism and smaller ($P<0.0001$) vertical and sagittal jaw relation as well as alveoloar prognathism in the mandible when comapred with others having hypodontia of 5-12 teeth (Nodal et al. 1994).

Ogaard and Krogstad (1995) investigated a sample divided according to their severity of hypodontia into absence of 2-5 teeth (N = 43), absence of 6-9 teeth (N = 15) and absence of 10 or more teeth (N = 29). Their findings revealed a significant incisor retroclination and an increased interincisal angle associated with an increase in severity of hypodontia. A retrusion in the upper lip and reduction in the anterior lower facial height in severe cases were also reported. It was concluded that this pattern of dentofacial morphology appeared to be related to compensation of the dentofacial structures, rather than due to a different growth pattern.

Hypodontia may be considered as a risk factor for apical root resorption in orthodontic patients. According to Levander et al. (1998), there is a high risk of resorption during orthodontic treatment in hypodontia patients. This was in cases with missing of four or more teeth particularly when they have an abnormal root form. They also suggested that the length of treament and the use of elastics and rectangular archwire are additional factors for this high risk. On the other hand, Lee et al. (1999) did not find any relation between hypodontia and root resorption.

2.4.3. Epidemiology

Hypodontia is usually considered as one of the most commonly observed anomaly affecting the human dentitions. The prevalence of hypodontia has attracted much investigation (Table 2). There is agreement that both the permanent and deciduous dentitions may be affected by hypodontia, with higher incidence in the permanent teeth. A small number of studies have been carried out as general surveys. Most of the published figures were based on individuals selected from schools and/or clinics.

2.4.3.1. Hypodontia of deciduous dentitions

In the deciduous dentition, the prevalence of hypodontia is very rare (Table 2). Few documented papers pointed out that the prevalence of hypodontia is much lower in the deciduous dentition than that for the permanent dentition (Werther and Rothenberg 1939, Ravn 1971, Brook 1974a, Ooshima et al. 1988). In a study by Werther and Rothenberg (1939), only one case out of 1,000 children had been presented as having hypodontia of the primary teeth. Grahnen and Granath (1961) reported 0.4 % of a Swedish sample comprised 1,173 children aged 3-5 years of age. It was higher in males than females but not significantly different. A similar figure (0.5%) was shown by Ravn (1971) among 4,564 children. Brook (1974a) reported a figure between 0.1 and 0.9% and in his sample, a 0.3% prevalence figure (two cases), out of 741 children was found.

Hypodontia of the deciduous dentitions may be a feature of hypodontia in permanent teeth so, if a child presents with hypodontia of the primary teeth, the risk of having hypodontia in permanent teeth is high, particularly the succedeneous (Grahnen 1956, Grahnen and Granath 1961, Foster and Van Roey 1970, Ravn 1971).

While Ooshima et al. (1988) reported a case with congenital absence of eight deciduous teeth in which their corresponding permanent teeth showed development. This means that it is not possible to precisely predict the pattern of hypodontia in the permanent teeth following its diagnosis in the deciduous teeth.

2.4.3.2. Prevalence in permanent dentitions

Many reports were published in the literature since 1930s until the present time, which did not usually take the 3rd molars into account. The prevalence of hypodontia in the permanent dentition, excluding the 3rd molars, ranges between 2.3% and 10% (Table 2).

Table 2: The overall prevalence of hypodontia in the permanent dentitions, for various population groups (excluding 3rd molars).

Study	Prevalence %	Country	Sample size	Ages (Y)
Dolder (1937)	3.4	Switzerland	10,000	6 – 15
Werther & Rothenberg (1939)	2.3 0.1*	USA	1,000	3 – 15
Grahnen (1956)	6.1	Sweden	1,006	11 – 14
Clayton (1956)	6	USA	3,557	3 – 12
Glenn (1961)	5.15	USA	777	3 – 16
Grahnen and Granath (1961)	0.4*	Sweden	1,173	3 – 5
Davies (1968)	5.9	Australia	2,170	14
Muller et al. (1970)	3.5	USA	14,940	11 – 15
Ravn (1971)	0.6*	Sweden	4,564	3 – 3.5
Hunstadbraten (1973)	10.1	Norway	1,295	7 – 14
Brook (1974a)	4.4 0.3*	Britain		11 – 14 3 – 5
Wisth et al. (1974a)	6.6	Norway	813	9
Magnusson (1977)	7.9	Iceland	1,116	8 – 16
Silverman & Ackerman (1979)	4.3	USA	4,032	3 – 18
Maklin et al. (1979)	7.4	USA	847	4 – 12
Rolling (1980)	7.8	Denmark	3,325	9 – 10
Buenviaje and Rapp (1984)	3.7	USA	2,439	2 – 12
Ruprecht et al. (1986)	5	Saudi Arabia	1581	0 – 69
Davis (1987)	6.9	Hong Kong	1,093	12
Al-Emran (1989)	4**	Saudi Arabia	500	13.5 - 14.5
Lai and Seow (1989)	6.4	Australia	1,032	6 – 19
Warnakulasuriya (1989)	3.2	Sri Lanka	683	13 – 16
Aasheim & Ogaard (1993)	6.5	Norway	1,953	9 – 12
Ghaznawi et al. (1999)	4.16	Saudi Arabia	1,010	12 – 40

** Deciduous dentitions, ** Males only included.*

The study by Dolder (1937) perhaps is the classic survey carried out in Bern, Switzerland. The sample consisted of 10,000, 6 to 15-year-old schoolchildren, from both genders. The prevalence of hypodontia was 3.4%. In 5% of hypodontia children, familial hypodontia was noticed supporting the role of heredity in the aetiology of hypodontia. Dolder did not mention whether his study included radiographic evaluation or not.

A further survey (Werther and Rothenberg 1939) investigated 1,000 3-5 year-old children at the Dental School, the University of Pennsylvania, USA. The prevalence of hypodontia was 2.3%, whereas the 1.6% presented supernumeraries and 0.7% of the subjects demonstrated both hypodontia and supernumerary dental anomalies individually the ratio being 3:1.

Thomsen (1952) investigated the prevalence and genetic relationship of hypodontia for 169 inhabitants out of a population of 188 individuals of Tristan da Cunha islands in the Atlantic Ocean, with use of radiographs and study casts. Thomsen found 18% of Tristanites have hypodontia including 3rd molars. The population was isolated and resulting from several generations of inbreeding of mixed colour with the majority of white origin. In a clinical as well as genetic study on the permanent dentition hypodontia, Grahnen (1956) investigated 11-14-year-old Swedish school children and reported a 6.1% prevalence of hypodontia.

In a private practice, Glenn (1961) investigated clinically and radiographically, the prevalence of hypodontia in 777 subjects (405 males, 372 females) aged 3-16 years. The incidence was 5.15% for the developmental absence of one or more teeth. That was similar to other studies. Agenesis and peg-shaping of the permanent dentition were clinically and radiographically investigated by Davies (1968). The sample comprised 2,170 schoolchildren from Sydney, Australia (950 females and 1,220 males), with the majority of them at age 14. About 1/3 of the sample were examined for third molar formation. The study revealed the following findings: the frequency of hypodontia and/or peg-shaping of teeth was 5.9%. The overall frequency of subjec with hypodontia and/or peg-shaping of one or more teeth was found to be 22.2%.

Another clinical and radiographical survey was carried out on 14,940 Negroid and Caucasian children aged 11 to 15 year, drawn from Evanston and Oak Park, Illinois, USA (Muller et al. 1970). The observations demonstrated that, 521 subjects had hypodontia of permanent teeth with an overall prevalence of 3.49%. Hunstadbradent (1973) has stated a higher prevalence, 10.1%, in a clinical and radiographic investigation for 1,295 male and female schoolchildren in Modum, Norway.

Wisth et al. (1974a) investigated the frequency of hypodontia in the permanent dentition for Norwegian children, 428 boys and 385 girls (total of 813) at age 7 using orthopantomographic examination. These children were re-examined at the age of 9 using pantomograms and study casts to ascertain prevalence of hypodontia as well as its relation to tooth size and dental arch width. The control group consisted of children with similar ages from both genders and taken from the same area of Bergen. At both ages, the following conclusions have been shown: 7.1% of children demonstrated congenital absence of teeth at age 7 and a 6.6% at age 9, due to late development of the lower second premolars in males at age 7. Female subjects exhibited a higher frequency (8.1%) than males (5.6%) at age 9. Girls were also shown to have more teeth absent per individual. Other findings were that, there were no significant differences in the sizes of teeth and widths of the dental arches between the control group and study sample. In the permanent dentition, the prevalence of supernumerary, tooth invagination, double tooth, microdontia and megadontia was 2.1%, 4.1%, 0.1%, 1.1%, and 2.5% respectively.

The prevalence of six dental anomalies (hypodontia, supernumerary teeth, microdontia, megadontia, invaginated teeth and double teeth) in two groups of both genders of Slough schoolchildren, Buckinghamshire Britain, was investigated (Brook 1974a). The first group included 741 subjects aged 3-5 years, while the second group comprised 1,115 subjects aged 11-14 years. His findings revealed a 4.4% prevalence of hypodontia in the permanent dentition.

The prevalence of congenital tooth absence was 7.9% according to Magnusson (1977). The sample size was 1,116 subjects (521 males and 595 females) and comprised 9.5% of all schoolchildren in Reykjavik, Iceland, aged 8 to 16 years. The 2nd and 3rd molars, as well as cases with congenital deformities, trauma and previous orthodontic treatment were not included.

Silverman and Ackerman (1979) reported a 4.34% frequency of hypodontia using radiogrphs of a sample consisting of 4,032 black and white subjects in Pennsylvania, USA, aged between 3 and 18 years from both genders. The prevalence of hypodontia for the permanet dentition has also been investigated by Maklin et al. (1979), in a sample of 847 children, from the files of the LSU School of Dentistry, New Orleans, USA. The ages ranged between 4 to 12 years and the majority were 8 years old. Clinical as well as radiographic test were used, in which subjects who had recieved orthodontic treatment and/or presented any general developmental anomaly were excluded. It was demonstrated that the prevalence of developmental absence of teeth was 7.4%.

In another clinical and radiographic investigation into the prevalence of dental anomalies (of number, shape, position and structure), Buenviaje and Rapp (1984) examined 2,439 male and female children, ranging in age from 2 to 12 years, from the Dental School, the University of Pittsburgh. They noted that, the congenital absence of permanent teeth is the commonest anomaly and demonstrated a prevalence figure of 3.7%.

Rolling (1980) examined 3,325, 9-10-year-old Danish children (1,668 boys and 1,657 girls) by clinical and orthopantomographic examination. Children with cleft palate, were not included in the study. It was shown that, 7.8% of children have had one or more teeth absent.

Three studies have been carried out to investigate the prevalence of hypodontia among Saudi Arabian people and reported different figures (Ruprecht et al. 1986, Al-Emran 1989, Ghaznawi et al. 1999). The former study reviewed 5,543 charts of patients attending the College of Dentistry, King Saud University, Riyadh, (Ruprecht et al. 1986). Subjects with adequate radiographic surveys and clear histories were included and subjects too young to permit assessment of dental development were excluded. 79 (5%) out of 1581 subjects whom have fulfilled the criteria of the study have been found to have congenital absence of one or more teeth. Association with other anomalies: 17.7% of hypodontia subjects have shown one or more taurodonts, 5% supernumeraries, 3.8% enamel hypoplasia, 2.5% gemination, and 1.3% tooth transposition. Al-Emran (1989), on the other hand, examined 500 male school children living in Riyadh, aged between 13.5 and 14.5 years. The figure of hypodontia was 4% incidence. Peg-shaped teeth were also observed in 4% of the total sample. According to Ghaznawi et al. (1999), the incidence was 4.16 % of a total sample (n=1,010) aged 12-40 years. When including third molars the incidence was 9.41 %.

Davis (1987) tested the prevalence of hypodontia in a sample of Hong Kong children randomly selected from schools. 1,093 subjects (561 males and 532 females) aged 12 years, were examined radiographically and evaluated through questionnaires. It was found that 6.9% of the sample presented with hypodontia of one more teeth.

In a sample which comprised 683 (430 females and 253 males) with age ranges between 13 and 15 years, Warnakulasuriya (1989), investigated dental anomalies, including hypodontia for Sri Lankan schoolchildren, using clinical and whenever possible radiograph tests. The prevalence of hypodontia was 3.2%. Other anomalies found included the peg-shaped lateral incisors.

A study by Lai and Seow (1989) was carried out in the Dental School on 1,032 6-19-year-old Australians. Clinical as well as radiographic examination were used, conditions with syndromes were excluded. It has been found that 6.4% of the sample have had a congenital absence of one or more teeth.

Aasheim and Ogaard (1993) investigated the prevalence of hypodontia, using dental casts and radiographic evaluation, at age 9 and then at age 12 years. The study comprised 1,953 schoolchildren from Norway (993 boys and 960 girls). They noticed a delay in the development of the second premolar, and demonstrated a hypodontia prevalence of 6.5% (7.2% in females and 5.% in males).

2.4.3.3. Prevalence in families

Grahnen (1956) to test families of 171 hypodontia patients conducted an important genetic investigation. After examining a total of 685 members. Approximately 31 % of the first-degree relatives were affected by hypodontia and are significantly more than that of the general population. A similar figure (33.8%) also demonstrated by Brook (1984) in a study that included 153 hypodontia patients and 327 relatives. Another conclusion reveals that the relatives have a higher chance of being hypodontic with increase in severity of hypodontia in the index individuals.

A family study (Woolf 1971) evaluated radiographically the relatives (sibs, parents, grandparents, aunts, uncles, and first cousins) of 103 individuals with missing upper lateral incisors. Both the study group (103 families) and control group (187 families) were obtained from Salt Lake City, Utah, USA. Findings indicated that the frequency of subjects with missing and/or peg-shaped upper lateral was significantly increased in relatives of the study group as compared with controls. In 69% of study group's families, at least one first-, second- or third-degree relative had a missing or peg-shaped lateral.

Another study had been carried out by Chosack et al. (1975) and similarly showed a higher prevalence of hypodontia among the relatives than the normal population (10.3% and 2% respectively). In parents of probands, the prevalence of hypodontia was 9.4%, while in siblings of probands, the prevalence was 14.8%. They added that more mothers and sisters than fathers and brothers were affected by hypodontia.

Data of eleven hypodontia patients and their first- and second-degree relatives (total of 204 individuals) was retrospectively evaluated (Arte et al. 1999). Hypodontia was found in 43 and 33% of the first- and second-degree relatives, respectively. The mean number of tooth absence was 2.3 and 1.5 for the probands and relatives, respectively.

2.4.3.4. Ethnic variations

Differences in the overall prevalence of hypodontia among various cultures were documented and even among people of the same community. In the Swiss sample (Dolder 1937), the prevalence was 3.4%. Dolder noted that, in short-skulled Alpine types, the absence of the second premolars was more common compared with the absence of upper lateral incisors, which was more common in the Nordic long-skulled types.

In the British population, the frequency was 4.4% in the permanent dentition, according to Brook (1974a), however, in an old Romano-British population, it was 13% apart from 3^{rd} molars (Brook and John 1995). Whilst in the Australian population, Davies (1968) found a 5.9% frequency in subjects of mixed origins, i.e., subjects of British and Continental European decent. A close figure (6.4%) was found among Australians (Lai and Seow 1989).

In Sweden, the prevalence was 6.1% for 11-14 year-old subjects (Grahnen 1956). Whereas, the figure was 7.9% for both genders in Iceland (Magnusson 1977). In Norway, three figures have been demonstrated. The prevalence was 10.1% according to Hunstandbraten (1973), 6.6% at age 9 according the study by Wisth et al. (1974a), and 6.5% by Aasheim and Ogaard (1993), in Norwegian children. On the other hand, Rolling (1980), reported a 7.8% prevalence in an investigation in Danish subjects.

In the USA, reports of the prevalence varied. Werther and Rothenberg (1939) demonstrated a 2.3% prevalence for hypodontia of permanent teeth. On the other hand, Maklin et al. (1979) found a higher figure of prevalence (7.4%) in a sample taken from New Orleans. The rest ranged between 4.3.4% and 6% (Clayton 1956, Glenn 1961, Silverman and Ackerman 1979). According to Muller et al. (1970) including Caucasian and Negroid subjects, it was 3.49%.

In Saudi Arabia the general figure of prevalence ranged between 4 and 5% (Ruprecht et al.1986, Al-Emran, 1989 Ghaznawi et al. 1999).

Among Israeli Jews, the prevalence of hypodontia was 2.1% for one or more missing upper lateral incisor and 0.7% for the lower incisors (cited by Chosack et al. 1975).

The prevalence of hypodontia among Hong Kong Chinese people, has shown an overall 6.9% figure with girls 7.7% and boys 6.1% (Davis 1987). Wherea, in the Sri Lankan sample according to Warnakulasuriya (1989), the prevalence was 3.2%.

2.4.3.5. Sexual dimorphism

Many studies have shown that females were more frequently affected by hypodontia than males (Glenn 1961, Davies 1968, Muller et al. 1970, Hunstadbraten 1973, Wisth al. 1974a, Brook 1974a, 1984, Magnusson 1977, Davis 1987, Ghaznawi et al. 1999). Glenn (1961) reported a tendency of higher incidence in females. It is believed that the difference between both genders is real and not merely a chance finding, however, it is not highly significant (Davies 1968). Females were more commonly affected than males in every tooth site and 20.8% of males showed hypodontia and/or peg-shaping of one or more teeth, while in females it was 24%. Davies pointed out that this difference might be explained by the genetic factors being less penetrated in males than females, since autosomal genes are equally distributed in the sexes.

The tendency of more females to be affected by hypodontia than males has also been confirmed by Muller et al. (1970) who investigated Negro and White children. There was little difference between both Negro and White children, where the White girls tended to have a higher mean number of hypodontia teeth than the Negro girls, and the opposite tendency holding in boys.

Girls demonstrated 11.8%, while boys 8.4% of overall hypodontic patients, according to Hunstadbraten (1973). Wisth et al. (1974a) has also reached a similar conclusion, 8.1% in girls and 5.6% in boys. Brook (1974a) presented a statistical difference value ($P<0.05$) in which females more frequently have permanent hypodontia and microdontia. Icelandic girls presented 8.9% frequency of hypodontia, while boys shown a 6.7% frequency

(Magnusson 1977). Among 28 hypodontia Sri Lankan subjects, 18 girls and 10 boys were affected (Warankulasuriya 1989). In family studies, Chosack et al. (1975) confirmed that more mothers and sisters were affected by hpodontia than fathers and brothers, among relatives of probands.

Many authors, however, did not find differences in the frequency of hypodontia between males and females (Dolder 1937, Werther and Rothenberg 1939, Thomsen 1952, Grahnen 1956, Silverman and Ackerman 1979, Maklin et al. 1979, Rolling 1980, Ruprecht et al. 1986, Lai and Seow 1989). In the meantime, Dolder noted that, in females, a greater absence of the upper lateral incisors, while there was a greater absence of the upper second premolars in males. It was nearly equal in both genders 11:12 according to Werther and Rothenberg (1939).

Thomsen (1952) and Maklin et al. (1979) have noted that, there is no significant statistical difference between the sexes. Rolling (1980) added, although more teeth were congenitally absent in females, the general prevalence was the same in both males (7.7%) and females (7.8%). Ruprecht et al. (1986) reported a 5.1% incidence in females and 4.9% in males, with no significant difference. Others (Lai and Seow 1989, Aasheim and Ogaard 1993) also suggested this conclusion. The frequency was also similar in both genders according to a study which invesigated only hypodontia and malformation of the upper laterals incisor (Rantanen 1956).

In severe hypodontia (Schalk-van der Weide 1992), on the other hand, males demonstrated significantly more missing teeth than females, when hypodontia was part of a syndrome. There was no significant difference between genders in non-syndromic hypodontia.

2.4.3.6. Prevalence in relation to severity

The prevalence of hypodontia in relation to severity of tooth absence had been examined. Studies pointed out that most hypodontia cases involved absence of one or two teeth (Dolder 1937, Werther and Rothenberg 1939, Grahnen 1956, Glenn 1961, Hunstadbraten 1973, Wisth et al. 1974a, Silverman and Ackerman 1979, Ruprecht et al. 1986, Magnusson 1977, Rolling 1980, Lai and Seow 1989, Aasheim and Ogaard 1993).

Dolder (1937) reported that 44% of hypodontia subjects have hypodontia of one tooth, 36% two teeth and 20% three to eleven teeth. This means that 80% of hypodontia subjects have shown absence of one to two teeth only. Similarly, Werther and Rothenberg (1939) noted that, 40%, 45%, 5% and 4% of hypodontia individuals have shown missing of one, two, three and five or more teeth, respectively.

Grahnen (1956) reported that 85% of hypodontia children showed one or two teeth missing and the greatest number of missing teeth was eight. Hunstradbraten (1973) noted that 44.2% of hypodontia cases have one tooth absent and 75% have one or two teeth absent. Wisth et al. (1974a) have also demonstrated that, approximately 80% of hypodontia patients, have shown an absence of either one or two teeth, and males are more likely to present with only one tooth absent, while hypodontia of two or more teeth was more common in females.

Glenn (1961) noted that, over 90% of hypodontia cases have demonstrated hypodontia of either one or two teeth. This finding had been supported by other investigators. Silverman and Ackerman (1979) reported that, 79.82% of hypodontia individuals lacked not more than two teeth. It was rare to find cases with congenital absence of more than four teeth and only two cases (1.7%) of hypodontic subjects presented with eight or more teeth. They did not find any case with complete agenesis of teeth.

Ruprecht et al. (1986) noticed that, out of 79 hypodontia subjects, 33 had one tooth missing, 32 lacked two, and 13 had more than three absent teeth. The maximum number of missing was 14 teeth in one patient. On the average, each hypodontia child in the sample had 1.9 teeth absent (Magnusson 1977). Absence of one tooth has been noticed on 44% of subjects, and 40% had absence of two teeth. The absence of four teeth was more frequently found than three missing. The maximum number of congenital tooth missing was four in males, and six in females.

It has also been demonstrated that, nearly 85% of hypodontia subjects have shown absence of either one or two teeth, and about in 50% there was absence of only one tooth. (Rolling 1980). With significant differences ($P<0.05$), more males than females had absence of only one tooth, while more females had two teeth missing. It has been also noted that more than half of the sample with hypodontia have shown absence of one to three teeth (Lai and Seow 1989). Aasheim and Ogaard (1993) noted that 86% of their sample demonstrated absence of one or two permanent teeth.

The figures shown in table 2 were demonstrating the overall prevalence related to hypodontia of one or more teeth. The prevalence of severe hypodontia i.e. hypodontia of six or more teeth was found to be 0.3% in British population i.e. one in fifteen hypodontia individuals (Hobkrik and Brook 1980). Schalk-van der Weide (1992) also investigated its prevalence in the Netherlands. The study sample comprised 332 subjects with age ranging from 4 to 45 years. The control group was a group of normal individuals with full complement of teeth. Excluding 3rd molars, the prevalence was 0.08% (1:1,250) for the non-syndromic cases.

2.4.3.7. Prevalence of specific tooth type

The 3rd molar is the most frequently absent tooth reported in the literature. It had been shown that the frequency of hypodontia of one or more 3rd molars to be up to 49% in Hungarian population (Dahlberg 1945). According to Thomsen (1952), 19% of the sample showed absence of 3rd molars before any other tooth type, and in 74% of them no other class of teeth was missing. Other figures have also been documented e.g. Davies (1968) reported 18.9% whereas Bailit (1975) reported a range between 10 and 25% of the northwest European populations.

Sofaer (1975) reported a frequency of 1% in some African Negro and Australian aboriginal samples, over 30% among Japanese, where Caucasians fell in between. According to Burzynski and Escobar (1983), the absence of one or more 3rd molars was found in 2.5 to 35 % of that examined population. Hypodontia of 3rd molars had a frequency of 39% in a Romano-British population and found to be associated with other absences in some cases (Brook and John 1995). Ghaznawi et al. (1999) suggested that nearly 56 % out of hypodontia cases demonstrated hypodontia of 3rd molars.

A link between the hypodontia of one or more 3rd molar teeth and the frequency of hypodontia and morphological alteration in the remaining teeth has been found (Werther and Rothenberg 1939, Dahlberg 1945, Grahnen 1956, Davies 1968, Lavelle et al. 1970). It has been pointed out that hypodontia of one or more mandibular 3rd molars was associated with an increase in the prevalence of hypodontia of the other tooth types i.e. up to 13 times greater than general population (Garn and Lewis 1970).

Furthermore, the 3rd molars are often to be congenitally absent in individuals who have had hypodontia of deciduous teeth (Burzynski and Escobar 1983).

There is no consensus about which tooth is the most commonly affected by hypodontia after the 3rd molar. However, there is general agreement that the three teeth most frequently affected by hypodontia are the mandibular and maxillary 2nd premolars and the maxillary lateral incisors. Three main descending orders for the frequency of hypodontia in different teeth were documented.

The first rank order is "the mandibular 2nd premolar, maxillary 2nd premolar and maxillary lateral incisor" then, the rest of tooth types follow (Dolder 1937, Magnusson 1977, Hunstadbraten 1973, Wisth et al. 1974a, Rolling 1980, Aasheim and Ogaard 1993, Schalk-van der Weide 1992). The detailed description of frequencies, according to Dolder (1937) are: the mandibular 2nd premolar (47.3%), maxillary 2nd premolar (25.3%), maxillary lateral incisor (12.3) then, the maxillary 1st premolar (5.5%), mandibular 1st premolar (3%), mandibular central incisor (2.2%), maxillary canine (1.8%), mandibular lateral incisor (1.1%), maxillary 2nd molar (0.8%) and mandibular 2nd molar (0.7%). No maxillary central incisors, mandibular canines and mandibular and maxillay 1st molars were congenitally absent.

According to Hunstadbraten (1973), the lower 2nd premolars, upper 2nd premolars and the upper lateral incisors accounted for 45.8%, 28% and 11.7, respectively, of the total number of absent teeth. Wisth et al. (1974a) reported the same order followed by the lower central teeth. They did not find any other types of teeth developmentally absent.

Magnusson (1977) reported that lower 2nd premolars (55% in girls and 51% in boys), upper 2nd premolars (19% in girls and 18% in boys) and upper lateral incisors (18% in girls and 6% in boys) are the most commonly affected teeth. Then, upper 1st premolars, lower incisors and finally upper canines.

Rolling (1980) has also demonstrated a frequency of 42%, 25% and 19% for these teeth respectively, followed by lower lateral incisors, upper 1st premolars, lower 2nd molars and the lower central incisors. So, in total; 67% of hypodontia cases involved the 2nd premolar teeth. Clayton (1956), on the other hand, suggested 55.7% figure for the 2nd premolars and 29.5% for the lateral incisor.

The second rank order of hypodontia is " the mandibular 2nd premolar, maxillary lateral incisor and maxillary 2nd premolar" then, the remaining teeth. Grahnen (1956) reported that out of hypodontia cases, the frequency was 2.8%, 1.6% and 1.4% respectively. Glenn (1961) reported that 2nd premolars accounted for 61.5% of missing teeth and the frequency was 49.2% for the lower 2nd premoar, 32.3% for the upper lateral and 12.3% for the upper 2nd premolar, while the next figures were equal (1.5%) for the lower central, upper 1st premolar, lower canine and upper 2nd molar.

Davies (1968), published the following figures for hypodontia of these three teeth: 3%, 1.8% and 1.1% respectively, followed by lower central incisors (0.3%), lower lateral incisors (0.05%), and lower 1st premolars (0.05%). According to Silverman and Ackerman (1979), the figures were 37.33%, 24.66% and 18% respectively, followed by and lower central incisors (8.7%), then random absences. None of the subjects has shown hypodontia of the lower 1st premolar. Similarly, Maklin et al. (1979) suggested 38.6% for the lower 2nd premolars, 31.5% for the upper lateral incisors, 15.9% for the upper 2nd premolars and 3.3% for the lower central incisors. They have also concluded that, no statistical difference in the frequency of absence between lower 2nd premolars and upper lateral incisors. The same order has been also suggested by Svinhufvud et al. (1988) and Warnakulasuriya (1989).

Lai and Seow (1989) noted the following frequencies of tooth types: 19.4%, 18.8%, 12.4%, 10.2%, 7.3%, 6.7%, 5.4%, 5.1%, 4.1%, 2.9% and 1% for the lower 2nd premolar, upper lateral incisor, upper 2nd premolar, lower central, lower lateral, lower 2nd molar, lower 1st premolar, upper canine, upper 2nd molar, upper 1st premolar, lower canine, and last the upper central, upper 1st molar and lower 1st molar teeth, respectively. Al-Emran (1989) reported the same order, 1.6% for the lower 2nd premolars followed by the upper lateral incisors (1.2%), upper 2nd premolars (0.8%) and then upper 1st premolars (0.4%). No other missing types were reported.

The third rank order on the other hand implies the following: "the maxillary lateral incisor, mandibular 2nd premolar and maxillary 2nd premolar" then, the remaining teeth. Werther and Rothenberg (1939) presented the following figures: 38.5% for the upper laterals and 14.5% for 2nd premolars. Then, the remaining teeth: 6.5% for the lower lateral incisor and upper canine, 3% for the upper 1st premolar, lower canine, lower central incisor, upper and lower 2nd molars, and finally 1.5% for the lower 1st premolar and the upper and lower 1st molars.

Muller et al. (1970) demonstrated that the upper lateral incisor teeth are those most commonly affected by congenital absence (47% of the total hypodontia individuals) as well as the most frequently involved in different combinations of other dental anomalies. The next teeth were the lower 2^{nd} premolars (35.5%), upper 2^{nd} premolars (20%) and followed by the lower central incisors (6.7%). Baum and Cohen (1975) pointed out, in both genders, the maxillary lateral incisor was the most frequently affected tooth, followed by the mandibular 2^{nd} premolar.

Other orders have also been suggested. Apart from 3^{rd} molars, Thomsen (1952) published the following rank order of tooth absence: The 2^{nd} premolars in 7%, then the lower central incisors in 1%, lower lateral incisors in 1% and upper lateral incisors in 0.7% of individuals with hypodontia. Ruprecht et al. (1986) reported maxillary lateral incisor (33%), mandibular 2^{nd} premolar (24.7%), mandibular central incisor (10.8%), maxillary 2^{nd} premolar (7.2%), mandibular lateral incisor (5.4%), mandibular 1^{st} molar (4.2%), maxillary central incisor and 1^{st} premolar (3.6%), maxillary canine (2.4%), maxillary 1^{st} and 2^{nd} molar (1.8%), and mandibular 2^{nd} molar (0.6%) were found to be affected. Ghaznawi et al. (1999) reported 16.79 % for the upper laterals and 14.74 for the 2^{nd} premolars.

Among Chinese, the lower incisor teeth are most frequently affected teeth by congenital absence, with a percentage of 58.7% of hypodontia subjects and 4% of the total sample (Davis 1987). Davis did not specify whether he was referring to the central or lateral incisors. The next commonly affected teeth are the upper 2^{nd} premolars 10.6% and upper lateral incisors 8%.

In subjects with hypodontia of four or more teeth, excluding 3^{rd} molar, the 2^{nd} premolar was the most frequently missing tooth, followed by the 1^{st} premolar and upper lateral incisor (Rune and Sarnas 1974).

The prevalence of missing and peg-shaped upper lateral incisors was studied by Rantanen (1956) in 2,218 Finnish Freshman. The various combinations of missing and malformed teeth indicated an incidence of 2% and approximately equal frequencies for the two anomalies. The frequency was equal in both males and females and between the two halves of the maxilla. Alvesalo and Portin (1969) found that 4.25 % of the sample were having at least one absent tooth while 2.29% and 1.31% showed tooth size reduction and tooth malformation respectively.

2.4.3.8. Combinations of absence

The combination of various types of hypodontia in individual cases has been investigated. Studies have shown combinations of tooth missing particularly in the teeth, which were generally regarded as unstable. Werther and Rothenberg (1939) stated that, in most cases the maxillary lateral incisors, 2nd premolars, 3rd molars and mandibular central incisors were absent, either separately or in combination at the same time. Muller et al. (1970) reported that the upper lateral incisors with lower 2nd premolar, and the upper 2nd premolars with lower central incisors are the most frequent combinations. On the other hand, Silverman and Ackerman (1979) found that the upper and lower 2nd premolar combination occurred more frequently.

2.4.3.9. Jaw location

Hypodontia may occur in the upper and/or lower jaw. It has been found that, the lower jaw has a greater tendency to be affected by hypodontia than the upper (Dolder 1937, Grahnen 1956, Gelnn 1961, Wisth et al. 1974a, Rolling 1980). The ratio of hypodontia between the jaws has been shown to be 7:6 (Dolder 1937) although, more teeth were absent in the upper jaw than the lower. Grahnen (1956), Glenn (1961) and Rolling (1980) reported 61:48, 34:34 and 165:135 ratios between the mandible and maxilla.

The opposite has been also documented in the literature. Werther and Rothenberg (1939) noted that the upper jaw was more frequently affected by hypodontia than the lower and gave the ratio of 15:5. The ratio was 1.44:1 according to Muller et al. (1970). Rune and Sarnas (1974) reported 56% of congenital tooth missing were from the upper jaw. The same conclusion has been driven by Ruprecht et al. (1986).

Others did not find significant differences between the jaws, in terms of the number of missing teeth (Thomsen 1952, Silverman and Ackerman 1979, Maklin et al. 1979, Davis 1987, Schalk-van der Weide 1992). Little difference has been demonstrated; the mandible 52% and the maxilla 48% of the total number of cases (Thomsen 1952).

2.4.3.10. Side location

Hypodontia may occur in either side or both sides of the mouth. Many investigators suggested no difference between right and left sides (Dolder 1937, Thomsen 1952, Muller et al. 1970, Rune and Sarnas 1974). This finding has been confirmed statistically in other studies (Grahnen 1956, Maklin et al. 1979, Schalk-van der Weide 1992).

Differences between the two sides have however, been indicated by some authors. Wisth et al. (1974a) demonstrated a slightly higher frequency of hypodontia on the left side than the right. This was consistent with the findings reported by Rolling (1980), who demonstrated a 197:228 ratio for hypodontia between the right and left sides. A tendency to side difference was also reported by Davies (1968), but only for hypodontia of the lower 2nd premolars. The ratio was 2:1 in favour of the left side. The opposite has also been suggested. Grahnen (1956) gave a figure of 55:54 between the right and left side. Similarly, Glenn (1961) noted a ratio of 35:34. While Maklin et al. (1979), reported 22.3% in the right side and 16.3% in the left side (for lower 2nd premolars), 15.9% right, 15.5% left (for upper lateral incisors) and 9.2% right, 6.7% left (for upper 2nd premolars).

When each jaw has been separately investigated different observations have been made. Muller et al. (1970) found that a greater absence of teeth on the right side than on the left in the maxilla, and the opposite finding in the mandible.

2.4.3.11. Symmetry of tooth absence

Unilateral as well as bilateral congenital absence of teeth have been demonstrated in the literature. Grahnen (1956) demonstrated a symmetrical distribution, in about 49% of hypodontia cases. Magnusson (1977) noted that about 50% of the hypodontia cases showed symmetry. In all cases with symmetrical hypodontia of the upper 1st and 2nd premolars among females, symmetric hypodontia have also existed in another tooth class. No statistical difference has been noticed by Maklin et al. (1979) between unilateral and bilateral tooth absence.

Bilateral hypodontia occured more frequently than unilateral hypodontia (56% and 44%, respectively) according to Silverman and Ackerman (1979). This was in agreement with the results published by Lai and Seow (1989) who demonstrated that 74% of all hypodontia cases showed bilateral absence of teeth. Bilateral symmetry has also been shown by Muller et al. (1970) who noted the presence of bilateral symmetry for individual teeth, except for the lower 2nd premolar, where the left side dominates. They also pointed out that bilateral symmetry occurs in 90% of the missing two-tooth-combinations.

It has been found that, 3rd molars as well as upper lateral incisors were affected bilaterally more often than premolars (Davies 1968). Out of 51 abnormal effects on the upper lateral incisors, 15 occurences have shown bilateral hypodontia, 12 occurences of hypodontia on one side and peg-shaped in the other side, 12 occurences of unilateral tooth absence and 5 occurences of unilateral peg-shaped laterals.

Rolling (1980) demonstrated symmetrical distributions for three tooth types: In hypodontia of the upper and lower 2nd premolar, significant symmetrical distribution was found in girls and asymmetrical distribution (absence of either right or left tooth) in boys. Hypodontia of the upper lateral incisors did not show differenece in symmetry. Symmetrical distribution for hypodontia of 2nd premolar occured nearly twice as often in females as in males. Davis (1987) analysed hypodontia of the lower incisor and found that, out of 44 subjects, there were 16 unilateral and 20 bilateral tooth absences.

In contrast, Glenn (1961) reported that, 55% of the sample presented a unilateral absence distribution. Wisth et al. (1974a) demonstrated a greater unilateral incidence of hypodontia for all the affected teeth, except the lower central incisors in which they demonstrated a higher frequency of bilateral missing teeth.

2.4.3.12. Hypodontia with different malocclusion

There is a lack of information concerning the link between various types of dental malocclusions and the prevalence of hypodontia. Basdra et al. (1999) evaluated the relationship between dental anomalies (hypodontia, peg-shaped laterals, impactions, transpositions and supernumeraries) and malocclusion. They investigated 267 patients with Class II Division 2 and 200 with Class III malocclusions and found that the frequency of hypodontia was higher in Class II cases than Class III (4.5 and 13.86 % respectively).

2.4.3.13. Other factors related to prevalence

The above studies confirm the existence of variation in the relative frequency of hypodontia. The influence of clinical records is another factor affecting the acutal prevalence. In some investigations, clinical examination was not accompained by adequate radiographic survey. Radiographs are also important to distinguish between retained deciduous tooth and permanent tooth.

Furthermore, the registration of the prevalence of hypodontia may also be affected by the developmental age of the sample. At older ages, tooth absence due to extraction or trauma may affect the diagnosis. The momory of patients concerning tooth loss may provide inaccurate information especially when the dental record is not available.

On the other hand, a child may be misdiagnosed as being with hypodontia at an early age and then found to demonstrate late dental development. Wisth et al. (1974a) found a higher incidence of hypodontia at age 7 than age 9 year. Aasheim and Ogaard (1993) supported this observation in their sample and found it due to late mineralization of the 2^{nd} premolars particularly in males, between the ages of 9 and 12 years. Another report for a 12-year-old girl who demonstrated hypodontia of some teeth includes premolars (Alexander-Abt 1999). A one year-radiographic follow-up revealed initial mineralisation of one premolar.

One causal element for variation is the differentiation between the type of dentition. A survey of malocclusion in 1,000 Sheffield schoolchildren, boys and girls, between the ages of 6 and 15 years demonstrated that 1.6 % of the children were found to have hypodontia (Gardiner 1956). But, it was not clear if this included the deciduous and/or permanent teeth.

2.4.4. Aetiology

The exact aetiology is still unknown and under investigations. The literature suggests that there is no single factor can be identified as the only element in the aetiological mechanism of the congenital absence of teeth and there is general agreement on the contribution of both genetic and environmental factors. The following are the main theories proposed which have gained different levels of acceptance.

2.4.4.1. Evolutionary factors

Evolutionists and anthropologists suggest that humans are developing smaller jaws, which will accommodate a fewer number of teeth. Accordingly, hypodontia may be regarded as being a variant of normality and human dentitions are in the intermediate stage of evolution (Schultz 1932, Dahlberg 1945, Begg1954, Hunt 1961, Lavelle 1968, Lavelle et al. 1970, Jorgenson 1980, Burzynski and Escobar 1983). The dental formula for the future will be one incisor, one canine, one premolar, and two molars per quadrant, i.e., 20 instead of 32 permanent teeth (Jorgenson 1980).

This trend has been identified by comparison with ancestral mammals, which possessed 3 incisors, one canine, 4 premolars and 4 permanent molars, in each jaw quadrant. While recent mammals are generally considered to have possessed 3 incisors, one canine, 4 premolars and 3 molars in each quadrent (Osborn 1973).

2.4.4.2. Butler's field theory

There are morphological similarities between adjacent teeth of mammalian dentitions. In 1939, Butler proposed his theory, which divided teeth into developmental fields. The key tooth is the most stable member within each field and the stability progressively decreases mesially or distally to that tooth (Bailit 1975). The field's concept has been used by Dahlberg (1945) to explain dental variations in humans. In each arch, four morphological fields were identified (incisor, canine, premolar and molar). Each field has a sphere of influence and a key (most stable or conservative) tooth, which retains the structure and traits even if the traits were missing from the peripheral teeth. The polar, or stable teeth were the central incisor, canine, 1st premolar, and 1st molar. However there is an exception to this rule in that the mandibular lateral incisor is more stable than the central.

Many investigators have reported findings generally in agreement with the field's theory.

The stability of the upper and lower 1^{st} premolars is higher than that of 2^{nd} premolars, while the 3^{rd} molars are less stable than the 2^{nd} molars and the 1^{st} molars being the most stable teeth in this group (Kieser 1990).

2.4.4.3. Interaction between developing tooth germs

Proponents of this theory belive that development of teeth is not independent, it is influenced by their surroundings. Therefore, any variation in one tooth may be reflected in others. A compensatory interaction mechanism between the developing teeth may explain variations of dental traits. Sofaer et al. (1971) noted that "if, in a given field the teeth which develop early are large, the adjacent teeth which show late development tend be small and/or with different morphology, or missing". Their explanation suggests that the initiation of central incisor and canine teeth proceeds of the lateral incisor, and the lateral incisor depends on the local requirement left by the central and canines for its initiation. Therefore, a normal lateral indicates a good environment, while the peg-shaped lateral is the product of a poor environment. The absence of a lateral in one side and a normal lateral in the opposite side may be due to an inadequate primordium in a good environment that allows the developmental compensation. The example is increased sizes of the central incisors in the unilateral and bilateral congenital absence of the lateral incisors.

Stewart and Poole (1982) pointed out that regression and agenesis of tooth germ may occur as a result of space deficiency where competition for nutrition in a constricted area exists, e.g., the 3^{rd} molar.

Kieser et al. (1986), on the other hand, argued that no evidence was found for such interaction. They investigated mesiodistal and buccoligual dimensions of 125 models for Caucasian children. The 1^{st} developing tooth in each tooth class that were either larger or smaller than the norms was further examined to determine any effect on the 2^{nd} developing tooth size and no indication for developmental compensation was revealed.

2.4.4.4. Environmental factors

Environment has been claimed to have a significant role in the aeiological mechanism of hypodontia. Many local and systemic factors were considered as causes in the literature.

These include pathological conditions during pregnancy (osteomylitis, syphilis, tuberculosis, scarelt fever, rubella infection), rickets, vitamin defiencies and endocrine disturbances or excessive exposure of irradiation might affect adversely developing tissues including the dentition (Werther and Rothenberg 1939, Thomsen 1952).

The endocrine role in the aetiology of hypodontia was suggested. Werther and Rothenberg (1939) compared their figure of prevalence for hypodontia (2.3%) with that (3.4%) reported by Dolder (1937) and suggested that, the prevalence was higher in Switzerland because there was a greater incidence of thyroid disorders. Sarnat et al. (1988) investigated the effect of human growth hormons (hGH) on dental structures using study casts and radiographs of 32 patients with hypothyroidism. The 1st group comprised 19 patients with isolated growth hormone deficiency who recieved hGH replacement. The other group (13 patients) had high immunoreactive growth hormone and IGF-1 deficiency (Larson-type dwarfism) and could not benefit from hGH treatment. A comparison of both groups revealed that, 90% of the Laron-type dwarfism cases demonstrated absence of 3rd molars and 30% of subjects from both groups showed absence of some teeth.

Weyman (1968) described the relationship between hypodontia and the irradiation of developing teeth. Maguire et al. (1987) investigated the dental features of long term treatment (radiation and chemotherapy) of malignant disease in childhood. The sample comprised 85 patients, aged 3-22 years. Their findings revealed that 70% of the sample had dental abnormalities including hypodontia and microdontia.

Rubella syndrome has been implicated in developmental problems. Sever et al. (1965) reported the effect of epidemic which occured in the United States in 1964. Gullikson (1975) also investigated 55 children born in the epidemic year and found many abnormaliteis including hypodontia, enamel hypoplasia and abnormal tooth morphology.

The use of certain drugs, such as, thalidomide during pregnancy has a teratogenic effect (Axrup 1966, Nanda 1975). The effects of chemotherapeutic agents on the developing human dentition have been tested by Welbury et al. (1984). Their sample comprised 64 subjects aged between 3 and 20 years who were in long term remission from malignant disease. There was an increased frequency of hypodontia (19%) and hypoplasia (36%) which might be related to the disease, or its therapy. Similar findings were reported by Kinehara (1999).

An alteration in the rates of body size development in the prenatal period has also been suggested to be associated with hypodontia (Bailit and Sung 1968, 1975, Garn and Lewis 1970). Low birth weight and very young mothers were related to hypodontia. On the other hand, Grahnen (1956) found no definite link between the frequency of hypodontia and infection, maternal health during pregnancy and the age of mother at childbirth.

Other explanations suggested that as due to physical and inherent disruption of the dental lamina, which might result in obliteration of tooth buds and agenesis of teeth (Jorgenson 1980). It is also possible that metabolic imbalance in odontogenesis may be responsible for tooth agenesis. However, the timing and duration of disruption are important factors in the expression of the anomaly (Sofaer et al. 1971).

2.4.4.5. Genetic factors

Much attention has been given for the role of heredity in the congential absence of teeth, although, the mode of transfer is a matter of debate. Animal experiments, family and twins studies provided the support for this theory. Familial relationship indicates that, if a parent has developmental absence of teeth, their child has a greater risk of being affected by this anomaly (Grahnen 1956, Woolf 1971, Brook 1984, Zilberman et al. 1990). Jorgenson (1989) pointed out some indicators for the genetic aetiology such as a positive family history of the trait. Graber (1978) reported some characteristics of genetic disease are in parallel with the phenomenon of hypodontia. These include the occurrence of the disease in definite proportions among individuals, failure of the disease to spread to nonrelated individuals and occurrence of the disease more often in identical rather than fraternal twins.

Mode of inheritance:

Familial and twins studies of hypodontia subjects have provided the main evidence of the mode of its inheritance. Mendelian patterns of inheritance as a result of a single gene have been suggested. Thomsen (1952) pointed out that it behaves, in most situations, as a Mendelian recessive according to the Tristanites pedigrees, which have shown a very high prevalence.

Several authors belived that hypodontia is inherited as an autosomal dominant trait with varying penetrance and expression (Grahnen 1956, Alvesalo and Portin 1969, Phillip and Caurdy 1985, Ranta 1985, Svinhfvud et al. 1988, Niemienen et al. 1995, Arte et al. 1996). In his family study, Grahnen (1956) suggested the penetrance of trait to be 86% and the variation in penetrance and expressivity might be due to genetic modifiers and environmental factors.

Alvesalo and Portin (1969) examined 306 individuals living in the island of Hailuoto, Finland to investigate the inheritance pattern of three anomalies affecting permanent upper lateral incisors and found that 1.31, 4.25 and 2.29% of the participants had at least one peg-shaped, absent and reduced size tooth respectively. A map of the family lines was prepared which included 4-5 generations. From the pedigrees, peg-shaping and absence laterals exist in families indicating that the anomalies are hereditary and expressions of one dominant autosomal gene with 72 % penetrance. A peg-shaped incisor is a weaker expression of the gene that causes absence of the tooth thus therefore this may be considered as one trait.

In a study of monozygotic twins, Gravely and Johnston (1971) found differences in severity and distribution of tooth absence and supported the view that hypodontia is not an isolated trait, but that it is associated with other anomalies such as retardation of dental development. They concluded that congenital absence of teeth is genetically determined but its expression may be affected by non-genetic factors. Another case report of monozygotic twins had shown variable expression of hypodontia (Kindelan et al. 1998). Common missings were found but one twin demonstrated an additional absence of a 2nd premolar while the other showed absence of a 3rd molar.

Investigation into candidate genes in the aetiology:

Unfortunately, the genes causing hypodontia in human are still unknown. With the advancement in molecular biological techniques, segregation and linkage analyses are used to explore the mode of inheritance and to map the possibly responsible gene loci. Some attempts have already started by Thesleff and associates, to isolate and clone genes in human populations that are thought to be responsible for hypodontia (Nieminen et al. 1995, Arte et al. 1996, 1997, Thesleff and Aberg 1997). The theoretical principle was that since the homeobox genes have been earlier mentioned as candidates during odonogenesis, mutation of any one of these genes might lead to the inhibition of odontogenesis.

In their first linkage analysis study on five Finnish families who exhibited a uniform phenotype hypodontia (autosomal dominant transmission hypodontia), all members were examined clinically as well radiographically (Nieminen et al. 1995). The criteria used, in diagnosis of hypodontia, was to include any case with developmental absence of one to four teeth and/or the presence of one or more peg-shaped incisors. Twenty individuals were found to be affected by hypodontia. Avenous blood samples were taken from 42 members of these families and high molecular weight DNA (deoxyribonucleic acid) was extracted from leucocytes to enable the analysis of the Msx1 and Msx2 genes. Their findings revealed no linkage between these genes and hypodontia.

In another investigation on 77 individuals of seven Finnish (three-generation) families expressing an autosomal dominant transmission hypodontia, Arte et al. (1996) selected some growth factors and receptors for analysis. The congenital absence of one to six permanent teeth and/or the presence of the peg-shaped or small mesiodistal dimension of the maxillary lateral incisor teeth were considered in selection hypodontia subjects. The observations excluded another 4 genes from the aetiology of hypodontia (EGF, EGFR, FGF-3 and FGF-4). Moreover, a study (Arte et al. 1997) on eight Finnish three-generation families also excluded a number of genes as a cause (Msx1, Msx2, EGF, EGFR, FGF-3, FGF-4, 13MP-2, BMP-4 AND DLX2).

PAX9 gene has been suggested to be candidate gene in tooth development. A recent study by Goldenberg (2000) investigated 21 family members who demonstrated dentitions with a unique form of autosomal dominant hypodontia of several teeth. The patients presented normal deciduous dentitions and hypodontia of all the permanent 1^{st}, 2^{nd} and 3^{rd} molars but many of them also showed hypodontia of the 2^{nd} premolar and mandibular central incisor teeth. A complete scan of the genome using microsatellite markers and linkage analysis suggested mutation in PAX9 gene in these individuals and the mutation anlysis on MSX1 indicated no defects in this gene.

2.4.4.6. Multifactorial theory

It has been noted that, some discontinuous traits appear likely to be inherited as a result of a polygenic (multiple genes) predisposition with a threshold beyond which individuals are at risk (Carter 1969). Carter stressed for the need to discover the individual gene loci involved, the mechanism by which genetic predisposition acts, the nature of the additional environmental factors and the way of interaction between environment and such predisposition. Many investigators considered hypodontia as a multifactorial trait with various degrees of expressivity and severity, in which the anomaly is the result of many factors including a number of genetic and the environmental factors (Gravely and Johnston 1971, Woolf 1971, Suarez and Spence 1974, Brook 1974a, 1984, Bailit 1975, Chosack et al. 1975, Peck et al. 1993, 1994). It is of a polygenic origin influenced by environment with a discontinous distribution (quazi-continuous distribution) where the trait of tooth absence occurs when the threshold crosses the extreme end of the distribution.

An aetiological model had been proposed by Brook (1984), to explain anomalies of tooth number and size (Figure 3). Hypodontia is a quasi-continuous variable based on an underlying continuous distribution of tooth size. Persons below the biological threshold of genetic predisposition are not expected to have hypodontia, while those beyond the threshold are expected to have hypodontia.

The proponents of this theory believe that there is a pologenic dental system in which environment and gene mutations interact together and that it manifests itself clinically by various degrees of expressivity and severity. The peg-shaped lateral incisor tooth is a prime example of variation of expressively, which is some times seen on patients with and without developmental absence of other teeth. Other evidence supporting this concept offered by several studies, discussed below i.e. the association between hypodontia and microdontia, and between supernumeraries and macrodontia.

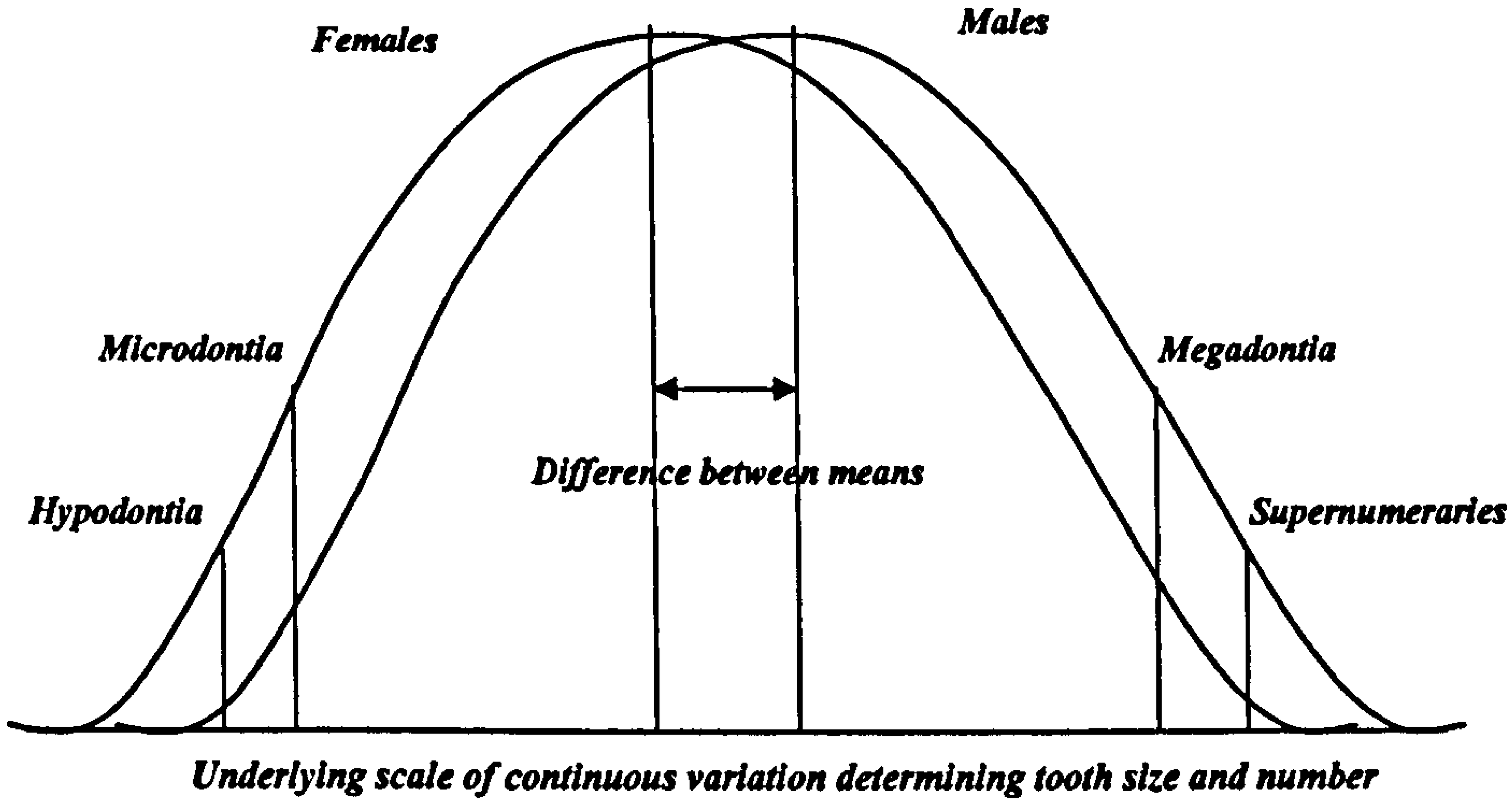


Figure 8: The model proposed by Brook (1984) to explain the aetiology of tooth number and size anomalies. The model combines polygenic and environmental factors. Individuals beyond the lower threshold will have hypodontia. * *The figure has been reproduced with permission.*

2.4. ASSOCIATION OF HYPODONTIA WITH OTHER ANOMALIES

Hypodontia is frequently associated with developmental dental anomalies and/or syndromes and several writers have reported this association based on case reports, twins and familial studies or general surveys.

2.5.1. Associations with Dental Anomalies

Hypodontia may represent only a single part in a comprehensive phenomenon that involves a wide variety of alterations in the development of the remaining teeth. In the present investigation, more attention has been given to the relationship between hypodontia and anomalies of tooth morphology (Figures 1-5). For the rest of anomalies the association has been briefly reported.

2.5.1.1. Hypodontia and tooth size

Several studies have reported in association of hypodontia with a change in sizes of all or part of the remaining teeth (Dahlberg 1945, Rantanen 1956, Alvesalo and Portin 1969, Garn and Lewis 1970, Lavelle et al. 1970, Foster and Van Roey 1970, Chung et al. 1971, Sofaer et al. 1971, Cohen 1971, Baum and Cohen 1971, 1975, Wisth et al. 1974a, Rune and Sarnas 1974, Joho and Marechaux 1979, Jarvinen 1984, Brook 1984, Ooshima et al. 1988, Brook and John 1995, Baccetti 1998, Ghaznawi et al. 1999).

The hypodontia and microdontia association has been demonstrated in cases with multiple developmental absence of teeth whether with or without ectodermal dysplasia (Winter and Geddes 1967, Redpath and Winter 1969). A reduction in tooth size had been found in many of the Hailuoto population, which was associated with hypodontia (Alvesalo and Portin 1969). Lavelle et al. (1970) examined 301 dental casts and radiographs for British subjects aged 1-25 years, when 3^{rd} molars are present or congenitally absent. The findings showed that 11% of the sample presented agensis of 3^{rd} molars and the size of the tooth as well as the arch were smaller in hypodontia of 3^{rd} molars group than in those with complete dentition.

The pattern of size reduction in hypodontia cases has been also tested. If an upper lateral incisor is developmentally absent, the other side often presents with a microdontial lateral incisor tooth (Rantanen 1956). The mesiodistal diameters of all permanent teeth, excluding third molars, have been measured (Garn and Lewis 1970). The first group consisted of 82 subjects who had hypodontia of one or more 3rd molars, 19 others with multiple absence of the lateral incisors and 2nd premolars presented the second group. Their findings demonstrated that the permanent teeth were smaller in both groups compared with the controls. They also found a correlation between the number of absent teeth and crown size reduction of the remaining teeth. The greater the number of missing teeth, the more reduction in size and the more disturbance in the size distributions. There was a gradient size reduction, in which the incisors are more reduced then, the canines, premolars and the molars reduced least of all.

Tooth measurements for 104 Caucasian individuals (71 females, 33 males), aged 6-24, with hypodontia of one or more teeth, have been evaluated and compared with a control group (N=243 subjects) using study casts (Cohen 1971, Baum and Cohen 1971). It has been shown that, teeth of males exhibit a greater size reduction than those of females. The direction of the greatest size reduction in the remaining teeth varies. In males, it affected mesial teeth rather than the distal.

A further investigation has been carried out (Baum and Cohen 1975). Apart from 3rd molars, mesiodistal and buccolingual tooth dimensions were obtained from study casts. The hypodontia sample was compared with two groups from the same ethnic background. The subjects in the first group were 66 females and 35 males , aged 7-21 with all teeth present including 3rd molars. The other sample consisted of 93 females and 91 males aged 3-18 (of Moorrees et al. 1957). Their observations indicate that the relationship of the mesiodistal and buccolingual diameters is complex and that the reduction in size from normal appears to be independent of each other. Tooth size variability in the hypodontia sample was significant when considering the mesiodistal dimension and it was greater in the anterior teeth than the premolars and molars, particularly in the maxilla. The tooth type presented an unexpected significant figure in which the 1st molars and canines demonstrated the greatest variability of tooth size, a finding contradicting the field theory (Butler 1939, Dahlberg 1945).

Rune and Sarnas (1974) investigated 45 males and 46 females, aged 7-19 years suffering from hypodontia of four or more teeth, the 3rd molars were excluded. With the exception of the upper central incisor, the mean tooth size in hypodontia cases was significantly smaller than the controls. No significant difference was found between boys and girls.

The mean values of the mesiodistal dimensions for the upper and lowers 1st molars and central incisors in individuals with hypodontia and controls were compared (Wisth et al. 1974a). They found a significant difference between males only. The lower 1st molar teeth demonstrated larger mesiodistal diameters in the hypodontia sample than the control group. Females were shown to have a slight general tendency for tooth size reduction in the anomaly sample, which was not significant. On the other, the lower central incisors exhibited the least size variations between the two groups. Small 1st permanent molars may be ssociated with a congenital missing of 3rd molars (Lavelle et al. 1970).

Chung et al. (1971) claimed that when central incisors are large, the lateral incisors tend to be absent, and the centrals were small when the lateral incisor teeth were peg-shaped. Sofaer et al. (1971) investigated 3,734 students whose ages ranged between 11 and 20 years. The maximum mesiodistal widths of the upper incisors were directly obtained from the mouth. Their observations demonstrated different figures for the measurements of the upper central incisors in accordance with the condition of the upper lateral incisors. The finding suggested that when both lateral incisors were normal, there was a tendency for the left central to be larger than the right. In cases with absence of lateral, the central incisors were larger than normal. The figures were significant in unilateral absence of laterals (normal lateral in the opposite side) i.e. the central incisor was particularly larger than normal on the missing side than on the other side. In bilateral absence of laterals, the right central tended to be larger than the left one. The dimensions of central incisors were smaller than normal in any combination of a peg-shaped lateral.

Brook (1984) is also in agreement with opinions suggesting associations between hypodontia and microdontia of the remaining teeth and added the more severe the hypodontia, the greater the chance of microdontia in the remaining teeth. His evidence was based on the fact that all cases which presented hypodontia of six or more teeth had also microdontia. Females were found to be more frequently affected by hypodontia as well as microdontia than males. It is also the case in a Romano-British sample that there was a significant association between microdontia and hypodontia (Brook and John 1995).

Baccetti (1998) investigated seven dental anomalies (hypodontia of 2nd permolars, small upper lateral incisors, palatally displaced canines, infraocclusion of primary molars, enamel hypoplasia, ectopic eruption of 1st molars and supernumerary teeth), in the untreated orthodontic population aged 7 to 14 years, and reported significant associations ($P<0.005$) between the first five anomalies. This finding provides further evidence supporting the hypothesis of a common aetiology for the disturbances in tooth development. Clinical reports also demonstrated this relationshp between hypodontia and reduction on sizes of the teeth (Jarvinen 1984, Ooshima et al. 1988).

2.5.1.2. Hypodontia and tooth shape

Hypodontia has been reported to occur with alteration in tooth shape of the remaining teeth (Dahlberg 1945, Rantanen 1956, Davies 1968, Alvesalo and Portin 1969, Foster and Van Roey 1970, Lavelle et al. 1970, Garn and Lewis 1970, Chung et al. 1971, Sofaer et al. 1971, Woolf 1971, Baum and Cohen 1975, Jarvinen 1984, Warnakulauriya 1989, Lai and Seow 1989, Basdra et al. 1999).

The overall frequency of subjects with hypodontia and/or peg-shaping one or more teeth was found to be 22.2% (Davies 1968). A genetic relationship exists between the peg-shaped and hypodontia of upper lateral incisor (Alvesalo and Portin 1969, Woolf 1971). The shape of the dentition has been investigated in 32 patients who demonstrated hypodontia of 1-26 teeth, excluded 3^{rd} molars (Foster and Van Roey 1970). Conical teeth that affect the deciduous and permanent incisors were usually associated with severe hypodontia. The narrow teeth, including the so-called peg-shaped upper laterals, affected the incisors and less frequently the canines of the permanent teeth and a pointed incisal edge were other malformation described.

Peg-shaping for upper lateral incior teeth as the main malformation of permanent dentition has also been documented by Magnusson (1977). According to Sofaer et al. (1971), peg-shaped lateral incisors were significantly more common on the left side than the right, and were associated with small central incisors.

Lai and Seow (1989) reported that 8.9% of hypodontia subjects demonstrated conical incisor malformation, which was significantly different from the controls ($P<0.01$). They noted that, half of the peg-shaped incisors were noticed in cases with premolar hypodontia, and only 16.7% in subjects with multiple hypodontia. In their familial study, Svinhufvud et al. (1988) reported some cases with peg-shaped upper lateral and conical lower incisor associated with cases having hypodontia and malposition of teeth.

Basdra et al. (1999) found that 3.5 and 7.5 % of their sample were having peg-shaped teeth in Class III and Class II Division 2 cases.

The shape of teeth is altered by malformation occurred in hypodontia cases. The deficiency of cusps in human teeth has been also documented to be associated with hypodontia. In their studies, Foster and Van Roey (1970) noted that this malformation usually affecting the palatal cusp of the upper 1st premolar or of one or more cusps of the permanent 1st molars. Moreover, some incisor teeth demonstrated irregular deficiency of crown formation. Lavelle et al. (1970) also reported that, on the 1st molar the hypoconulid (with distolingual cusp) pattern was lacking in 8% of the sample, and was more frequently lacking in individuals with hypodontia of 3rd molars.

2.5.1.3. Hypodontia and tooth eruption

Disturbance of tooth eruption was observed in subjects with congenital absence of teeth. Bailit et al. (1968) investigated radiographically and clinically 70 males and 107 females with hypodontia of one or more teeth (3rd molars were not included), and demonstrated a delay of tooth eruption compared with subjects with complete complement of teeth. In twins study, Gravely and Johnston (1971) also suggested that hypodontia is related to retardation of tooth development. Rune and Sarnas (1974) are also in agreement, particularly in the upper jaw in both males and females, and suggested considerable individual variations. Jarvinen (1984) reported that some of the permanent teeth showed signs of ectopic eruption and retained the deciduous teeth.

In severe hypodontia cases, Schalk-van der Weide et al. (1993) investigated tooth formation of patients with hypodontia of six or more teeth in a sample consisted of 216 patients (95 males and 121 females). The findings revealed that there is a tendency of delayed tooth formation in the hypodontia group when compared with controls, and the delay was more in males than females. However, the delay was in some stages, and confirmed the existence of individual variations.

The realtionship between hypodontia and tooth impactions or malpositions were documented in the lierature. Tooth impaction with hypodontia was found in all members of one family (Roberts 1973). A direct cause and relationship between canine malposition and the absence or anomalous lateral incisor has been suggested (Oliver et al. 1989). The guidance concept was suggested for palatal canine displacement in which the canine lost its path guidance of eruption due to the anomalous lateral incisor (Brin et al. 1986, Becker 1995). They reported that nearly 50% of patients with palatally displaced maxillary canines have demonstrated normal lateral incisors, while 5.5% have absence, 25% microdont and 17% peg-shaped lateral incisors. These observations have been confirmed in their study that included 2,440 individuals (1,267 females and 1,173 males).

Peck et al. (1994, 1996) also suggested a genetic origin for the palatally displaced canine, and suspected the presence of association in the phenomenon of tooth absence and tooth malposition. This has been supported by findings reported by Basdra et al. (1999). The occurrence of these two anomalies has been tested, in clinical and radiological examinations (Pirinen et al. 1996). The sample comprised both male and female patients (N=106) and their relatives. They concluded that, the displaced canine belongs to the spectrum of dental abnormalities related to hypodontia.

Relatives are likely to exhibit palatally displaced canines, in addition to having four times of population prevalence of anomalous lateral incisors (missing, peg-shaped or small), late developing dentitions (Zilberman et al. 1990). In a familial study, Svinhufvud et al. (1988) suggested a dominant inheritance of tooth malposition, and supported other study findings, which confirmed the association between palatally displaced permanent caines and hypodontia (Pirinen et al. 1996).

Bjerklin et al. (1992) found relationship between the hypodontia of premolars, ectopic eruption of maxillary canines and 1st permanent molars and infra-occlusion of deciduous molars. Findings revealed that in 18-28% of the sample, there were two anomalies in the same subjects, and in 2-3% two additional anomalies were found. They hypothesised that these are different manifestation of one syndrome, each having incomplete penetrance. Baccetti (1998) suggested a statistically significant association between palatally displaced maxillary canines and hypodontia of 2nd premolars.

2.5.1.4. Hypodontia and ankylosis and infra-occlusion

Lai and Seow (1989) found 65.7% of their hypodontia sample showed ankylosis compared to the control group (1.5%), with a significant difference (P<0.001). Subjects with multiple missing teeth were responsible for 52.3% of all cases of ankylosis. Another case report by Roberts (1973) has demonstrated the association of hypodontia and some dental anomalies including ankylosis of the deciduous teeth, in a family where parents and four children having the anomalies. A similar conclusion has been given by other reports (Evans and Briggs 1996, Baccetti 1998).

The relationship between hypodontia and infra-occlusion of deciduous molars has been also demonstrated (Bjerklin et al. 1992).

2.5.1.5. Hypodontia and enamel hypoplasia

A significant figure ($P<0.01$) has been given by Lai and Seow (1989) for hypodontia cases as also having enamel hypoplasia (11.9%), when compared with the controls. Multiple missing of teeth has been noticed in 75% of all cases with enamel hypoplasia, a finding supported by Baccetti (1998).

2.5.1.6. Hypodontia and taurodontism

The relationship between the hypodontia and taurodontism of the lower permanent 1st molar has been reported. Lai and Seow (1989) demonstrated a significant difference ($P<0.001$) between cases with hypodontia that have also taurodontism (34.3%) and the controls with full units of teeth (7.1%). Multiple tooth absence was behind 51.9% of taurodontism cases. Rune and Sarnas (1974) demonstrated a single root with large pulp chamber or taurodontia of the molar root morphology. The most frequent dental anomaly aassociated with hypodontia was taurodontism according to family study by Arte et al. (1999).

2.5.1.7. Hypodontia and individual cases

Other rare dental anomalies have been shown in the literature to have a link with hypodontia:

1) The disturbance of tooth order and position is very rare condition although its occurrence with hypodontia has been documented in the literature. In a sample comprising 21 patients with tooth transpositions, Chattopadhyay and Srinivas (1996) noted a significant association between transposition and other anomalies including

missing and peg-shaped lateral incisors. Similarly, a high incidence of hypodontia and peg-shaped laterals was found among 54 subjects with transposed upper and lower canines (Plunkett et al. 1998). Basdra et al. (1999) reported the trait with other anomalies in different malocclusions.

Out of 43 subjects with the maxillary canine-first premolar transposition, approximately 50% also demonstrated missing or peg-shaped lateral incisors (Peck et al. 1993, 1996). This accounts for 4-10 times the normal frequency, and suggests a genetic influence within a multifactorial inheritance model. The transposition of mandibular lateral incisor-canine also significantly associated with hypodontia and peg-shaped maxillary lateral (Peck et al. 1998).

2) An association between hypodontia and double teeth (fusion and gemination) in identical twins was found by Nik-Hussein and Salcedo (1987). This has been confirmed by another study carried out on primarly double teeth and its association with other anomalies including hypodontia (Aguilo et al. 1999). Lai and Seow (1989) investigated the presence of tooth fusion and gemination, and hypodontia together in the same subjects. But, no significant difference between the anomaly and control subjects was found.

3) A simultaneous presence of hypodontia and supernumerary teeth is rare although, it has been documented in the literature. The combined conditions involved both the upper and lower jaws, from both genders. Spyropoulos et al. (1979) reported three cases in which, both anomalies were present in each patient, and confirmed by clinical and radiographic tests. Nik-Hussein and Salcedo (1987) also reported in identical twins report that, one of them showed hypodontia, supernumerary as well as double teeth. Basdra et al. (1999) has also demonstrated this trait associated with dental anomalies in Class III maloclusions.

4) The presence of root dilaceration has been evaluated in hypodontia sample and another sample with normal number of teeth (Lai and Seow (1989). The two anomalies were found to be associated, however, they did not find statistical difference between groups.

2.5.2. Associations with Syndromes

There have been many syndromes documented in the literature, in which hypodontia is an integral part of the syndrome. Hall (1983) pointed out that missing teeth may be, in many cases, the main feature defining the syndrome and even takes part of its name, such as, Hypodontia and Nail Dysgenesis syndrome. Hall also reported 56 syndromes demonstrating hypodontia as one of the features of the syndrome. The following are some syndromes presented in the literaure.

2.5.2.1. Hypodontia and ectodermal dysplasia

The association between the congenital missing of teeth and ectodermal dysplasia symptoms has been shown in many papers. The pathognomonic features are hypodontia, hypohidrosis (lack or problems in sweat glands) and hypotrichosis (defects in the nails and skin). Another symptoms were demonstrated such as conical teeth, sparse scalp hair, largely absent body hair, prominent forehead, depressed nose and periorbital pigmentation (Redpath and Winter 1969, Soderholm and Kaitila 1985, Clarke 1987, Bergendal et al. 1991, Stephen et al. 1999).

Graber (1978) pointed out that in some cases, correlation of hypodontia with systemic disease may lead to the hypothesis that this anomaly may present a microform of systemic ectodermal dysplasia. Graber added, almost 20 ectodermal dysplasia-hypodontic syndromes alone have been described, with various modes of inheritance, and the majority seemed to be transferred in an autosomal dominant pattern with different levels of expressivity.

The most common type is the so-called X-linked hypohidrotic ectodermal dysplasia (Soderholm and Kaitila 1985, Bergendal et al. 1991). According to Clarke (1987), the estimated rate of frequency to be 1 per 100,000 births. Another condition demonstrates hypodontia with nail dysgenesis, i.e. Witkop tooth and nail syndrome (Hudson and Witkop 1975, Hall 1983, Hodges and Harley 1999). This is mainly characterised by hypodontia (of mandibular incisors, second molars and maxillarly canines), nail problems (spoon-shaped, slow growing and easily broken) as well as tooth-shape abnormalities. Rapp-Hodgkin syndrome is another rare form (Crawford et al. 1989).

On the other hand, Schalk van der Weide et al. (1994) did not find such association. Their conclusion based on evaluation of 167 patients who were compared with 135 healthy subjects. The controls did not show any significant difference when compared with hypodontia subjects without syndromes, except the skin.

2.5.2.2. Hypodontia and clefts of lip and palate

Hypodontia has been reported in cleft lip and/or palate conditions. There are aetiological differences for various patterns of clefts (Poole 1975, Ranta 1986, Shapira et al. 2000). The prevalence of cleft lip and/or palate is generally higher than that of isolated cleft palate. It had been found that males demonstrated a higher prevalence of cleft lip and palate, while females presented a higher frequency of isolated cleft palate. If the deformity is unilateral, the left side was more commonly affected. As the degree of relationship decreases from the first relative to no relation, the risk also decreases. The literature had also revealed a population variation among communities.

The association of clefts and dental anomalies (number, size, shape, formation and eruption) has been tested by several investigators (Ranta et al. 1983, Ranta 1984a,b, 1986, Noar 1990, Eerens et al. 1999, Shapira et al. 2000). A higher prevalence of hypodontia was found in cleft patients, even outside the cleft alveolus, than control individuals. The severity of hypodontia increased with the severity of cleft. The upper lateral incisor was most often susceptible to hypodontia and was more prevalent in the upper jaw than the lower and more frequently on the left side.

Similarly the sizes of tooth crowns are smaller and abnormal in shape, particularly the upper lateral incisors. Supernumerary teeth in the region of the upper lateral incisors were also documented.

Ranta et al. (1983) noted that, in a sample comprised 841 children with clefts, the frequency of hypodontia of the permanent dentition in the region of the alveolar cleft increased from 9.3% to 68.4%. A higher figure of prevalence i.e. 77% has been recently demonstrated for a sample consisted of 278 individuals with cleft lip, cleft palate or both aged 5 to 18 years, hypodontia of third molars and cleft cases with craniofacial syndrome were not included (Shapira et al. 2000). In cleft side, the maxillary lateral incisor was the tooth most frequently absent followed by maxillary 2nd premolar and then mandibular 2nd premolar, in the noncleft side, the rank order was maxillary 2nd premolar, maxillary lateral incisor and then mandibular 2nd premolar.

In another report, Ranta (1984a) investigated the development of the permanent dentition of 251 children affected with isolated cleft palate. Observations revealed a 0.7 year of developmental delay compared with noncleft subjects, and the presence of hypodontia promoted the delay significantly with increasing number of teeth absent. Ranta (1986) also pointed out higher prevalence when the cleft is associated with Pierre Robin and Van der Woude syndromes, and the permanent dentition is smaller in size compared with noncleft subjects.

2.5.2.3. Hypodontia and Rieger syndrome

This rare condition is an autosomal dominant disorder manifested by dental and occular abnormalities. The main manifestations are abnormalities of the anterior segment of the eye and hypodontia (Drum et al. 1985, Childers and Wright 1986, Tewari 1991, Murray et al. 1992, Skrinjaric et al. 1999). These studies reported other features of this condition. Anomalies of the dentition involve hypodontia in the maxillary incisor region, microdontia, malformed teeth and delayed eruption. While the extraoral symptoms are malformations of the anterior chamber of the eye, hypertelorism, midface flattening, broad flat nasal bridge, relative prognathic mandible, and prominent lower lip. The epidermal growth factor (EGF) gene on chromosome 4 has been implicated in the aetiology of this syndrome (Murray et al. 1992).

Axenfeld-Reiger anomaly is a similar condition, when the case present only occular abnormalities (Childers and Wright 1986, Murray et al. 1992). The frequency of the condition in general population suggests a figure of 1:200,000 (Childers and Wright 1986).

2.5.2.4. Hypodontia and other syndromes

Many other syndromes associated with hypodontia were documented in the literature. The following are some examples and the reader is asked to refer to the references for more detail:

1) Down's syndrome (trisomy 21) has been reported as having developmentally missing teeth (Cohen 1975, Moore and Persaud 1993).

2) Ellis-van Creveld syndrome (Chondroectodermal dysplasia) is an autosomal recessive disorder (Winter and Gegges 1967, Biggerstaff and Mazaheri 1968, Himelhoch and Mostofi 1988, Aljohar 1999). The oral manifestations include hypodontia (usually upper and lower incisors), malformed teeth (including conical incisors), delayed eruption of teeth, natal and neonatal teeth and a high incidence of dental caries.

3) Another autosomal dominant condition known as lacrimo-auriculo-dento-digital (LADD) syndrome, characterised by dental problems (missing, small or peg-shaped teeth) as well as defects in the lacrimal and tear system, hearing loss and digital malformations (Wiedemann and Drescher 1986).

4) Burgersdijk and Tan (1978) reported congenital absence of teeth with patients having Wolf-Hirchhorn syndrome, which is also manifested by facial clefts and heart defects, as well as mental retardation.

5) Ectrodactyly ectodermal dysplasia is a condition characterised by associated defects of ectrodactyly (lobsterclaw hands and feet), ectodermal dysplasia and cleft lip and /or palate, as well as hypodontia (Kaiser-Kupfer 1973).

6) Klinefelter (47 XXY) syndrome may demonstrate severe hypodontia and taurodontism (Rock and McLellan 1990) and bigger tooth size than normal individuals (Townsend and Alvesalo 1985).

7) Incontinentia pigmenti (Bloch-Sulzberger syndrome) is another rare condition that occurs in female infants, and is manifested by cautaneous lesions, which is sometimes associated with other problems, such as dental anomalies (hypodontia, malformed teeth and retarded teeth), central nervous system, occlular and /or bony abnormalites (Francois 1984, Yamashiro et al. 1998, Tanboga et al. 1999, Van den Sten et al. 1999).

8) Borgstrom et al. (1996) reported hypodontia, microdontia and short roots in cases having Laurence-Moon-Bardet-Biedl (LMBB) syndrome. Other manifestiations of this syndrome are retinal dystrophy, polydactyly, obesity and mental retardation.

9) Gorlin's syndrome has been also reported with Hypodontia (Romero et al. 1999).

10) Nazif (1973) presented a case with hypodontia of some permanent teeth, anomalies of extremities and stenosis of lacrimal ducts and suggested a possibility of an incomplete form of the ankyloglossum superius syndrome. This syndrome invloves congenital ankylosis of the tongue to the hard palate or maxillary alveolar ridge, hypoplasia of the

digits, cleft palate and hypodontia.

11) Hypodontia has been also found in Mobious Syndrome (Jacobsson et al. 1999).

2.6. MEASUREMENT OF DENTAL DIMENSIONS

The measurement of tooth dimensions to evaluate tooth morphology make uniting interest for dental science, human biology, forensic science and physical anthropology. Physical Anthropology is the science that deals with variations of the measurements of the human skeleton. One of its branches focuses only on the measurement variations of the human teeth and is known as Dental Anthropology. Odontometry is another term used in the literature for measuring the size and proportion of teeth and commonly for measuring the mesiodistal crown dimensions. In clinical orthodontics, it comes as part of the space analysis and malocclusion of the dental arches.

2.6.1. Terminology of Tooth Dimensions

There have been many different terms and definitions utilised in the literature to indicate various measurements of tooth dimensions:

2.6.1.1. Mesiodistal dimension (MD)

Different terms have been used such as tooth width (Miyabara 1916, Lundstrom 1954), mesiodistal width (Neff 1957, Bolton 1958), tooth breadth (Lundstrom 1955) and mesiodistal crown diameter (Ballard 1944, Bolton 1962, Lavelle 1968, Arya et al. 1974, Axelsson and Kirveskari 1983).

Many authors favoured the use of the maximum reading between the contact points or the points where the contact would normally occur (Ballard 1944, Moorrees et al. 1957, Bolton 1962, Alvesalo and Tigerstedt 1974, Lavelle 1971, Peck and Peck 1972a,b, Perzigian 1976, Potter et al. 1981, Axelsson and Kirveskari 1983, Kieser et al. 1985). The minimum distance between the contact points measured parallel to the occlusal plane was also utilised (Lavelle 1972).

According to Lundstrom (1954), it is the distance between contact points in anatomically correct occlusion, projected on the occlusal plane. Lavelle (1971) noted that it is the greatest distance between the normal contact areas on the proximal surfaces of the tooth crowns, measured parallel to the occlusal plane.

Some investigators suggested that the MD to be taken while holding the callipers parallel to both the occlusal and buccal (vestibular) surfaces (Moorrees et al. 1957, Potter al.

1981, Axelsson and Kirveskari 1983). According to Moorrees et al. (1957), it was determined by measuring the greatest distance between the contact points while holding callipers parallel both to the occlusal and vestibular surfaces. Furthermore, it was defined as the maximum distance between the contact points of a tooth in normoocclusion (Kieser et al. 1985).

2.6.1.2. Buccolingual dimension (BL)

This is also known as the buccolingual crown diameter (Lavelle 1968), faciolingual diameter or tooth thickness (Miyabara 1916, Axelsson and Kirveskari 1983), width (Hinton et al. 1980) and breadth (Perzigian 1976, Hinton et al. 1980, Kieser et al. 1985).

The maximum BL dimension of the tooth as taken perpendicular to the MD dimension has been considered (Moorrees et al. 1957, Lavelle 1970, Hinton et. 1980, Potter et al. 1981, Axelsson and Kirveskari 1983, Kieser et al. 1985). Lavelle (1972) noted that this was taken as the distance between the most buccal and lingual crown convexities, measured at right angles to the mesiodistal crown diameter, the greatest distance being recorded.

2.6.1.3. Occlusogingival dimension (OG)

This dimension was far less often used in the literature than the MD and BL dimensions. Bolton (1958) used the term of incisogingival height to describe this dimension. This has been also called crown height (Miyabara 1916, Lavelle 1968, Volchansky and Cleaton-Jones 1981) and taken from the buccal surface.

According to Miyabara (1916), it is the distance between the cutting edge and the enamel margin, and is always measured along the buccal surface of the crown. Lavelle (1968) used this diemension in premolars, canines and incisors, from the point on the upper surface of the crown above the lowest point of the amelocemental junction or free gingival margin. In molars, on the other hand, the measurement was taken between the tip of the mesiolingual cusp to the lowest point on the amelocemental junction or free gingival margin. It was the distance between the occlusal line and the cementoenamel junction (Volchansky and Cleaton-Jones 1981).

2.6.2. Estimation of Tooth Dimensions

It is generally agreed that, the mesiodistal dimensions of the upper permanent teeth, on average, exceed the widths of the deciduous teeth. The tendency of human teeth to be proportional in size has been suggested by some workers. If the anterior teeth are smaller than the average sizes, the posterior teeth are expected to be smaller than the average sizes as well.

Moorrees et al. (1957) investigated the mesiodistal diameters for the permanent teeth and deciduous teeth and longitudinally evaluated a sample consisting of 184 North American children of European stock (91 males and 93 females) aged 3 to 18 years. A wide individual variation was found and the conclusions were: (1) The total diameters of permanent incisors and canine is larger than that of the deciduous measurements and vice versa for the premolars and deciduous molars. (2) The combined widths of all the deciduous teeth is smaller than of their successors by an average value of 5.22 mm. in the maxillary and 0.77 mm in the mandibular arch.

There are two basic ways to measure dental arches. The first one is by measuring the mesiodistal dimensions of each tooth from the contact points and then counting their total. It can be directly performed by contouring a brass wire in the line of occlusion, which can be straightened out for measurement (Peck and Peck 1975). The other way is by dividing the arch into linear segments for easier measurement. However, such analysis is only applicable for cases with erupted teeth. For younger patients with mixed dentitions, other methods may be used to predict the sizes of unerupted teeth. These involve the use of estimated average values of tooth dimensions. The use of sizes of only erupted permanent teeth to predict the sizes of unerupted teeth (Moorrees et al. 1957). Or, the use of both radiographs and sizes of the erupted teeth.

Hixon and Oldfather (1958), proposed another method to predict the sizes of unerupted permanent canines and premolars. The sample comprised of 41 American children using study models for the deciduous teeth and radiographs for the unerupted permanent teeth, and then later models for all erupted teeth excluding permanent molars. They concluded that on average, the combination widths of the permanent canine and premolars was 2.1 mm., smaller than that of the their predecessors. A wide variation for the combined widths has been also found which ranged from 0.1 mm to 4.4 mm.

Lysell (1960) measured the differences between the permanent canines and premolars and their successors. Study casts for 100 children (50 males and 50 females) were used at age 3-5 years and then at age 14. Similar values of differences were demonstrated; 1 mm. for each quadrant in the upper arch and 2 mm. in the lower. Tanaka and Johnston (1974) suggested another prediction values, based on the lower incisors. One half of the total diameters of the lower incisor teeth is added to 10.5 mm. and 11 mm., to predict the sizes of the lower and upper unerupted permanent canine and premolars, respectively.

Staley and Kerber (1980) reviewed the prediction method suggested by Hixon and Oldfather and introduced their method with the use of radiographs and tables, in order to predict the size of unerupted canines. This method is valid in the lower arch only and can be achieved by the sum of incisor widths (taken from the study cast) and the premolar width (taken from the radiographs).

2.6.3. Odontometric Variations

A number of writers reported variations on tooth size and demonstrated important findings and conclusions. These involve variations between different ethnic groups as well as among individuals of the same population, individual of different generations, differences between twins, gender differences, variations in locations and differences of various types of occlusions and/or body size.

2.6.3.1. Controlling factors

As mentioned earlier, interactions of genetic and environmental factors, the evolution trends and the field's concept have been implicated in the development and determination of tooth dimensions. Lavelle (1968) investigated mesiodistal and buccolingual dimensions when measurements were obtained from Anglo-Saxon and modern British populations. There was general trend toward reduction in dimension in contemporary British subjects except the molars that showed the opposite conclusion.

Potter et al. (1976) compared mesiodistal and buccolingual dimensions of 28 permanent teeth on 43 monozygous pairs of twins and 32 dizygous pairs of twins. Amongst the genetic factors identified, one appeared to affect the upper teeth in general, whereas a second influenced mainly the lower anterior teeth. The results indicate that the genetic determination of the upper and lower dentition seem to be independent of each other and mandiblular teeth showed a wide range of genetic factors than the uppers. On the other hand, there was a tendency on both sides to be associated with the same genetic factor.

Dempsey et al. (1995) investigated the contribution of these two factors on the mesiodistal diameter of the upper and lower permanent incisors. The sample comprised of study casts for 149 monozygous and 149 dizygous twins. The findings showed a significant gender difference in the mean values for males, which were higher than females. They suggested that a general genetic factor (gene or group of genes) was involved. Kabban et al. (1999) also demonstrated concordance (similarity) in tooth size and occlusal morphology in 22 monozygotic twins when they compared them with 12 dizygotic twins. Baydas et al. (1999) also in agreement that tooth size has a high heritability following their mesiodistal measurements of 103 siblings.

Poor maternal condition and small birth size have been reported to be asssociated with small tooth dimensions (Garn et al. 1980). A recent study (Sew and Wan 2000) investigated morphometric changes in the primary dentitions of a pre-term sample of 111 children who were divided into three categories according to their birthweights (very low, low and normal birthweight). Measurements for mesiodistal and buccolingual dimensions were obtained. The findings indicate that there is a significant link between tooth size reduction and low birthweight and the reduction in tooth dimension increases as the birthweight getting low. Heikkinen et al. (1994) also reported reduction of tooth size in children of smoker mothers during gestation.

The relationship between sex chromosomes and the size of tooth crown have been of interest for Alvesalo and his associates (Alvesalo et al. 1975, Townsend et al. 1984, Townsend and Alvesalo 1985, Varrela et al. 1988, Mayhall et al. 1991, Alvesalo 1997). The size and structure of tooth crowns of individuals with sex chromosome anomalies and their normal relatives have shown differential direct effects on growth of genes on human X and Y chromosomes. These differential effects explain the expression of sexual dimorphism in various somatic features e.g., tooth number, size and shape (Alvesalo 1997). Another information suggests that X chromosome affects enamel formation and has little or no effect on the growth of dentine whereas Y chromosome promotes growth of both tissues. These chromosomes operate early and apparently in a continuous manner during tooth development.

The effect of Y chromosome on the size (mesiodistal and buccolingual dimensions) of permanent teeth of 12 individuals with a 47XYY males (male with extra Y chromosome) was investigated (Alvesalo et al. 1975, Alvesalo 1997). Tooth sizes were found to be larger than those of control males (46XY) and females (46XX). The deciduous teeth were generally larger than those of control males. Another study investigated 77 males with 47XXY (Klinefelter syndrome) and a control group, which comprised of 150 Caucasian males (Townsend and Alvesalo 1985). Findings indicated that the mean height of the 47XXY males was above average and their tooth sizes were larger than those of normal males.

The role of X chromosome on dental development was also tested in 45X (Turner syndrome) females (Townsend et al. 1984). General reduction in tooth size was found in a sample comprised of 121 syndrome cases and 171 control subjects. On the other hand, 46XY females or the complete form of testicular feminising syndrome have similar tooth sizes to normal males (Alvesalo 1997).

In other developmental anomalies, the mesiodistal diameters of each permanent tooth of 40 patients with hemifacial microsomia were measured (Farias and Vargervik 1998). In general, teeth were smaller in the affected side than on the opposite side. The asymmetry was parallel with an increase in severity and it was particularly significant for the lower canines and 1st molars.

2.6.3.2. Ethnic variations

Differences in tooth dimensions between ethnic groups have been demonstrated. An earlier study conducted by Miyabara (1916) demonstrated differences between Japanese and European populations in various measurements. For example, maxillary lateral incisors demonstrated larger dimensions and being more stable in Japanese, on the other hand, Europeans showed larger occlusogingival dimensions. Moorrees et al. (1957) pointed out that the mean diameters of both permanent and deciduous teeth are smaller than those of Swedish children.

The mesiodistal and buccolingual diameters of the deciduous teeth were measured, using study models, of 150 children (50 Caucasians, 50 Mongoloids and 50 Negroids) from both genders (Lavelle 1970). Findings indicated variations between the three population samples. Tooth dimensions of Negroids were on averge 9.4% greater than Caucasians and 4.7% than Mongoloids. Those of Mongoloids were 4.3% greater than Caucasians.

For an Indian Knoll population, both mesiodistal and buccolingual diemnsions showed larger values than many modern population and being smaller than Australians (Perzigian 1976).

In an Icelander schoolchildren sample (N=1,010) mesiodistal and buccolingual crown dimensions of the permanent dentition have been measured from their dental casts of and compared with other population groups (Axelsson and Kirveskari 1983). Observations showed that sample teeth have larger dimensions than Ohio Caucasians of Northwest European origin. In Tagalog Filipino sample (100 males and 152 females), the mesiodistal and buccolingual dimensions were investigated (Potter et al. 1981). The teeth were small as for Southeast Asian of Mongoloid origin and the maxillary lateral incisor was large as related to the cental tooth, a feature differentiates the Asian Ancentary (Bailit 1975).

The sizes of the permanent teeth were found to be larger in Chinese than those of Caucasians but, smaller than those of Australian Aboriginals (Yuen et al. 1997).

2.6.3.3. Sexual dimorphism

Moorrees et al. (1957) observed that males presented broader dimensions of the crowns compared with females, particularly in the permanent dentition. Garn and associates (Garn et al. 1967, Garn and lewis 1970) confirmed that for both size and shape. There were gender differences in the mesiodistal and buccolingual dimension and the later exceeds the former. Another study was carried out by Arya et al. (1974) to investigate the mesiodistal measurements for both genders who demonstrated Class I and Class II occlusions. The sample comprised 48 males and 47 females of Northwest European origin aged between 4.5 and 14 years. When the type of occlusion was disregarded, there were significant gender differences, males showed larger figures than females, except the mandibular permanent central incisor. In the deciduous dentitions, only maxillary 2^{nd} molar showed significant gender difference.

Lavelle (1975) reported that boy generally had greater tooth measurements than girls. This is in agreement with Perzigian (1976) who added one exception to this trend i.e. the maxillary lateral incisor tooth. Richardson and Malhotra (1975) have noted that teeth of males were larger than teeth of females for each tooth type in both arches. The study included measurement of mesiodistal crown dimensions of 3,980 individual teeth of sample comprised 81 males and 81 females, American Negroes. Axelsson and Kirveskari (1983) also found sexual dimorphism.

Moreover, measurements of mesiodistal and buccolingual crown dimensions were obtained from 124 South African Caucasoids and demonstrated a higher degree of sexual dimorphism variability than other Caucasian groups but with similar pattern and degree of variability (Kieser et al. 1985). Yuen et al. (1997) investigated the mesiodistal crown dimensions of the permanent and deciduous dentitions of 112 Hong Kong Southern Chinese. Males exhibited larger teeth than females except the lower incisors in both dentitions, although the difference was not significant.

2.6.3.4. Tooth type variations

As mentioned earlier, the field's theory suggests that the key teeth being less affected with tooth size and shape alteration than the other members of each group. Moorrees et al. (1957) found variation in tooth size and shape. Alvesalo and Tigerstedt (1974) investigated tooth mesiodistal and labiolingual dimensions, except 3rd molars. Their observations indicate that with the exception of the lower incisors, the mesial member of each tooth group has higher heritability than the distal ones. The highest values for the mesiodistal dimensions came from the central incisors, canines and 1st premolars in the upper arch and from the lateral incisors, 1st premolars and molars in the lower arch. On the other hand, the highest values for the labiolingual dimensions came from the canines, 1st premolars and molars in the upper jaw and from the 1st premolars and molars in the lower jaw. They concluded that, in general, the teeth with high heritability are less influenced by environmental change than teeth with low heritability.

Bailit (1975) also suggested that the key tooth in each tooth class carried the highest heritability, while the distal tooth, such as the 3rd molar can be influenced more by environmental factors. Kieser et al. (1985) also in agreement that the distal tooth of each group is subject for more variation than the mesial tooth with the exception of in the lower incisors. They also noticed the opposite in the upper incisor teeth for male South

African. In an earlier study (Miyabara 1916), the maxillary lateral incisors showed bigger tooth dimensions and demonstrated less variability in form for Japanese as compared to European population.

Axelsson and Kirveskari (1983) reported that the 1st molars have the greatest stability of crown shape, while the upper lateral and lower incisor teeth have the greatest variabilities. The posterior teeth were found to be less variable than the anterior teeth in both deciduous and permanent dentitions. The anterior tooth of each morphological field was less variable than the posterior one, a finding also reported by Perzigian (1976).

Considering the difference between genders, the greatest difference suggested was related to canine teeth in both dentition (Moorrees 1957, Yuen et al. 1997) or in permanent dentition only (Miyabara 1916, Arya et al. 1974). From another perspectives, the upper and lower canines showed the biggest gender differences in both mesiodistal and buccolingual dimensions followed by the mesiodistal dimension of upper central incisor and buccolingual of upper 1st molar (Potter et al. 1981). Others also suggested that the greatest difference to be related to the canine teeth and the opposite be for the maxillary lateral incisors (Axelsson and Kirveskari 1983).

2.6.3.5. Symmetry in tooth dimension

Ballard (1944) investigated the asymmetry in tooth size, for 500 sets of study models of the various types of malocclusion (139 Class I, 104 Class II and 19 Class III), drawn from four sources. The greatest mesiodistal diameters of the permanent dentition, (except 2nd and 3rd molars) were measured and then, each tooth was compared with that of the opposite side. The distribution in terms of occlusal classification was also performed. A right-left discrepancy in measurement was found in 90% of the sample. The jaw distribution suggested the lateral incisors and the 1st molars were most frequently involved in the maxilla and the canines and the 1st premolars in the mandible.

Garn et al. (1967) have shown that the size of symmetry is inherited more frequently in males than females, which in turn leads to greater shape variation in the male. The mandibular 2nd premolar and the 2nd second molar and the maxillary lateral incisors were the teeth, which demonstrated greatest gender difference in tooth shape.

Kieser and Groeneveld (1988) examined dental casts of 106 South African Negroids by measuring their mesiodistal and buccolingual dimensions. Subjects were found to be significantly more asymmetric than South African Caucasoids.

In a twin study (Potter and Nance 1976), bilateral tooth measurements (mesiodistal as well as buccolingual) have been investigated. No differences were found between monzygotic and dizygotic twins in terms of either asymmetry or mirror imagery.

2.6.3.6. Tooth dimensions and occlusion types

The relationship between dental dimensions and various types of occlusions had been of interest to many authors. To make comparisons between various occlusions, the measurements of tooth dimensions were obtained and then evaluated (Arya et al. 1974, Lavelle 1975). Mesiodistal measurements in Class I and Class II occlusion were investigated (Arya et al. 1974). When the measurements for both genders were combined, no differences were found related to the category of occlusion except the mandibular permanent 1st molar and mandibular deciduous 2nd molar, in which Class I demonstrated larger measurement than Class II.

Lavelle (1975) examined measurements of 300 males, white British, with age range 16 to 18 years divided into equal subgroups of Class I, II and III dental occlusion as well as skeletal patterns. In the lower teeth, the mesiodistal and buccolingual dimensions were greater in Class I than Class II (by 0.6% and 0.7%, respectively) and Calss III (by 0.7% and 1.2%, respectively). In the upper teeth, the mesiodistal and buccolingual dimensions were larger in Class III (by 2.9% and 4.9%) and Class II (by 1.3% and 3.1%) than Class I, respectively.

Malocclusion caused by hypodontia has not been subjected for a comprehensive research to test pattern of tooth dimension changes, taking into account the number of tooth missings and gender.

2.6.3.7. Tooth dimensions and body size

The relationship between dimensions of permanent teeth, dental arch, skull and stature in three different British population samples (Caucasoids, Mongoloids, Negroids), has been investigated (Lavelle 1971). The main conclusion reveal that, with the exception of tooth and dental arch which presented significant correlations, all variables to be poorly correlated one with another. Bailit (1975) has also pointed out that there is no relationship between the tooth size and body size because Australians who were shorter than northern Europeans have demonstrated larger teeth.

2.6.4. Odontometric Ratios and Indices

Some odontometric ratios, oftenly called indices, have been proposed to help investigation trends in tooth morphology as well as for clinical purposes. Individual teeth and certain segments in the dental arches, therefore, can be assessed.

2.6.4.1. Composite measurements ratios

Tooth morphology ratios incorporating combination of tooth dimensions have been reported in some of the above-mentioned studies. Lavelle (1968, 1970) suggested the crown index to investigate the shape of tooth crown i.e. the ratio of the buccolingual and mesiodistal crown dimension expressed as a percentage. Peck and Peck (1972a,b) have also utilised this index to investigate the relationship between tooth crown dimensions and dental crowding. Oral measurements for the mesiodistal and buccolingual dimensions of each lower incisor were obtained for all subjects. Findings revealed that the lower central and lateral incisors were significantly smaller mesiodistally and larger labiolingually in aligned dentitions than the controls. They concluded that tooth shape was related to dental crowding in which values above the range may contribute to the crowding.

The crown module has been also utilised (Lavelle 1968, 1970) and defined as the sum of mesiodistal and buccolingual crown dimensions divided by 2 that may provide a general picture of crown size. However this was of rare use.

Furthermore, the crown area (robustness) i.e. the product of mesiodistal dimension times buccolingual dimension has been reported (Lavelle 1968, Hinton et al. 1980). It is also rarely used because, although it gives an overall impression for crown size, it does not take into account variations and differences in crown morphology.

2.6.4.2. Interarch relationship ratios

Deviations from the average interarch relationship can be due to many factors, in which local factors are more often to be the maxillary lateral and central incisors and the lower premolars. Other factors include mismatch in size and/ or relationship between upper and lower dental arch teeth. Laino et al. (1999) reported that 75% of the sample (115 females and 85 males) had demonstrated a tooth size discrepancy that is related to the anterior teeth. The significance of the intermaxillary tooth width ratio in occlusion was given attention by many investigators (Lundstrom 1954, 1955, Bolton 1958, 1962, Stifter 1958, Richardson and Malhotra 1975, Ta et al. 1999, Nie and Lin 1999, Laino et al. 1999, Heusdens et al. 2000, Smith et al. 2000).

The anterior and overall intermaxillary indices were introduced by Lundstrom (1954, 1955), as a percentage ratio, to investigate the existence of any mesiodistal deviations that disturb the occlusion, particularly the overbite and overjet. Bolton (1958, 1962) re-introduced these indices and suggested three ratios, the anterior, posterior and overall ratio for the relationship between the mandibular and maxillary teeth. Bolton had observed that there was a tendency of the lower premolars to have larger mesiodistal dimensions than their opponents. Similar attempt was made by Neff (1957) who suggested the anterior percentage relation (APR) in an attempt to evaluate the relationship of the overbite with tooth size in labial segments. The upper six anterior teeth being divided by the lower six anterior teeth count this. Many reports (Stifter 1958, Richardson and Malhotra 1975, Ta et al. 1999) published similar figures for these ratios.

The difference in intermaxillary tooth size discrepancies among different malocclusions has been examined (Nie and Lin 1999). Class III and Class II occlusion cases demonstrated higher discrepancies than Class I malocclusions.

2.7. RELIABILITY OF MESUREMENTS

The term of reliability generally reflects the extent of accuracy of any used system, which is affected by many factors. There are two important factors determining value of reliability i.e. the precision and accuracy (Houston 1983, Kieser 1990). The former factor refers to the reproducibilty or repeatability of a measurement. The more precise the method, the more closely clustered about a mean value. While the latter factor refers to the validity of measurement or an estimate of how close the measured value is to the true value, i.e., how unbiased is the measurement. However, the term of reliability is sometimes used to reflect both validity and reproducibility.

Houston further classified the errors on any measurement system into systematic (bias) and random errors. Examples for systematic errors: If a particular measurement is consistently under- or over-recorded, or if more than one operator is involved with a different concept of landmark identification or in one operator whose experience has changed over time. Random errors may occur as a result of difficulty in identifying a landmark or variation in image quality. Some approaches to control erorrs were suggested e.g. obtaining films (images) with high quality, calibration to improve landmark identification and randomisation of the measurement records.

2.7.1. Factors Affecting Reliability of Measurements

Reliability of measurements varies according to the quality of records, the surrounding condition, and the care and skill of the operator. The following are main sources of measurement errors mentioned in the literature.

2.7.1.1. Investigator

The person(s) who performs the measurments is a key factor in the system reliability. All investigators list certain criteria for their measurement methods in order to avoid or minimise errors and improve reliability of their data collection (Lundstrom 1954, 1955, Hunter and Priest 1960, Lavelle 1971, 1972, Peck and Peck 1972a, Richardson and Malhotra 1975, Potter et al. 1981, Volchansky et al. 1981, Axelsson and Kirveskari 1983, Houston 1983, Kieser et al. 1985, Yuen et al. 1997).

He/she must be familiar with the technique and has received enough training and calibration prior to starting the study measurement and each study stage should be undertaken in proper conditions.

2.7.1.2. Impression and casting procedures

Impression flaws and casting errors are important factors in the measurement reliability and study models are usually selected according to their quality and clarity (Lavelle 1970, Potter et al. 1981, Axelsson and Kirveskari 1983, Kieser et al. 1985, 1986, Yuen et al. 1997). Reversible as well as irreversible hydrocolloid (alginate) impression materials have improved in accuracy and manipulation (Kieser 1990).

The accuracy of the cast made from an impression is affected by the technique used by the operator in terms of all conditions related to the correct mixing of the impression material under his control (quantities of materials, mixing time, temprature, tray filling, seating the tray in the mouth, removal the tray, and pouring the cast as soon as possible). For instance, there are two important physical properties, in storage conditions, affecting the accuracy of impression; syneresis (water loss) and imbibition (water gain). The ideal alginate impression material should have the tendency to compensate for these properties (Cohen et al. 1995). They pointed out that irrespective of the type of material used, immediate pouring produces the most accurate casts.

Measurements were taken from plaster casts of 24 subjects randomly chosen by two investigators. Replicates casts for the same subjects were obtained and subjected for another set of measurements (Hunter and Priest 1960). Impressions were all taken with alginate materials and poured in model plaster. Findings revealed that there were no significant differences between the two sets of measurements for one investigator. Whereas, mean differences between the investigators were significant at the 0.10 level. However, it has been pointed out that, regardless of the material or technique used, some linear distorsion was a consistent finding (Hollinger et al. 1984). The have also noted that, the effect of material distorsion and shrinkage is unpredictable.

2.7.1.3. Tooth and gingival conditions

The tooth structure is always subject for loss. The loss could be due to one or a combination of wear (attrition, abrasion and erosion), trauma, and/or carious lesion. While this may occur in occlusal or proximal surfaces, an appreciable effect change on tooth dimension measurement would result (Lundstrom 1954, 195, Lavelle 1968, 1970, 1972, Richardson and Malhotra 1975, Potter et al. 1981, Axelsson and Kirveskari 1983, Kieser et al. 1985, 1986, Kieser and Groeneveld 1988, Yuen et al. 1997). However, a small amount of loss has been considered as normal, and only teeth without marked loss may be involved in odontometric purpose.

Similary, the measurement error may occur during taking the measurements from partially erupted, swollen gingiva, pathological recession and/or in a situations where the tooth fillings, calculus or irregularities (crowding, imbrication, rotation, ovelapping, malposition) obscure proper placement of the measurement device. Not only this, but the ginigiva undergoes physiological change. Volchansky et al. (1981) found a correlation between an increase in the clinical crown height and age. Although most odontometric studies utilise measurements taken on dental casts, reliable evaluation of calculus can only be made intraorally (Kieser and Groeneveld 1988, Kieser 1990).

2.7.1.4. Technique and type of measurement device

There have been different methods described to measure dimensions of the human dentition. Accordingly, each method of tooth dimension measurement has advantages, disadvantages and limitations. Subjectivity of technical problems is always associated with measurement techniques e.g. callipers placement on crowded teeth.

Dental models are used to obtain two- or three-dimensional analysis. The techniques are either traditional or advanced methods. Lowey (1993) classified these into direct (callipers) and indirect techniques (laser scanning, Xerox copying, radiographs, photography, use of computers e.g. Optocom). The following are some examples that were briefly described:

1) Manual technique with the use of dividers, sliding, vernieror dial callipers, or Boley gauge allow only linear measurements to be obtained (Bolton 1958, 1962, Moorrees et al. 1957, Hunter and Priest 1960, Garn and Lewis 1970, Lavelle 1970, Lavelle et al. 1970, Richardson and Malhotra 1975). The type of measuring instrument had been suggested to have a role in the accuracy of measurements. Hunter and Priest (1960) invetigated the errors and discrepancies of two different instruments; dividers and sliding callipers. The findings revealed larger measurements determined by dividers than did the callipers with

significant values.

2) Radiography is a helpful system to measure teeth but has disadvantages such as exposing individuals to irradiation and magnification.

3) The Optocom is a technique introduced to analyse dental casts (Van der Linden et al. 1972). It is a microscope mounted over a two-dimensionally movable table and the dental cast, attached to a base, is placed on a sliding table in a fixed position. They claim that the accuracy is high and the method takes about 20 minutes for an experienced operator to record 387 points for each single dentition.

4) The Reflex Metrography basically is an instrument with a semi-reflecting mirror in which an object standing in front of the mirror has its image at an equal distance behind the mirror (Richmond 1987). To record image points on the cast, a moving light source connected to a three-dimensional (X-Y-Z) slide system behind the mirror is used. Users of this technique claim that it has a high degree of accuracy, easy to use and no object contact is needed. It takes nearly 20 minutes to record 110 points by an experienced operator.

5) Image Analysis technique is a television-based system in which a dental study cast was placed on a macrostand (Brook et al. 1983). Linear, perimeter and area measurements of tooth crowns were obtained from video images of buccal and occlusal surfaces. Using this technique, Brook et al. (1986) measured the mesiodistal dimensions of the teeth for 50 male students. A comparison of this technique with the manual method has been made. In general, the image analysis produced more variability than did the manual method.

6) Laser scanning is another tool to analyse dental casts when projected and scanned with a slit-ray laser beam (Kuroda et al. 1996).

7) Soni digitisation (DigiGraph Workstation) is another technique used (Mok and Cooke 1998), which was not as reproducible as the digital callipers.

2.7.2. Counting Reliability of Measurements

There is no agreement in the literature, for the best method to thoroughly count reliability of the measurement errors. This fact may be due to differences between study purposes and techniques under investigation. Bolton (1958, 1962) and many others reported the following statistical formulae: (1) Standard error of the mean; a method to predict the degree of variation to be expected in the mean if measurements were repeated on other similar samples. (2) Standard deviation: measures the dispersion or degree of scatter about the mean. (3) Coefficient of variation: relates to the standard deviation of the mean by expressing the standard deviation as a percentage of the mean. A small coefficient of variation means standard deviation is statistically significant to the mean. (4) Coefficient of correlation: a method of correlating two measurements from the same sample.

2.7.2.1. Reproducibility

To test the system's reproducibility, a number of variables, selected at random, are measured and then re-measured (duplicate determinations), on separate occasions, to detemine the intra-investigator reproducibility (Lundstrom 1954, Peck and Peck 1972b, Potter et al. 1981, Houston 1983, Axelsson and Kirveskari 1983, Kieser 1985, 1986, Yuen et al. 1997). On the other hand, measurement accuracy has been tested as repeating the measurements five times (lavelle 1972) or ten times (Lavelle 1968) for part of the sample.

Or a number of double determinations by two or more examiners are made, then, an intra- as well as inter-investigator reproducibilities are counted and expressed as standard deviations of the differences (Lunstrom 1954, Moorrees et al. 1957, Moorrees and Red 1964). Richardson and Malhotra (1975) utilised measurements of teeth as taken by two observers, then the two sets of measurements were compared. The mean was taken when the difference between the values was 0.2 mm or less. The measurements were repeated if the difference was more than 0.2 mm. In another study, Lavell (1970) reported taking measurements five times by five different observers.

2.7.2.2. Reliability coefficient

It is a widely used method to determine error of the measurements. Teeth are measured and repeated, in which a Pearsonian product-moment correlation coefficient is computed between the two sets of measurements (Kieser e al. 1985, 1986). Bland and Altman (1986) on the other hand argue that this method is inappropriate because (1) the correlation coefficient tests the relation strength between two variables and not agreement so data with poor agreement may be shown to produce highly significant correlation. Houston (1983) reported this as one of the methods used to estimate the random errors.

2.7.2.3. Limits of agreement

Bland and Altman (1986) suggested this method to test the extent to which the two sets differ and plotting the difference between each pair of measurements against their mean. This plot permits investigation of the relationship between the true component and the error measurement. The intra- and inter-operator limits of agreement can be determined. The present investigation utilised this method to determine reliability of measurements (see section 5.4.1. for detail).

2.7.2.4. Method error statistic

This is as an attempt to quantify the inherent imprecision of a single observation of a variable as determined by duplicate measurements of that variable. It has a formula, which has been used by many orthodontists for cephalometric variables as well as anthropometrists (Dahlberg 1945, Lysell 1960).

2.7.2.5. Student's t- test

The relationship between the mean of a set of mesurements and a mean of a repeated set of measurements (as an idea of the bias of measurement process) may be evaluated by a test called Students's t-test. Houston (1983) noted that a sufficient number of cases must be replicated, otherwise only large number of systematic errors may be revealed. Kieser (1990) argues that this test is perhaps to measure systematic errors not random errors.

2.7.2.6. Analysis of variance

In a situation where replicates of measurements carried out by more than one operator, the reliability of measurement system may also be counted with the use of the analysis of variance (ANOVA). This method had been utilised to count the error of measurements taken on ten and five occasions for subjects selected at random (Lavelle 1968, 1971 respectively) or by measuring dentitions of five subjetcs as taken five times by two independent examiners (Lavelle 1975). Arya et al. (1974) has also used the analysis of variance to analyse the relationship between the mesiodistal dimension and sex and occlusion.

2.8. SUMMARY OF LITERATURE REVIEW

The literature concludes that hypodontia is a developmental phenomenon that is of great interest to many specialities including Genetics, Anthropology, Orthodontics and many other dental branches. Clinically, it is common anomaly affecting human teeth that necessitates an accurate diagnosis and appropriate management. Apart from the 3rd molars, the prevalence in the permanent dentition demonstrates a range between 2.3% (Werther and Rothenberg 1939) to 10.1% (Hunstadbraten 1973) with a higher frequency in females. In the deciduous dentition, 0.1 to 0.9% of the individuals are affected (Brook 1974a).

It has been shown that we cannot view hypodontia in isolation. This is true with regard to its aetiology and clinical aspects. The literature demonstrates the interrelation of tooth number, size and shape (Rantanen 1956, Davies 1968, Alvesalo and Portin 1969, Foster and Van Roey 1970, Lavelle et al. 1970, Woolfe 1971, Sofaer et al. 1971, Suarze and Spence 1974, Brook 1974b, 1984, Rune and Sarnas 1974, Baum and Cohen 1975, Magnusson 1977, Svinhufvud et al. 1988, Warnakulasuriya 1989, Lai and Seow 1989, Alvesalo 1997, Bacciti 1998, Ghaznawi et al. 1999, Arte et al. 1999). The possibility of an associated syndrome has to be considered in diagnosis, e.g. ectodermal dysplasia (Redpath and Winter 1969, Graber 1978, Hall 1983, Clark 1987, Schalk et al. 1994, Stephen et al. 1999), Rieger syndrome (Drum et al. 1985, Childers and Wright 1986, Murray et al. 1992, Skrinjaric et al. 1999) and cleft lip and/or palate (Poole 1975, Ranta et al. 1983, Ranta 1986, Noar 1990, Eerens et al. 1999, Shapira et al. 2000).

A number of theories were suggested to explain the aetiological mechanism of hypodontia although the precise cause is still under investigation. The role of heredity and environment has been frequently reported. A multifactorial basis has been considered describing the aetiology and mode of its inheritance and expressivity indicating that trait is the result of interaction between polygenic and environmental factors (Brook 1974b, Chosack et al. 1974, Bailit 1975). A multifactorial model proposed by Brook (1984) suggests that hypodontia is a discontinuous trait with a threshold effect and explains the distribution of anomalies of tooth number and size for both genders.

While the field concept (Butler 1939, Dahlberg 1945) suggests low stability in the distal tooth of each morphological class, variations have been demonstrated for the pattern of hypodontia and its effect on the morphology of the remaining teeth with regard to tooth types, location, genders and severity.

The nature of genetic factors has been of an interest for many researchers recently. Homeobox genes are believed to be good candidates as they have been shown to regulate development by controlling the expression of other genes. Recent animal work carried out by groups: Thesleff and associates (Vainio et al. 1993, Mitsiadis et al. 1995, Thesleff et al. 1995, Nieminen et al. 1995, Arte et al. 1996, 1997, Thesleff and Aberg 1997, Thesleff and Sharpe 1997), Sharpe and colleagues (MacKenzie et al. 1992, Tucker and Sharpe 1999), Berdal and co-workers (Berdal et al. 1987, 1995, 1996, Davideau et al. 1993), Satokata and Maas (1994) and others (Goldenberg 2000) all have demonstrated exciting observations at a celluar level and supported the multifactorial aetiology. Although, further work is still required to apply these findings to man.

Dental development and the causes of anomalies of tooth number are not fully explained so, to further understand them, additional research on dental morphology is required. Several techniques are available to analyse human teeth and all have advantages and drawbacks. Classical methods of manual measurements have limitations as only limited tooth dimensions are measured. The shape of teeth is also not possible to be accurately measured. As a result, little information is gained. Recent techniques allow for more comprehensive measurements to be obtained but showed variations in accuracy, ease of use, complexity, expense and time required for measurement performance.

Chapter 3

Aim And Objectives Of The Study

3.1. STATEMENT OF THE PROBLEM

There is a need to accurately measure the morphology of teeth of patients with hypodontia to increase understanding of the condition. Previous studies utilised limited measurement variables to demonstrate variation in tooth size, the mesiodistal dimension usually being studied. When tooth shape has been investigated, it has been in a subjective manner. Various dental dimensions to measure tooth morphology of patients with hypodontia have not been subjected to a comprehensive study taking into account certain factors i.e. severity of the anomaly, gender, age and ethnicity.

It is, therefore, appropriate to carry out an investigation designed to determine the relationship between hypodontia and variations in dental morphology. This has clinical relevance and may be basis for further aetiological studies in man of hypodontia.

Several techniques can be used to determine tooth dimensions. Manual measurement is the classical method, which has limitations as it can only be used to determine linear measurements. Advanced technology is important to provide increased information.

The present study utilised a new image analysis technique to enhance investigation of the morphology of teeth. The validity of this new technique is investigated. This study focuses on tooth crowns only with the measurements being obtained from dental casts of the study population.

3.2. AIM AND OBJECTIVES

3.2.1. Aim

The overall aim was to investigate tooth morphology in hypodontia subjects and a control group, taking into account severity of hypodontia and gender factors, and utilising a new image analysis technique, recently developed, in the Department of Child Dental Health, School of Clinical Dentistry, University of Sheffield. The investigator was a member of the departmental team in the development of this new system.

3.2.2. Objectives

1) To validate the image analysis measurement system against the classical manual measurements.
2) To develop a new method to quantify the taper of incisor teeth.
3) To measure crown dimensions of teeth for hypodontia and control subjects from both buccal and occlusal aspects. The measurement variables are listed in Chapter 4 (sections 4.4.2.1., 4.4.2.2., 4.4.2.3. and tables 4 and 5).
4) To assess reliability of measurement variables.
5) To compare the data obtained from groups with different severity of hypodontia.
6) To test whether hypodontia is associated with alteration in crown morphology of the erupted teeth.
7) To demonstrate the relationship between the severity of hypodontia and variation in crown morphology of the erupted teeth.
8) To evaluate gender differences in the measurements.
9) To identify further data obtainable by image analysis system which may not be determined by classical manual measurements.
10) To investigate the association between hypodontia and variation in tooth morphology.
11) To investigate the symmetry of bilateral measurements for the mesiodistal dimension and tooth taper of the buccal view, intermaxillary tooth size ratios (section 4.4.2.4.) and the number of cusps for premolar and molar teeth.

3.3. HYPOTHESES

The investigation, therefore, tested the following null hypotheses:

1) There is no significant difference in crown dimensions between the erupted teeth of subjects with hypodontia and teeth of the control group. *(Related to objectives 3, 5 and 10)*

2) There is no association between hypodontia and microdontia of the erupted teeth. *(Related to objectives 6 and 10)*

3) There is no association between hypodontia and variation in the crown shape of the erupted teeth. *(Related to objectives 6 and 10)*

4) There is no association between hypodontia and the tapering of incisor tooth crowns. *(Related to objectives 2, 3, 7, 8 and 10)*

5) There is no relationship between severity of hypodontia and crown morphology of the erupted teeth. *(Related to objectives 7, 8 and 10)*

6) There is no gender difference in crown dimensions between and within severity groups. *(Related to objective 8)*

7) The new image analysis technique does not offer any advantages in accuracy, reproducibility and ease of measurement and range of data obtainable, when compared with the manual method. *(Related to objectives 1-4 and 9)*

8) There is no evidence of difference in crown morphology between the right and left sides, in the number of cusps and in the intermaxillary tooth size ratios among different severity groups. *(Related to objectives 11 and 10)*

Chapter 4

Materials And Methodology

4.1. STUDY DESIGN

This investigation is descriptive and comparative in nature, measuring crown morphology of the permanent dentition of hypodontia and control subjects. For each tooth type, the measured values of hypodontia subjects were compared with those of subjects who have a full complement of the permanent teeth. Therefore, the study investigates differences and variations in crown morphology and whether there is any sexual dimorphism. The study also investigates symmetry in bilateral measurements for the mesiodistal dimension and tooth taper, difference in the mesiodistal intermaxillary ratios and the number of cusps present in the premolar and molar teeth.

This study forms part of a large departmental project investigating normal and abnormal dental development. The measurements were obtained using a new image analysis technique with specific developments for this study. Prior to embarking on the main study, the study period was planned to include pilot stages, starting with training and calibration processes. A measurement protocol was prepared for training, which was then revised accordingly for calibration of multiple departmental operators. A number of pilot studies were undertaken to achieve the following targets:

1) To validate the new image analysis technique against the classical manual measurement technique.

2) To evaluate the reproducibility of measurement systems i.e. the manual and image analysis techniques.

3) To test the feasibility of measurement methods on different tooth types.

4) To validate the measurement methods

5) To gather hypodontia subjects during the research period, to include at least 15 to 20 subjects per subgroup.

4.2. STUDY POPULATION

The study population comprised subjects with hypodontia and with a normal complement of permanent teeth, from both genders and born in the period between June 1963 and December 1989. All subjects were patients attending the clinics of the Charles Clifford Dental Hospital and School of Clinical Dentistry, Sheffield (Orthodontic, Paediatric, Restorative and Oral Surgery clinics), for treatment or consultation during the period from March 1985 to July 1999. The patients were residents of Sheffield, Doncaster, Rotherham and Barnsley districts, South Yorkshire, England. Their ages were taken from the dates shown in their pretreatment dental casts. Ethical approval to study hypodontia and control patients was gained from the South Sheffield Research Ethics Committe.

4.2.1. Criteria of Subject Inclusion

The subjects of both hypodontia and control groups were collected according to the following criteria:

1) All cases were from one demographic area (South Yorkshire, England) of one ethnic background (white Caucasians). However, no information was obtained regarding to their birthplaces.
2) The subjects were gathered from both genders.
3) The subjects were of similar age ranges (based on the dates of study casts).
4) None had any history of orthodontic treatment prior to their dental cast preparation.
5) No selection of particular dental occlusion or skeletal pattern was made.
6) Patients with syndromes (e.g. ectodermal dysplasia, clefts) were not included.

4.2.2. Subject Records

The hospital records of all subjects were initially examined by the investigator to consider the inclusion or exclusion of each case. The following were the minimum set of records accepted:

1) The file of each subject was reviewed for medical, dental and family histories.

2) One orthopantomogram (OPG), to confirm presence and absence of teeth and to eliminate possibility of extractions.

3) Original study casts of the maxillary and mandibular dental arches.

4.2.3. Sampling Methodology

The tooth was recorded as congenitally absent when the tooth or its germ could not be detected on the OPG and the dental record of the patient confirmed that the tooth had not been extracted. For the control subjects, evidence of the development of all 3rd permanent molars, clinically and/or radiographically, was required.

On accepting the candidate for inclusion, the name, gender, address, date of the birth, date of the impression of study models, and tooth presence and absence of each subject was obtained. All cases were checked for possible family relationships and no first-degree relatives were included based on the names and the addresses shown in the patients' record. Each subject was then given a code number to allow the measurements to be undertaken 'blind'.

Hypodontia varies in severity and the subjects were divided into four groups determined by the number of congenitally absent teeth (control, mild, moderate and severe hypodontia groups). The groups were balanced for gender, age and group size. They were also divided by gender so that eight subgroups were investigated.

Advice from a consultant statistician was taken to determine the sample size so that twenty subjects (N = 20), whenever possible were in each subgroup in order to allow statistical comparisons to be made. The female severe hypodontia subgroup size contained 21 subjects. The total sample size of the study population therefore was one hundred and sixty one subjects (N = 8 x 20 = 160, plus 1 = 161).

4.2.4. Study Groups

The study subjects were divided into the four main groups, as discussed above, balanced for gender, size and age according to the following definitions and criteria:

1) Control Group (Group 0): Cases who have full complement of the permanent dentition. The total size of this group was fourty subjects divided into two

subgroups (20 males and 20 females).

Each of the control subjects had evidence of the development of all 3rd permanent molars, clinically and/or radiographically.

2) Mild hypodontia (Group 1): Cases with hypodontia of one or two teeth, excluding the 3rd molars from both genders (20 males and 20 females).

3) Moderate hypodontia (Group 2): Cases with hypodontia of three to five teeth, excluding the 3rd molars (20 males and 20 females).

4) Severe hypodontia (Group 3): Cases with hypodontia of six or more teeth, excluding the 3rd molars (20 males and 21 females).

4.2.5. Study Casts

Only pretreatment models of good quality were used. The models of patients were made from two types of dental stone (Hercucite stone or Kaffir D, British Gypsum) and poured from one type of alginate impression material. The impression and casting procedures of the original casts were performed by multiple operators.

Yellow dental stone (Kaffir D, British Gypsum) duplicates of all original casts (upper and lower casts for each control and hypodontia subject) were then made for this project to standardise the material colour for image analysis purposes. These were prepared in one centre (Charles Clifford Dental Hospital Laboratory, Sheffield) and made from one type of casting material. After taking the impressions from the original models, dental casts were made from Erkoflex (EVA, Erkodent, Germany) impressions and poured in yellow stone. The laboratory work was performed by one operator (the investigator) who followed manufacturer's guidelines and was trained by a senior laboratory technician.

The possible effect of this duplication procedure on dental dimensions was measured. Fifteen original study casts and their duplicates were investigated in which both mesiodistal and buccolingual measurements were obtained from the occlusal aspect. Two tooth types (the maxillary central incisors and the mandibular first molars i.e. U1 and L6 respectively) representing variation in tooth morphology, were manually measured by the investigator, using digital callipers (Figure 11) and utilising the same measurement protocol reported in Chapter 5. The digital callipers were shown to be comparable in measurement reliability to the image analysis technique (detail in Chapter 5).

No significant difference in the measurements was found between the original and duplicated casts using a paired samples T-test (SPSS statistical package: V, 8.0, Statistical Solutions, USA). Table 3 shows the mean, standard deviation and the limits of agreement between pair measurements of the original and duplicated casts. A small overall difference, of no clinical significance, was revealed. The biggest differences found were related to buccolingual measurements of the molar tooth (standard deviation of differences of 0.25 mm and 0.50 mm limits of agreement) and the smallest difference were for mesiodistal measurements of the incisor tooth (0.11 mm standard deviation and 0.22 mm limits of agreement). The differences in pair measurements suggested that the teeth of the duplicated casts were not consistently larger or smaller than the originals. Thus it was concluded that these small differences were related to measurement errors rather than the duplication technique.

Table 3: Summary for duplication errors of study models.

Statistical Summary	Mesiodistal Dimension		Buccolingual Dimension	
	U1 (n = 15)	L6 (n = 14)	U1 (n = 15)	L6 (n = 14)
Mean of differences	-0.03	0.08	0.01	-0.02
Standard Deviation	0.11	0.18	0.20	0.25
Limits of agreement	0.22	0.36	0.40	0.50

For each variable, the limits of agreement are +/- the figure shown and the unit is mm.

For the purpose of this study, all permanent teeth with defined crowns were investigated. Since some teeth were not suitable to be examined, no measurement data was obtained of the following:

1) Deciduous teeth.

2) Third molars.

3) Partially erupted teeth.

4) Teeth with carious lesions, signs of trauma, restorations, severe tooth wear and gingival recession, crowding or damaged dental casts.

4.3. STUDY SYSTEM

The study utilised a new image analysis technique recently developed in the Department of Child Dental Health, School of Clinical Dentistry, University of Sheffield, to obtain measurements of tooth dimensions for the whole sample. Validation of the new technique against the manual measurements will be discussed in Chapter 5.

4.3.1. The New Image Analysis System

The overall design of this system is shown in figure 9. The system utilises a frame-mounted digital camera. Using separate acquisition and analysis software the system captures and analyses images of different sources e.g. study models, clinical photographs, radiographs, extracted teeth. It is safe to use on patients and provides many facilities: It allows modification of the contrast of the images, comprehensive analysis of the image and data storage. Standardised images can, therefore, be stored and retrieved allowing reproducibility. The following are the main system components used in the present study (Figure 10):

1) Camera: A 32-bit digital camera, Kodak/Nikon DCS 410 for capturing images of teeth from the study casts, and connected to a computer.

2) Camera mount, to support the camera and prevent movement while taking images.

3) Camera track (adjustable rod), to allow positional adjustments of the camera in vertical and horizontal directions.

4) Two white strip lights, to illuminating the cast for imaging and permitting light adjustment for image quality.

5) Steel ruler (short length reading in millimetres), to calibrate each image prior to measurement.

6) Platform with spring and two positioning screws adjustable in three planes, to mount the study casts.

7) Personal computer (PC: Pentium II-266 MMX, Viglen Ltd, UK).

8) Software: Adobe Photoshop (V 4.0, Adobe Systems Ltd, Europe) to acquire the images and Image Pro Plus (IPP: V 3.01, Media Cybernetics, USA) to analyse them.

4.3.2. Digital Callipers

The classical manual method was used to validate the new technique. Digital callipers (Mitutoyo Manufacturing Co. Ltd., Japan) were used to obtain tooth measurements (Figure 11). The tips of callipers were modified by fitting sharpened flat metal beaks. The measurements using this method are discussed in Chapter 5.

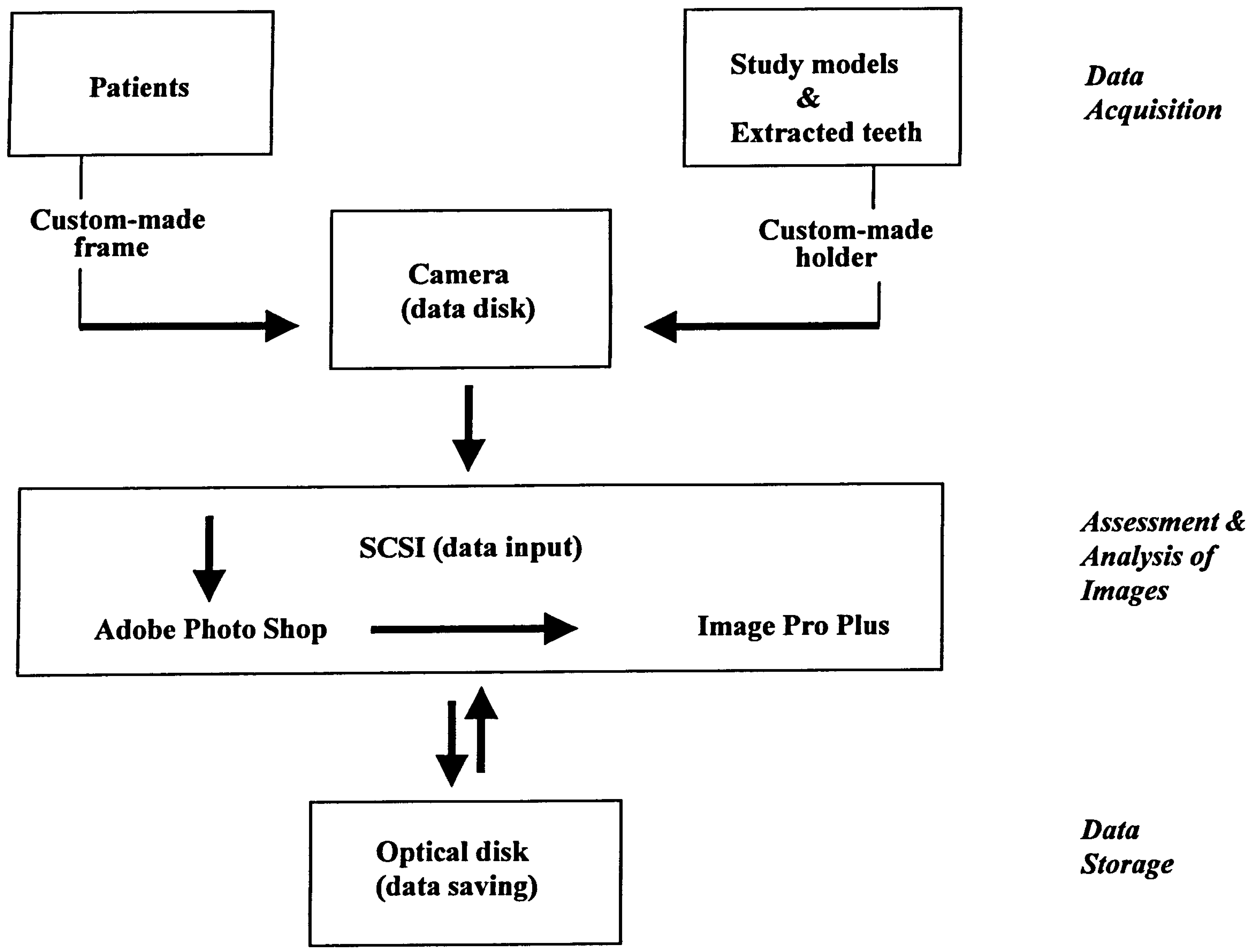


Figure 9: Schematic presentation for the overall design of the image analysis system.

Figure 10: The new image analysis system used in the study.

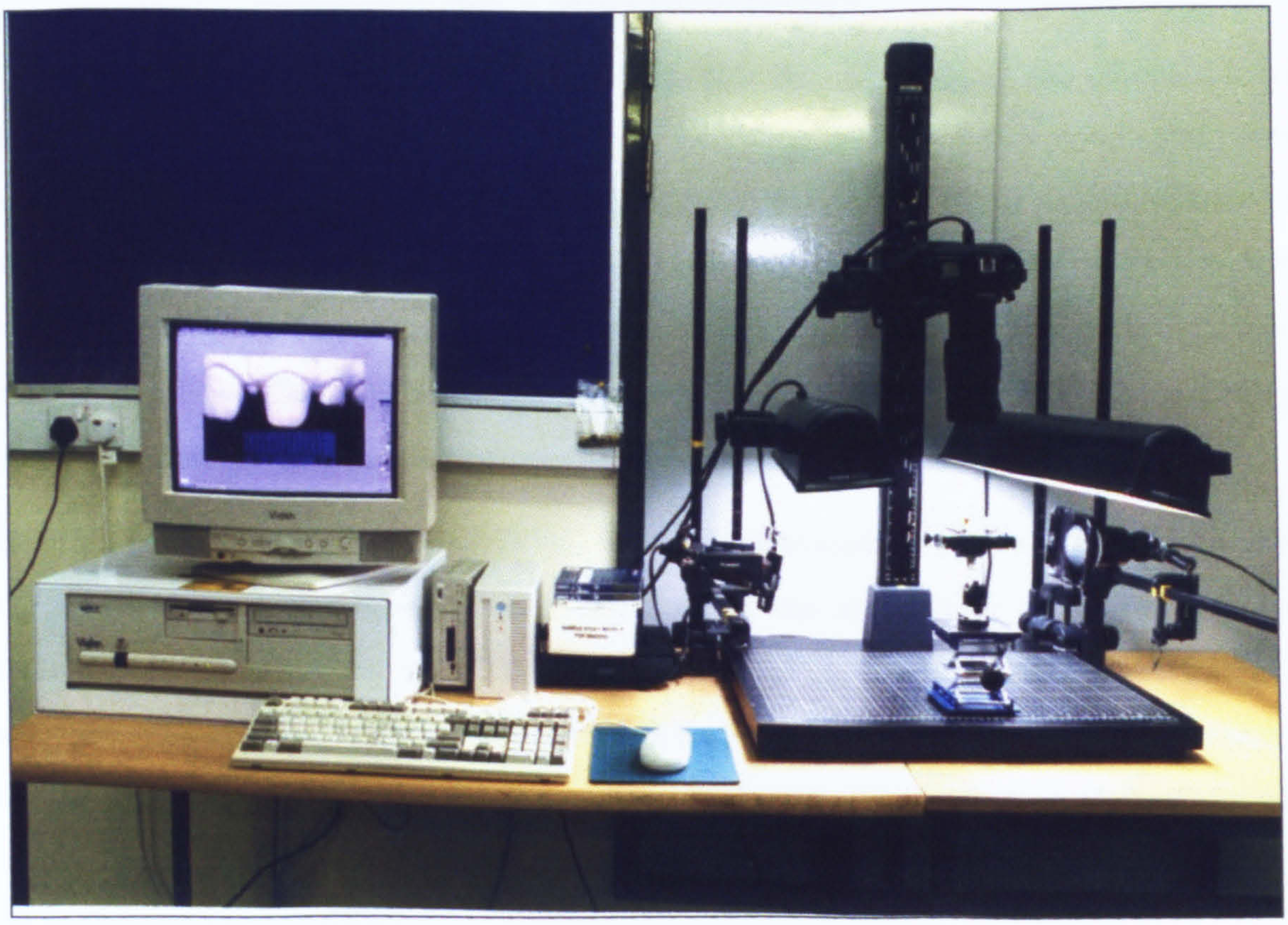
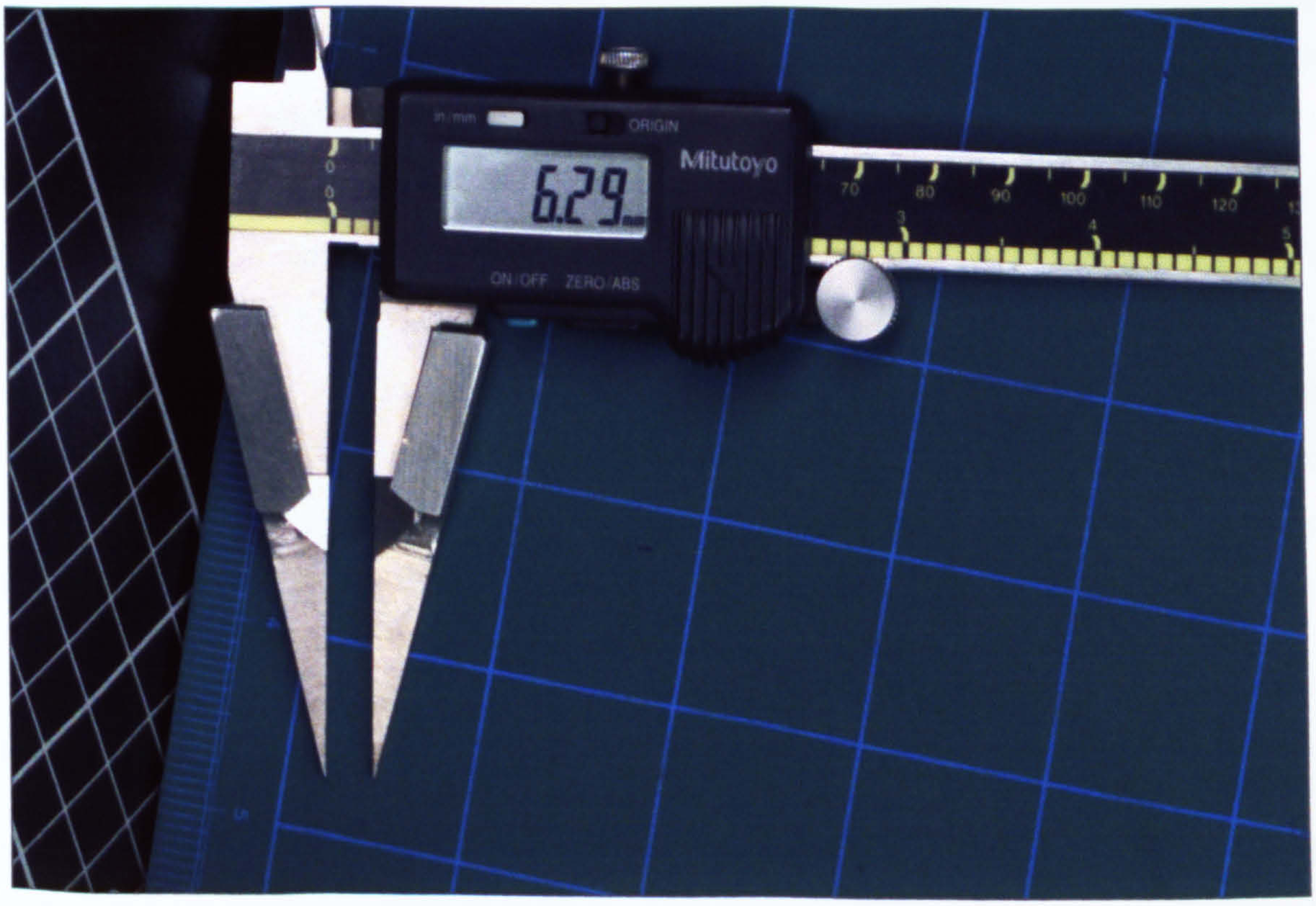


Figure 11: The digital callipers used in the validation studies.



4.4. METHODOLOGY

Part of the overall aim of the study was to use this new technology, and compare it with the traditional manual method for measuring tooth dimensions of hypodontia and control subjects. Data was obtained after investigating clinical crowns of all tooth types (central and lateral incisors, canines, first and second premolars and first and second molar teeth) for both maxillary and mandibular arches. Certain anatomical landmarks were given special attention. These included the mesial and distal contact areas and gingival margin for each tooth surface under investigation.

Each set of study casts of an individual subject was systematically investigated, in which the maxillary cast was observed first followed by the mandibular cast. The teeth were measured starting from the maxillary right most distal tooth toward the maxillary left side and then from the most distal mandibular left tooth finishing with the most distal tooth on mandibular right side. These steps were followed for both buccal and occlusal measurements in which each tooth was measured from its buccal view first, followed by its occlusal view.

This new system utilises a frame-mounted 32-bit digital camera (as detailed in 4.3.1.), captures and analyses images from individual teeth on study models. The specimen was placed on a calibrated variable stage under standard illumination. The stage can be rotated in three planes, allowing imaging from different orientations. The system therefore permits buccal and occlusal images of the teeth and these can be captured individually for greater accuracy. Each image takes approximately 5 minutes to produce. The camera chip has a resolution of 1.5 mega pixels and the images were displayed in an array of 1012 x 1524 pixels for analysis (on a 17 inch, 32-bit true colour monitor). The camera has a minimum frame interval of 0.25 seconds. Crown dimensions of each set of study model were systematically investigated by the investigator and through two stages; imaging and analysis.

4.4.1. Imaging Stage

The study model was placed on a platform (Figure 10). This was adjustable in three planes and the study model was held securely in place by a spring and two positioning screws. Each individual tooth was imaged separately, from both the buccal and occlusal aspects, using a 32 bit digital camera (Kodak/Nikon DCS 410). The camera was mounted horizontally above the study model on an adjustable rod. The steel ruler was placed adjacent to the particular crown surface being imaged and the study model was illuminated by multi-directional spot lights surrounding the model. The camera was connected to a PC (Pentium II-266 MMX, Viglen Ltd, UK) and Adobe Photoshop (V 4.0, Adobe Systems Ltd, Europe) was used to acquire the images from the camera (Figure 10).

The buccal images of tooth crowns were captured first followed by the occlusal images. For each image the focusing line of the lens (90 mm Elicar macro) of the camera was perpendicular to the centre of the tooth surface. It was also perpendicular, or parallel, to the long axis of clinical crown for buccal or occlusal image respectively. The steel rule was positioned as close as possible and at the same level of tooth surface. Following acquisition, each image was given an appropriate file name and saved as a Tif file.

4.4.2. Analysis Stage

The images were imported into Image Pro Plus analysis sofware (V3.01, Media Cybernetics, USA) to make the measurements. Each image was firstly calibrated using the steel rule and the following measurements were then obtained in millimetre units:

4.4.2.1. Buccal view measurements

The measurement variables of the buccal view consisted of (Table 4 and figures 12-14):

1) The perimeter measurement (Pb): This was the trace of maximum crown surface periphery. Accordingly, the other measurements were then determined.

2) The mesiodistal dimension (MDb): This was taken as the maximum distance between the proximal surfaces of tooth crown from the contact areas, lying on the trace determined above. In situations where the tooth was not in the optimal position or adjacent teeth were missing, the measurements were taken from the anatomical positions where the contact should normally occur. In the tapered teeth (usually associated with hypodontia), the contact areas might move apically which were subjectively identified to give the maximum reading.

3) The occlusogingival dimension (OG): This was the greatest distance between the

occlusal and gingival levels of the crown, perpendicular to and bisecting the MDb dimension. This was automatically determined using a custom written macro for the analysis software.

4) The area (Ab): This was the surface area bounded by the perimeter trace and was automatically determined from the trace made.

5) The distance (Db) between the MDb and occlusal surface across OG was also measured.

6) Incisor tooth measurements. These were three measurements parallel to MDb, and crossing OG at right angles at 25, 50 and 75 percentiles (MD25, MD50 and MD75 respectively).

4.4.2.2. Occlusal view measurements

As for the buccal view, a number of occlusal measurement variables were also defined (Table 5 and figures 15-17):

1) The perimeter (Po), using the same technique and definition as for buccal view.

2) The mesiodistal dimension (MDo) was determined from the occlusal aspect following the same criteria as for the buccal view.

3) The buccolingual dimension (BL): This was the greatest distance between the buccal and lingual (palatal) surfaces of the crown, perpendicular to and bisecting the MDo dimension. This was automatically determined using a custom written macro for the analysis software.

4) The area (Ao), using the same technique and definition for area in buccal view.

5) The distance (Do) between the MDo and buccal surface across BL.

6) Molar tooth measurements. These were two tooth measurements parallel to BL and perpendicular to the MDo, mesially at 25 % (BLm) and distally at 75 % (BLd) along MDo.

4.4.2.3. Ratios of tooth morphology

Furthermore, the crown morphology was also investigated by means of ratios calculated from the above measurements. Five ratios were determined and called indices (Tables 4 and 5):

1) Taper index for the maxillary and mandibular incisor teeth, was buccally determined according to the followig: MD50/MD75 (detail in Chapter 6).

2) Crown index of buccal morphology-1 (CIBM1) for each tooth was determined as MDb/OG.

3) Crown index of occlusal morphology-1 (CIOM1) for each tooth was determined as MDo/BL, similarly to previous studies (Lavelle 1970, Peck and Peck 1972a).

4) Crown index of buccal morphology-2 (CIBM2) for each tooth was determined by Db/OG.

5) Crown index of occlusal morphology-2 (CIOM2) for each tooth was determined by Do/BL.

4.4.2.4. Ratios of interarch relationship

Investigating the relationship between the mandibular and maxillary teeth of all subjects further tested the mesiodistal dimension of hypodontia subjects. Four intermaxillary ratios were calculated, three according to previous reports (Lundstrom 1944, Bolton 1958) and the fourth is proposed in the present study (Tables 4 and 5):

1) Anterior ratio (AR): The sum of MD dimension values of the mandibular incisors and canines divided by the sum of MD dimension values of the maxillary incisors and canines and multiplied by 100.

2) Posterior ratio (PR): The sum of MD dimension values of the mandibular premolars and 1st molars divided by the sum of MD dimension values of the maxillary premolars and 1st molars and multiplied by 100.

3) Overall ratio (OR): The sum of MD dimension values of all the mandibular incisors, canines, premolars and 1st molars divided by the sum of MD dimension values of the maxillary opponent teeth and multiplied by 100.

4) Grand overall ratio (GR): The sum of MD dimension values of all the mandibular teeth divided by the sum of MD dimension values of all the maxillary teeth and

multiplied by 100.

4.4.2.5. Further information

In addition to the above, other information was obtained from the patient records (including hospital notes, dental models and radiographs) to determine:

1) The frequency of the congenitally absent teeth.

2) The locations of the congenitally absent teeth.

3) The cusp number of premolar and molar teeth i.e. the buccal cusps (BC), lingual cusps (LC) and total cusp number (TC).

Table 4: The study variables of the buccal view for maxillary and mandibular teeth.

Variable	Definitions
	1. Measured Variables
MDb	The maximum distance between the proximal surfaces of tooth crown from the contact areas.
OG	The distance between the occlusal and cervical levels of the crown as being perpendicular to and crossing the MDb at its midpoint.
Pb	The trace of maximum crown surface periphery.
Ab	The surface area bounded by the Pb trace and was automatically determined from the trace made.
Db	The distance between the MDb and occlusal line across the OG.
MD25 *	A tooth width parallel to the MDb and crossing the OG at right angle and at 25% of its length.
MD50 *	Another tooth width parallel to MDb and crossing OG at right angle and at 50% of its length.
MD75 *	Another tooth width parallel to MDb and crossing OG at right angle and at 75% of its length.
	2. Statistically Calculated Variables
Taper *	A crown index to quantify the amount of tooth taper, statistically determined as: MD50/MD75.
CIBM1	A crown index of buccal morphology, statistically determined as follows: CIBM1 = MDb/OG
CIBM2	A crown index of buccal morphology, statistically determined as follows: CIBM2 = Db/OG
AR	The anterior ratio: The sum of MDb values of the mandibular incisors and canines divided by the sum of MDb values of maxillary opponent teeth and multiplied by 100.
PR	The posterior ratio: The sum of MDb values of the mandibular premolars and 1st molars divided by the sum of MDb values of the maxillary opponent teeth and multiplied by 100.
OR	The overall ratio: The sum of MDb values of all mandibular incisors, canines, premolars and 1st molars divided by the sum of MDb values of maxillary opponent teeth and multiplied by 100.
GR	The grand ratio: The sum of MDb values of all mandibular teeth divided by the sum of MDb values of all the maxillary teeth and multiplied by 100.

* *MD25, MD50, MD75 and Taper are variables related to the incisor teeth only.*

Imaging and Measurement Procedures From the Buccal View

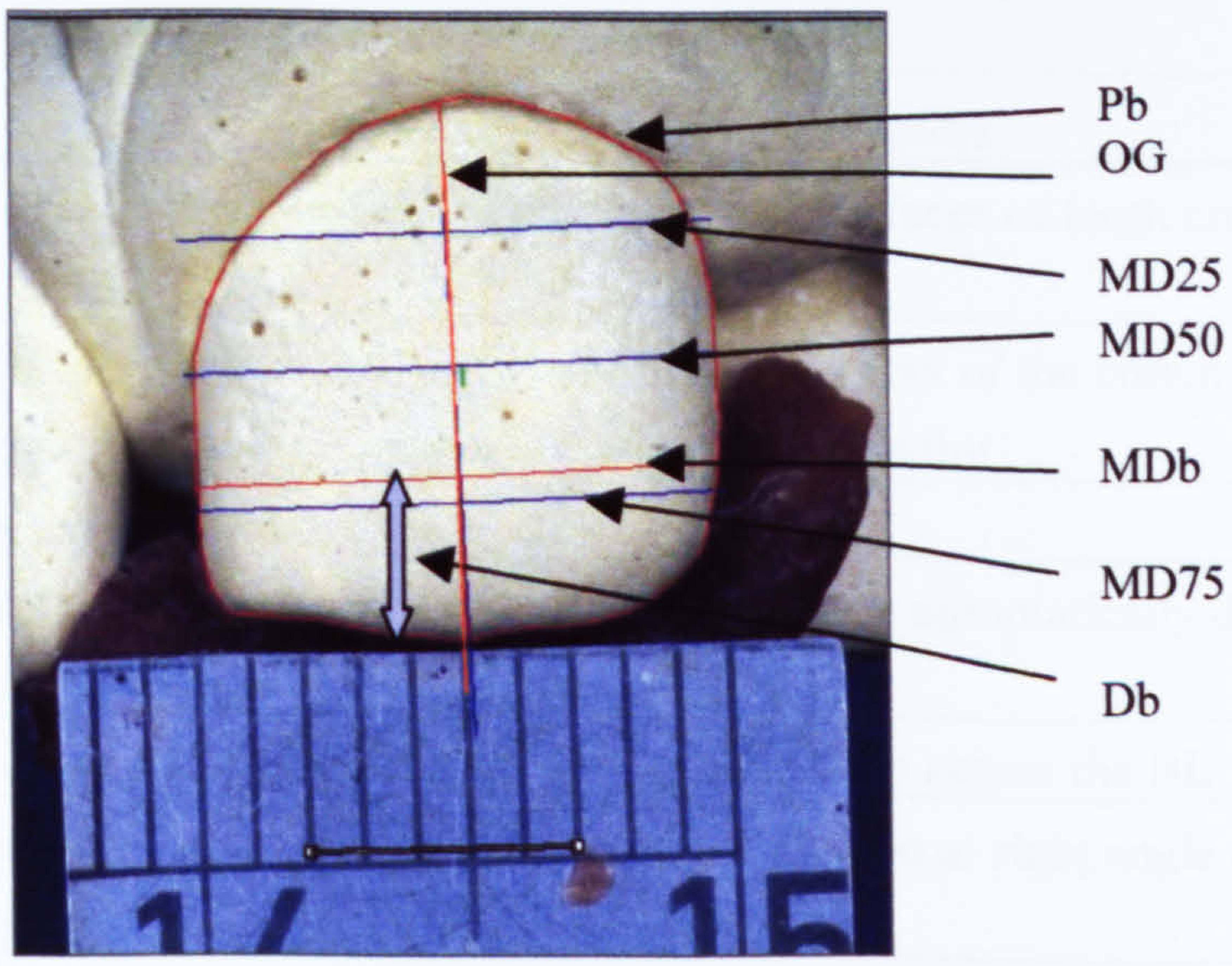


Figure 12: Buccal imaging and measurement for incisor tooth.

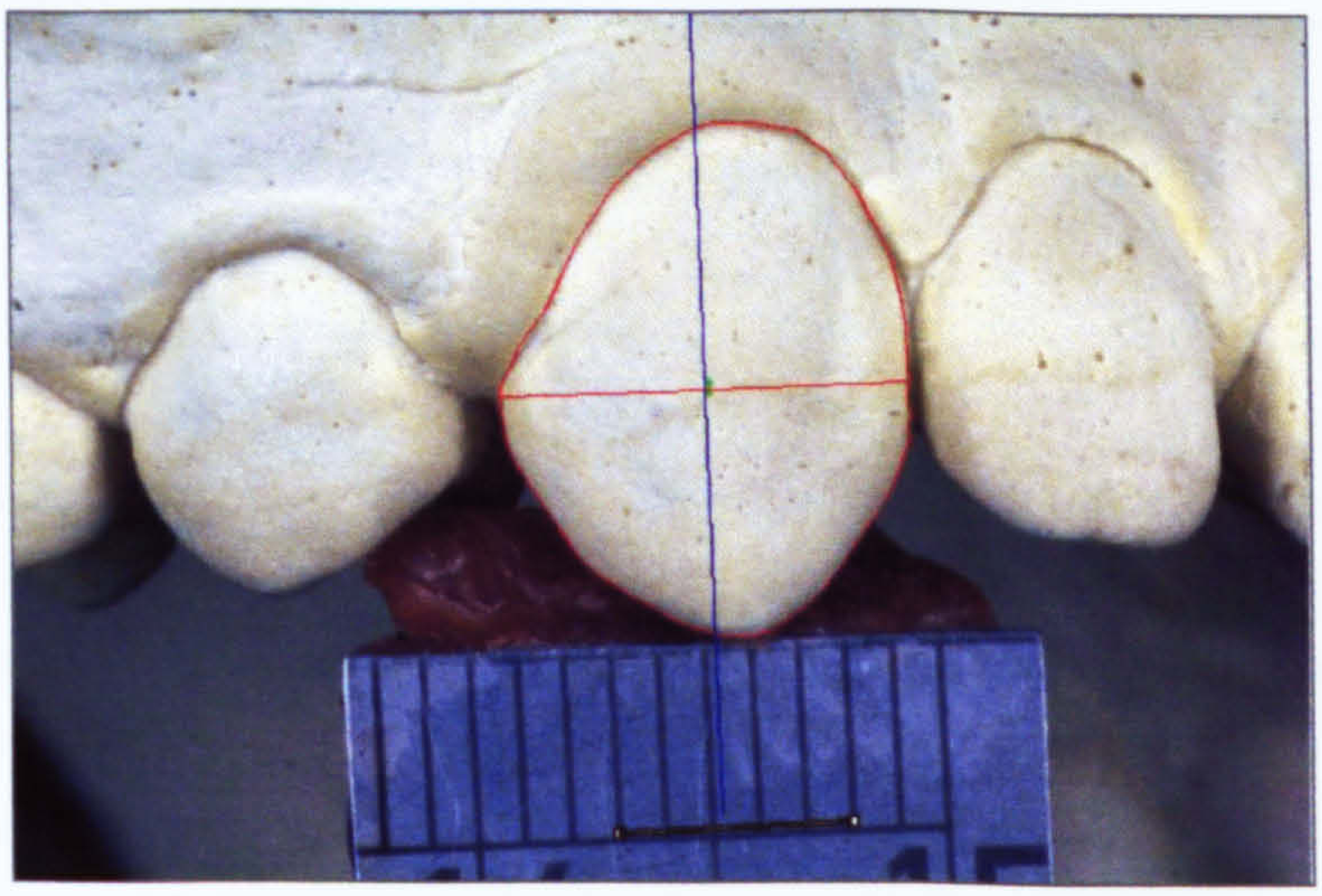


Figure 13: Buccal imaging and measurement for canine tooth.

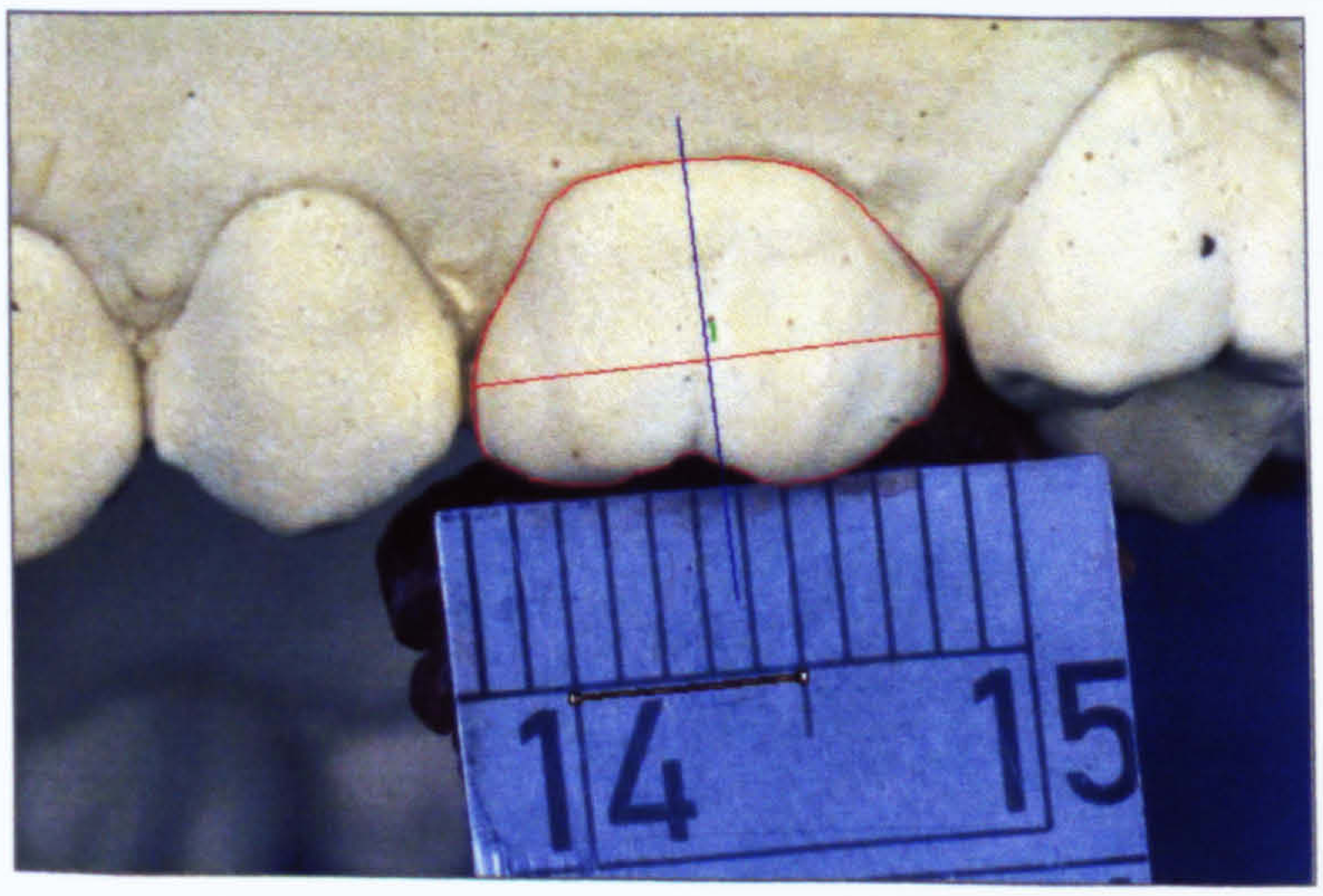


Figure 14: Buccal imaging and measurement for molar tooth.

Table 5: The study variables of the occlusal view for maxillary and mandibular teeth.

Variable	Definitions
	1. Measured Variables
MDo	The maximum distance between the proximal surfaces of tooth crown from the contact areas.
BL	The distance between the buccal and palatal borders of the crown as being Perpendicular to and crossing the MDo at its midpoint.
Po	The trace of maximum crown surface periphery.
Ao	The surface area bounded by the Po trace and was automatically determined from the trace made.
Do	The distance between the MDo and buccal surface across the BL.
BLm *	A tooth thickness parallel to BL and crossing MDo at right angle and at 25% (mesial) of its length.
BLd *	A tooth thickness parallel to BL and crossing MDo at right angle and at 75% (distal) of its length.
	2. Statistically Calculated Variables
CIOM1	A crown index of occlusal morphology, statistically determined as follows: CIOM1 = MDo/BL.
CIOM2	A crown index of occlusal morphology, statistically determined as follows: CIOM2 = Do/BL.
AR	The anterior ratio: The sum of MDo values of the mandibular incisors and canines divided by the sum of MDo values of maxillary opponent teeth and multiplied by 100.
PR	The posterior ratio: The sum of MDo values of mandibular premolars and 1st molars divided by the sum of MDo values of maxillary opponent teeth and multiplied by 100.
OR	The overall ratio: The sum of MDo values of all the mandibular incisors, canines, premolars and 1st molars divided by the sum of MDo values of maxillary opponent teeth and multiplied by 100.
GR	The grand ratio: The sum of MDo values of all the mandibular teeth divided by the sum of MDo values of all the maxillary teeth and multiplied by 100.
BC	The buccal cusp number (for premolars and molars).
LC	The lingual (palatal) cusp number (for premolars and molars).
TC	The total cusp number (for premolars and molars).

** BLm and BLd are variables related to the molar teeth only.*

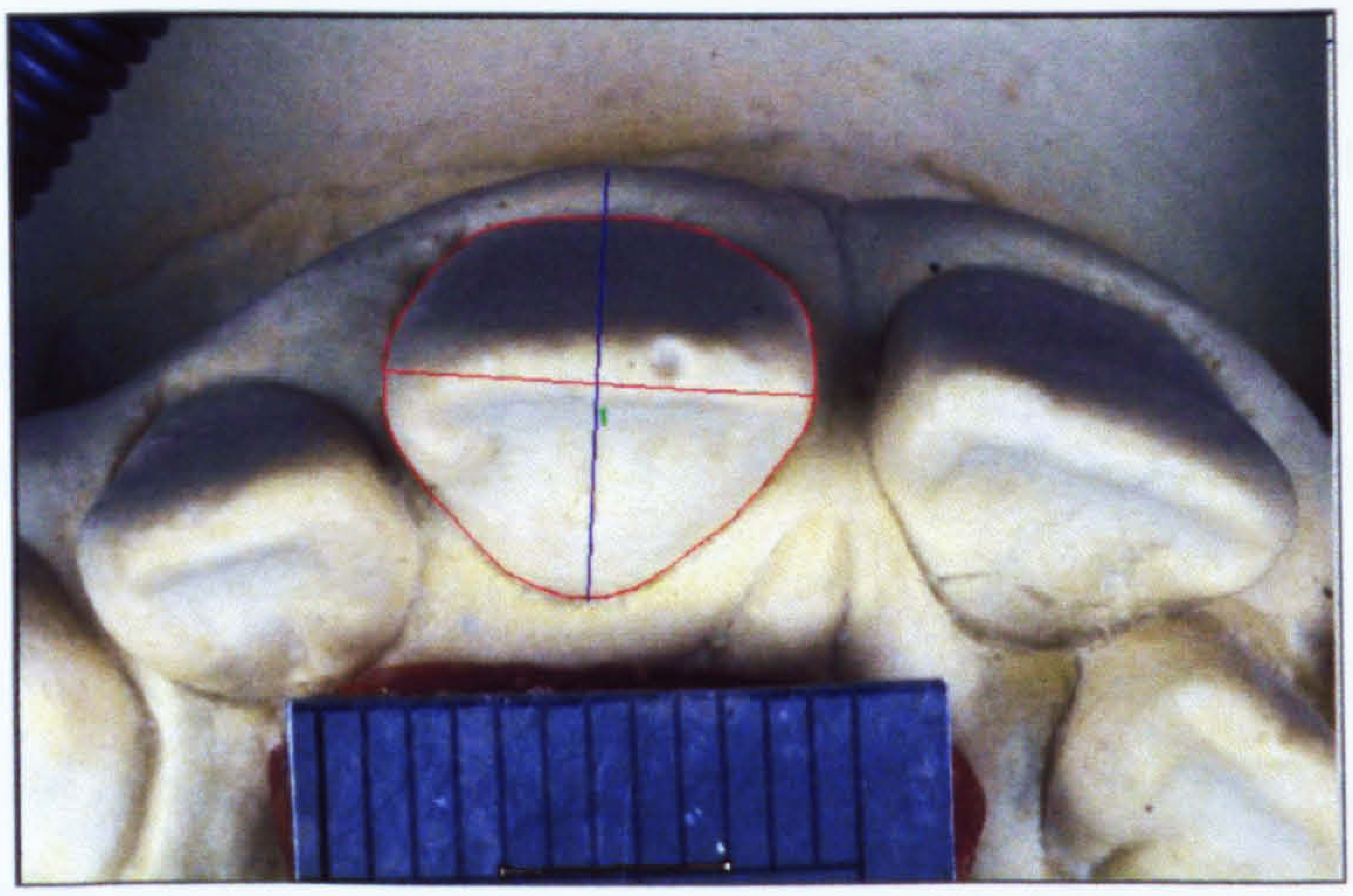


Figure 15: Occlusal imaging and measurement for incisor tooth.

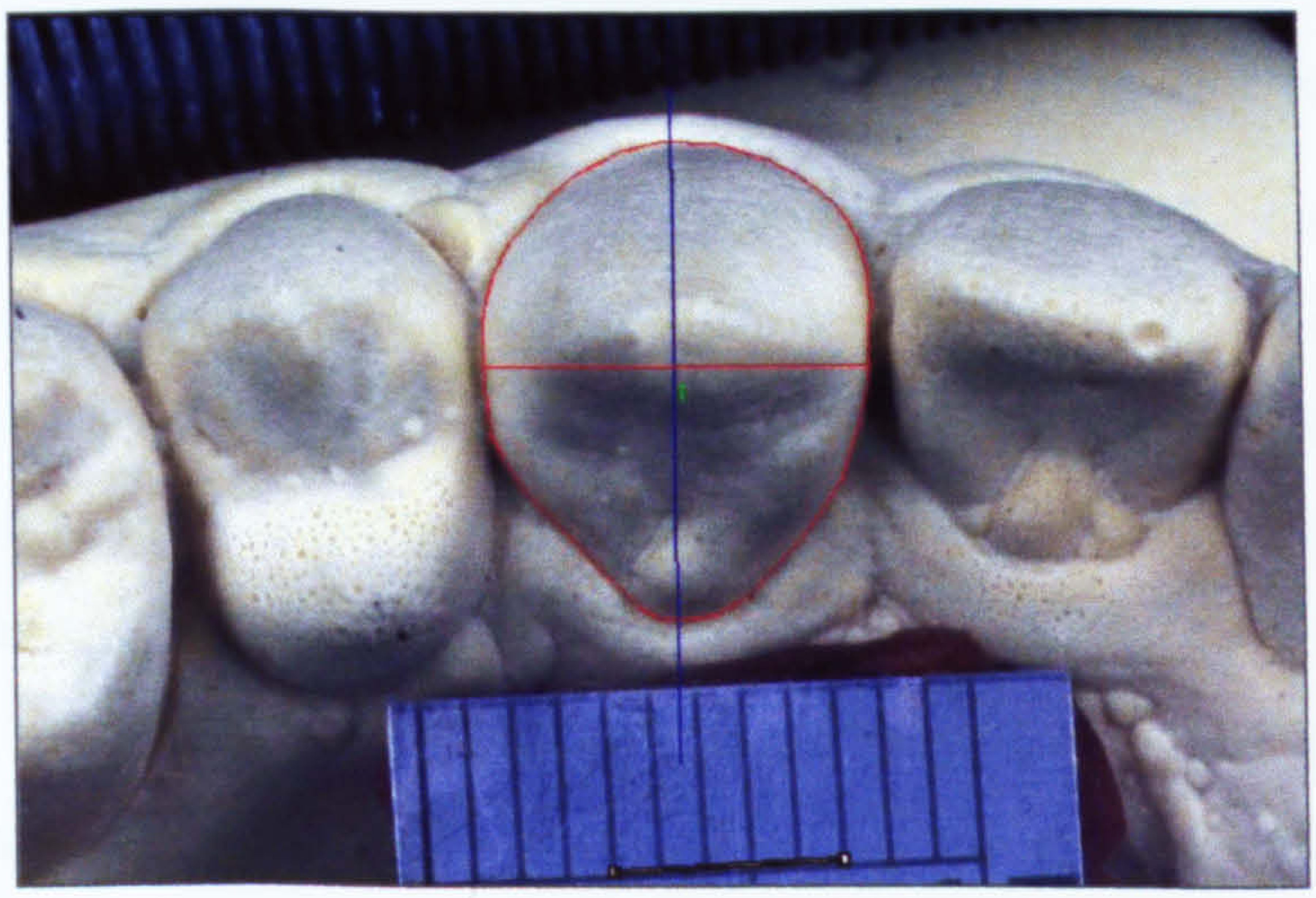


Figure 16: Occlusal imaging and measurement for canine tooth.

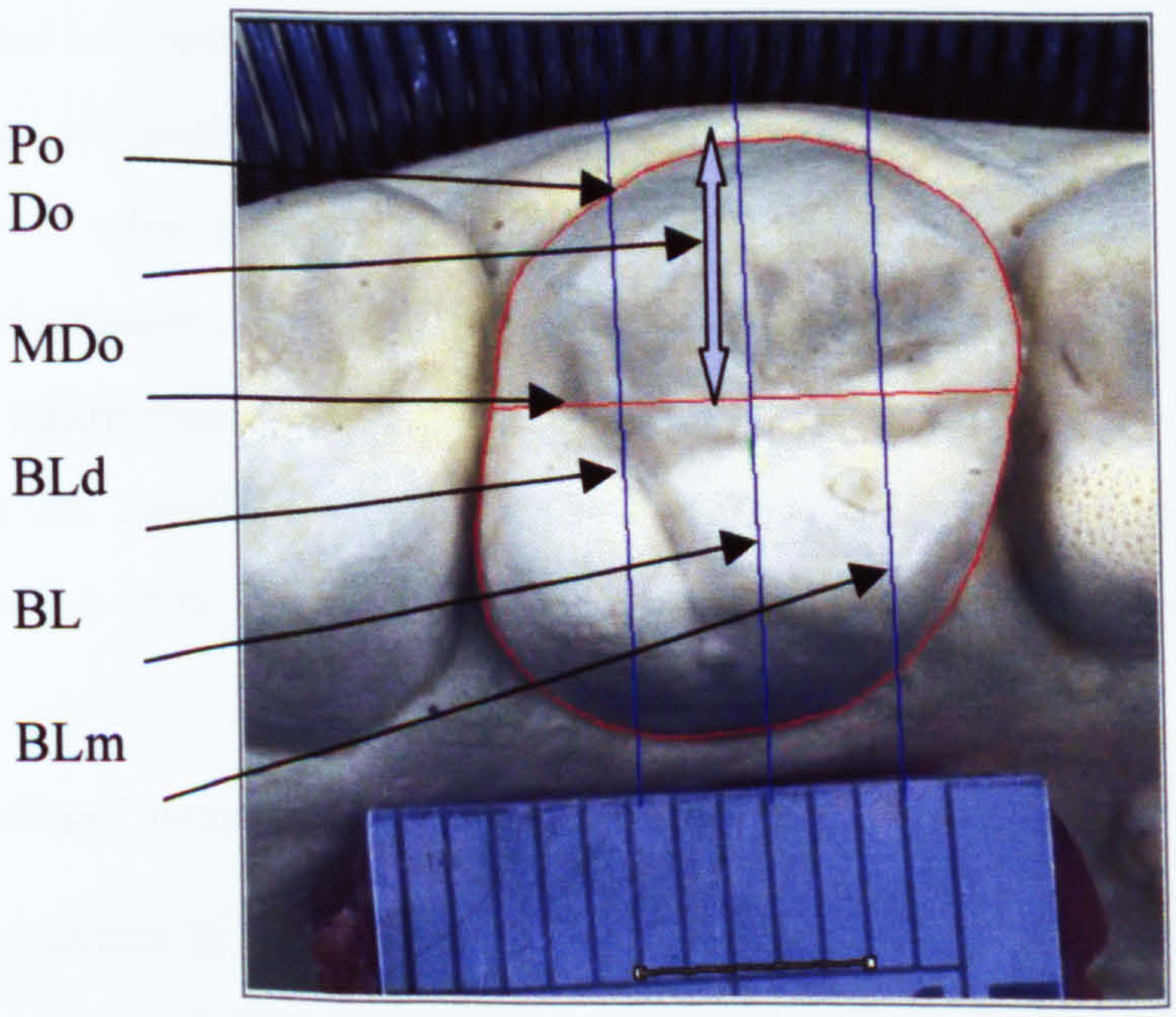


Figure 17: Occlusal imaging and measurement for molar tooth.

4.5. STATISTICAL ANALYSIS

The study investigates crown dimensions with regard to the effect of two factors i.e. severity of tooth absence and gender. The standard preliminary statistical approach would be to employ variable reduction technique such as principle components, prior to the main analysis, as many of these mesurements will undoutedly be correlated. However, since the aim of this project was intended to present clinically relevant and useable figures on each tooth, it was decided to analyse all measurements individually. This would mean that a larger than necessary Bonferroni adjustment to be used to allow multiple testing (since many variables are correlated) and so two sets of the significance levels are reported for each variable, (adjusted and unadjusted). This way the reader has access to the original p-value as well as those corrected to account for the number of variables analysed. However, conclusions will only be drawn on the final corrected values.

Initially, the data was checked using scatter plots for each measurement variable for all subgroups, using an SPSS statistical package (V, 8.0, Statistical Solutions, USA). Because the investigation involved multiple comparisons, the significance level of each test was reduced, using a Bonferroni correction, with greater adjustments for increasing number of tests. This concept is also important when deciding whether one should combine (i.e. average) the values of corresponding variables obtained from the opposite sides of the jaw, or whether bilateral measurements should be analysed separately. Before taking a decision, one needs to assess how similar the pairs of mesurements are.

Ideally, right and left measurements should be analysed separately but both may represent the same value of interest i.e. repeating the same test. If so, this is at the expense of significance level after making the required Bonferroni correction. Conversely, loosing part of the information, due to averaging bilateral measurements, is substituted by a reduction for adjustment of significance levels. As a result a decision was made to initially assess the variability between the right and left sides of the mouth. The useful approach to solve this particular problem is to calculate the intra-class correlation coefficient.

4.5.1. Intra-class Correlation Coefficient (ICC)

This relates the extent to which the left and right variables match, within an individual, to the variation in these dimensions between individuals. If the variation within a person is small compared to that between people then the two variables may be thought of as essentially measuring the same characteristic of the person. Little information about the individual will be lost by combining or using one of, the two measurements in question. The mean or just one, of the bilateral measurements will be adequate to describe this characteristic.

For each bilateral tooth, a one-way random effects model was used to compute estimates of the between person variation (in means) and within person variation (between sides of mouth). Then a relative measure was calculated; the percent of left and right variation which attributable to the individual was calculated according the following formula:

$$R = \frac{\text{Variation in measurements between individuals}}{\text{Total variation in measurements}} \quad (0 \leq R \leq 1)$$

And so therefore, 1-R = Percent of variation lost by ignoring differences between right and left measurements.

$$R = \frac{\text{Biological variation}}{\text{Biological variation + Symmetry variation}}$$

$$\text{i.e.} = \frac{\text{Variation in measurements between individuals}}{\text{Variation between individuals + Variation within individuals (between left and right)}}$$

Ideally, the ICC value has to be as close to 1 as possible to justify combining bilateral variables and then using the averages in the main analysis. Using their average should not negate any important variation between the two sides within an individual. On the other hand, the right and left variables should be considered separately when R is small. All the measurement variables were assessed and the results were demonstrated in Chapter 7.

4.5.2. Main Analysis

The next step was to utilise a two-way analysis of variance (ANOVA). Descriptive data as well as post-hoc tests information (mean, standard deviation, standard errors and significance levels) were obtained to describe the effect of the two factor variables (group and gender) on various dependent variables (e.g. buccal MDb). The interaction and main effects of the two factor variables, with their two-way plots, were then examined.

4.5.2.1. Definitions

The main effect of categorical or independent variable is the change in the dependent variable produced by a change in the level (category) of the independent variable regardless of any other variables. For example, one might expect that on average the MDb would be smaller as the extent of hypodontia increases, or that the MDb may on average, be larger in males than females.

The interaction effect (between the two independent variables) is the extent to which the value of the dependent variable due to one independent variable also depends on the particular level of the other independent variable. For example, females may have larger MDb than males in one of the hypodontia groups but not in the others and or control group, or the difference between male and female MDb values in the control group may be much bigger than in one of the hypodontia groups.

The two-way plots provided a visual comparison between two independent factors (groups and genders). Each point on the plot indicates the estimated marginal mean of the dependent variable at the different levels of the two independent variables. Parallel lines indicate that there is no interaction between factors, whereas non-parallel lines indicate an interaction.

4.5.2.2. Interpretation of the two-way ANOVA

When there was evidence of an interaction then the main effects were not interpreted. This is beacause difference between males and females, was not consistent across the hypodontia and control groups.

1) Evidence of interaction effect: When the analysis indicated a significant interaction effect between hypodontia groups and genders, a post-hoc and least significant difference tests option was used to compare subgroups, and plots obtained. Sixteen subgroup comparisons were of interest and so the significance levels were adjusted by a factor of 16 to obtain the Bonferroni corrected significance levels. Comparisons of interest were listed and abbreviated as follow:

1) Male control subgroup versus female control subgroup (M0 vs F0).
2) Male mild hypodontia subgroup versus female mild hypodontia (M1 vs F1).
3) Male moderate versus female moderate (M2 vs F2)
4) Male severe versus female severe (M3 vs F3).

5) Male control versus male mild (M0 vs M1).
6) Male control versus male moderate (M0 vs M2).
7) Male control versus male severe (M0 vs M3).
8) Male mild versus male moderate (M1 vs M2).
9) Male mild versus male severe (M1 vs M3).
10) Male moderate versus male severe (M2 vs M3).

11) Female control versus female mild (F0 vs F1).
12) Female control versus female moderate (F0 vs F2).
13) Female control versus female severe (F0 vs F3).
14) Female mild versus female moderate (F1 vs F2).
15) Female mild versus female severe (F1 vs F3).
16) Female moderate versus female severe (F2 vs F3).

2) No evidence of an interaction effect: When no interaction was present, the main effects were examined i.e. to evaluate the significance of gender regardless of the levels of the severity of hypodontia and vice versa, using Bonferroni corrected t-tests. If the p-value for the group is significant then it is of interest to see which pairs of categories of the group differ. The post-hoc (multiple comparison) tests were employed. Significance levels in the pairwise comparisons were automatically adujsted using a Bonferroni correction of factor 6 as the following six possible pairwise comparisons were:

1) Control group versus mild hypodontia group (0 vs 1).
2) Control versus moderate (0 vs 2).
3) Control versus severe (0 vs 3).
4) Mild versus moderate (1 vs 2).
5) Mild versus severe (1 vs 3).
6) Moderate versus severe (2 vs 3).

There were no post-hoc tests for gender since this factor variable has only 2 categories. The result for gender provided by the 2-way ANOVA would be be equivalent to the 2-sample t-test and propability values was taken without performing multiple comparisons.

4.5.2.3. Final adjustment of significance levels

A final overall adjustment to all p-values was made, accounting for the fact that many different variables on different tooth types from buccal and occlusal views had been measured (e.g. MDb on an incisor is a different variable to MDb on a canine, premolar or molar tooth). The number of dependent variables on all teeth were added to produce the overall number of variables analysed (i.e. N = 266). All significance levels from analyses were then adjusted by this factor i.e. by multiplying by 266. Both the original and corrected p-values were quoted in the results (to 3 decimal places) so it was possible to see what might have happened if a small number of variables had been analysed. Finally, corrected p-values ($P \leq 0.10$) were interpreted as the main findings. The secondary findings, on the other hand, are those with corrected p-values ($0.10 < P < 1.00$). If the adjusted p-value is >1.00, the figure of probability will be quoted as 1.00.

4.5.3. Assessment of Method Errors

The errors of any method are due to both systematic and random errors (Houston 1983, Kieser 1990). For data to be reliable, both systematic and random errors must be avoided or reduced to the minum level. To assess the estimation of these errors, reproducibility of measurement is necessary. The measurement system of this study is new. Prior to commencing the actual measurement of the sample, determination of the system errors and measurement reliability of the new technique were carried out through several phases; the training and calibration, and validation phases.

From study models, therefore, validity of tooth measurements obtained by a new technique was tested against those of an existing reliable method, i.e. manual measurements. While the reproducibility is assessed for intra- and inter-operator determinations. The next two chapters (Chapters 5 and 6), therefore, detail the assessment of method errors.

4.5.4. Other Analyses

Other statistical tests were utilised to achieve certain purposes:

1) Statistical tests to validate the new image analysis system and assess reliability of different measurement variables are discussed in Chapters 6 and 7.

2) Tooth taper analysis: A new method is proposed to quantify tooth taper in the incisor teeth. Details of statsical analyses used to validate the new method are shown in Chapter 6.

3) Symmetry analysis: Variation in the morphology of human teeth has been documented in the literature. One aspect of this issue is the mismatch or asymmetry

between right and left measurements that has been shown to affect both individuals with hypodontia and normal dentitions. The field concept indicates that the distal member of each tooth field is more frequently affected by morphological changes than the mesial one. The classical example is the maxillary lateral incisors particularly when associated with hypodontia, in which different morphological pictures in both sides have been demonstrated. The literature also suggests that the more severe the hypodontia the more the reduction in tooth size.

No studies have looked at the symmetry of tooth morphology in hypodontia patients, taking into consideration the severity of hypodontia and gender influences, and compare that with that of dentitions with full complement of teeth. The study population may present trends for the symmetry of tooth morphology. It is not a prime aim to investigate symmetry for all measurement variables. However, two measurement variables i.e. tooth taper and the mesiodistal dimension from the buccal aspect (MDb) are briefly investigated.

The findings demonstrated in the main analysis for the MDb were based on the mean values of right and left measurements that could be misleading to properly assess symmetry. The alternative method, therfore, is to investigate symmetry according to the true value of each measurement in both sides. The statistical test is to count the strength of the agreement between bilateral measurements. Investigation of symmetry of bilateral measurements was, therefore, carried out using the limits of agreement test (see section 5.4.1.).

4) On the other hand, only the mean values were determined to describe differences in the intermaxillary ratios and cusp number of different severity categories.

Chapter 5

Reliability Of The Measurements

5.1. INTRODUCTION

In research studies, the accuracy of the technique should be tested and the errors of method should be reduced to the minimum level. The broad meaning of reliability including both validity and reproducibility is utilised in this study (Houston 1983). Reliability of this new system is also affected by many factors, mentioned earlier, and controlling these factors, greater accuracy is possible. Adequate training and calibration and then publication of a number of pilot studies achieved validation of this new technique and measurement method.

5.2. AIMS

The aims considered in this section therefore, are:

1) To validate the new image analysis technique used in the study. This is in order

2) To determine reproducibility of all study measurements.

5.3. CALIBRATION STAGE

To make consistent observations for the measurement variables of the study sample, the investigator must be familiar with the technique he is using. Adequate training with the use of machines and in turn obtaining the measurements either manually or using image analysis technique was achieved. A departmental team protocol was developed for all operators using the new image analysis technique. Each member of the team was calibrated against the others (Brook et al. 1998).

5.3.1. Manual Measurements

Aims:

1) To initially evaluate both intra- and inter-observer measurement repeatability as obtained in two separate occasions.

2) To discuss problems involved in the measurements.

3) Then, to revise measurement protocol for future calibration tests.

Materials and methods:

Fourteen sets for maxillary and mandibular study dental casts had been selected from the records of the department. Only fully erupted permanent teeth were measured using digital callipers (Figure 11). Initially, the investigator and a second dental surgeon agreed on the criteria to measure the mesiodistal (MD) and buccolingual (BL) dimensions: The MD was obtained from the proximal contact points when the peaks of the calliper arms were directed from the buccal aspect and as perpendicular as possible to the long axis of the clinical crown for each tooth. In situations where there was difficulty in placing the calliper beaks e.g. tooth crowding, the measurements were taken from the occlusal or lingual aspect. The BL was taken from the most prominent points of the buccal and lingual (palatal) surfaces of tooth crowns. The callipers was held in a vertical position to the occlusal plane with the arms as parallel as possible to the long axis of the crown. All teeth that fulfilled the criteria were measured in two separate occasions at an interval of three weeks.

The difference between the 1st and 2nd occasion measurements of the investigator provide the intra-observer repeatability and differences between the 1st occasion measurements obtained by the investigator and a 2nd operator provide the inter-observer reproducibility.

Findings and problems:

The general assessment for the difference between 1st and 2nd occasion measurements revealed a wide range in which figures greater than 0.3 mm were considered unacceptable. Some occasions of inter- and intra-observer differences for both MD and BL had demonstrated 0.5 – 1.0 mm range. After discussion, the possible causes were:

1. Variation in tooth position and/or morphology. Orienting the callipers in crowded cases was difficult in the MD dimension. BL was also difficult to be determined particularly in the incisors when they were very proclined, and molars as whether to take measurements from the buccal and lingual grooves or from the midsurfaces or most prominent points.

2. Determining the MD from occlusal or lingual aspect (if not possible from buccal aspect) creates errors as one operator may take it lingually, while the other take it

from the occlusal aspect

3. Another problem was related to callipers as it gives more than one reading, for the same position, as the pressure applied to its arms changes.

Conclusions:

Manual technique of tooth measurements appeared to be subjective. The measurements of MD will be obtained separately from both buccal and occlusal aspects. The measurement protocol was then revised to match sections 4.4.2.1. and 4.4.2.2.

5.3.2. Image Analysis Measurements

Aims: As in manual method, the aims were to

1. Familiarise and train the investigator with the new image analysis technique.
2. Preliminarily, investigate the reliability of this system, i.e. its reproducibility.
3. Generally evaluate the system in order to standardise it (cast platform, light, camera, imaging and measurement procedures and software available) for future use.
4. Estimate the time required to performing certain measurements.

Materials and methods:

A study cast was investigated in which 5 different permanent teeth (central incisor, lateral incisor, canine, first premolar and first molar) of the upper right quadrant were imaged on two separate occasions, from both buccal and occlusal aspects. The tooth surface was oriented in a way facing the camera and assuming to be in parallel planes and the image was captured and then analysed. The variables investigated were mesiodistal, buccolingual, occlusogingival, perimeter and area measurements.

Findings and problems:

1. Difficulty in determining the mesial and distal contact points when there was a shadow due to light and orientation problems.
2. Difficulty in tracing perimeter, since the image shows wide gingival area.
3. Quality of study models, in cases with deformed perimeter outline.

4. Light reflection, particularly with using white models.

5. Time consideration with regard to orientation, imaging and then measurement as compared with manual measurement.

Conclusions:

1. It showed encouraging results and appeared to be very reproducible technique.

2. To improve it with regard to time factor, a yellow casts may be used and improve its software to give automatic determination for BL and OG (perpendicular to and from the midpoint of MD).

5.3.3. Final Image Analysis Calibration

Following training tests, the protocol of measurement was revised in which the measurement variables were defined as reported in previous chapter. Then, the departmental team conducted a calibration test.

Aim: To standardise the measurement system for multiple operators.

Materials and methods:

The images of 10 permanent teeth including 7 'normal' teeth (upper left 1, 5, 6, and lower right 2, 3, 4, 6) and 3 abnormal-shaped teeth (tapered central and lateral incisors and microdont lateral incisor), were captured by the investigator and then measured on two separate occasions. The measurements were also obtained by two other departmental members for double determinations. To improve measurement reproducibility, the attention was given to evaluate measurement differences. The discrepancy between the two occasion measurements was unacceptable when the difference was > 0.30 mm (for MD, OG, and BL) or > 1 mm (for perimeter).

Findings and conclusion:

In general, visual assessment of the observations revealed a good intra- and inter-observer reproducibility as all linear measurements were within < 0.30 mm and perimeters were < 1 mm. The measurement protocol for both image analysis and manual technique was then finally approved as descibed in Chapter 4. Some pilot studies below, were then conducted to validate the new imaging technique and the measurement method.

5.4. VALIDATION OF THE NEW TECHNIQUE

The overall plan for validation the new system during study period was to take part into:

1. Determination of the intra- and inter-operator measurement reproducibility (i.e. errors of measurement procedure).

2. Determination of the intra- and inter-operator imaging reproducibility (i.e. total errors of new system = errors of imaging procedure + errors of measurement procedure).

5.4.1. Statistical Method

Limits of agreement were used to determine reliability of measurements. This summarizes the differences between paired quantitative observations and calculates the agreement strength, using the same units of measurements, in which a range of values within which 95% of differences in measurement would be expected to lie (Bland and Altman 1986, Altman 1991). It is presented by upper and lower limits (range). For an individual case, the two occasions (observers or methods) are expected to show measurements that differ by no more than the limits. For inter-observer reproducibility the limits are:

Upper limit = mean difference + 1.96 x SD (differences about mean difference).
Lower limit = mean difference – 1.96 x SD (differences about mean difference).

For intra-observer repeatability in which the difference between two occasion measurement is assumed to be zero (although this needs to be examined), the limits are:

Upper limit = + 1.96 x SD (differences about zero).
Lower limit = – 1.96 x SD (differences about zero).

The value 1.96 SD (differences about zero) is the definition of repeatability adopted by the British standard institute (and also called repeatability coefficient).

This statistical method was utilised for comparison of limits of agreement for the new image analysis technique.

5.4.2. Validation Test 1 *(Pilot study 1)*

{The measurement of tooth morphology: Development and validation of a new image analysis system. Brook A H, Smith R N, Elcock C, Al-Sharood M H, Shah A A and Karmo M (1998). Proceedings of the 11th International Symposium on Dental Morphology, Oulu, Finland: 380-387}

Aim:

To determine the intra-operator reproducibility of tooth measurements on the computer screen images.

Materials and Methods:

On two separate occasions, the investigator and 2 other operators (Shah and Karmo) measured the permanent teeth of 5 sets of maxillary and mandibular casts, taken from the study population. The investigator captured the images of all teeth from both buccal and occlusal aspects. The measurements obtained were the mesiodistal, occlusogingival (buccolingual), perimeter and area of tooth surface for image analysis technique, while only mesiodistal and buccolingual for manual method. Criteria of imaging and measurement procedures and definitions of measurement variables were as described in previous chapter.

Data analysis:

The limits of agreement were calculated for each of the operator's differences between measurements (Bland and Altman 1986, Altman 1991). The Coefficient of Reliability (Houston 1983) of the difference between 1st and 2nd occasion measurements was also determined for intra-operator repeatability.

Results:

The results of the calculated limits of agreement for the three operator measurements using manual and image analysis techniques are shown in tables 6-8 (operator 3 is the investigator). The strength of agreement is interpreted as +/- of each individual figure presented for each individual measurement variable. The larger the value, the poorer is the repeatability. The extent of disagreement recorded within the operators for each measurement in each view were also displayed as a proportion of the mean measurement made (i.e. percentage measurement error, pesented in brackets). The coefficient of reliability is also presented.

Three linear measurement variables (MDb, MDo and BL) were used by both techniques. The manual measurements show limits of agreement ranging from 0.26 to 0.55 mm (3.25 to 6.89%) for all variables. The figures are smaller using the image analysis technique for each operator, ranging from 0.17 to 0.32 mm (2 to 3.51%).

For image analysis, the limits of agreement for perimter measurements ranged between 0.28 to 0.65 mm (1.04 to 2.24%). On the other hand, the area measurements demonstrated a range of 0.54 to 3.19 mm^2 (2.22 to 4.88%). There are however, three figures exceeding these ranges concerning perimeter and area measurements, which are considered below. The minimum coefficient value recorded for measurements using either technique was 0.97.

Table 6: Intra-operator summary of manual measurement. Table shows limits of agreement (and percentage measurement error recorded, in brackets) within operators and displays minimum Coefficient of Reliability within operators.

Repeatability	Buccal Aspect	Occlusal Aspect	
	MD	MD	BL
Operator 1	0.55 (6.89)	0.45 (5.76)	0.54 (6.46)
Operator 2	0.30 (3.89)	0.28 (3.50)	0.35 (4.13)
Operator 3	0.28 (3.40)	0.26 (3.25)	0.34 (3.79)
Coefficient of Reliability	0.98	0.99	0.99

For each variable, the limits of agreement are +/- the figure shown and the unit is mm.

Table 7: Intra-operator summary of image analysis buccal view measurement. Table shows limits of agreement (and percentage measurement error recorded, in brackets) within operators and displays minimum Coefficient of Reliability within operators.

Repeatability	Buccal View			
	MD	OG	Perimeter	Area
Operator 1	0.29 (3.54)	0.33 (4.57)	1.81* (6.88)	0.94 (1.90)
Operator 2	0.17 (2.00)	0.21 (3.00)	0.28 (1.04)	1.72 (3.57)
Operator 3	0.18 (2.10)	0.17 (2.30)	0.42 (1.59)	5.99* (12.42)
Coefficient of Reliability	0.99	0.99	0.97	0.97

*For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm^2). * Worst cases.*

Table 8: Intra-operator summary of image analysis occlusal view measurement. Table shows limits of agreement (and percentage measurement error recorded, in brackets) within operators and displays minimum Coefficient of Reliability within operators.

Repeatability	Occlusal View			
	MD	BL	Perimeter	Area
Operator 1	0.28 (3.28)	0.30 (3.21)	0.60 (2.03)	0.54 (2.22)
Operator 2	0.19 (2.22)	0.32 (3.51)	0.37 (1.25)	10.06* (15.17)
Operator 3	0.26 (2.79)	0.27 (2.93)	0.65 (2.24)	3.19 (4.88)
Coefficient of Reliability	0.99	0.99	0.99	0.98

For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm^2). * *Worst cases.*

Discussion:

This test was concerned with reproducibility of measurements to evaluate the accuracy of the new image analysis technique. Not all parts of the procedures were repeated for the new technique as only the repeatability of measurements on the computer's screen was investigated. However, the findings revealed that this new image analysis system permits comparable and smaller measurement repeatability of tooth dimension than that of the manual technique. The intra-operator repeatability assessment reveals small clinical values for the limits of agreement in the new technique for both buccal and occlusal views for all three operators. This is also reflected in coefficients of reliability findings that exceeding 0.90 for all linear measurements. This demonstrates a high degree of repeatability of the new system and ease of use. Although lower, the coefficient values for area and perimeter measurements and the values for extent of disagreement were still of an acceptable level.

For the manual measurements (Table 6), a relatively high degree of reproducibility was also revealed. The greater differences shown buccally for the MD dimension in comparison to MD occlusally are likely to be due to differences in calliper beaks placement and model orientation by the operators. Access of the calliper beaks was sometimes difficult, due to individual tooth positioning and their relation to the adjacent teeth and this can affect measurement. This may result in large mean estimates of tooth dimension in comparison to the image analysis measurements. The occlusal view was reported by the operators to be generally the easier to measure than the buccal view. However, the results showed comparable observations with a tendency for the occlusal measurements to be smaller than the buccal ones.

The BL dimension does show greater differences manually. Using the on screen image analysis method tooth orientation was constant such that the view of each tooth measured by all operators was the same. This is obviously not as controlled during manual measurement.

For the image analysis additional measurements to the manual technique were made in this study include perimeter and area determination of the tooth surfaces. In general, the differences between area measurements were greater than perimeter measurements. This was to be expected, as the area value is expressed in squared units. In the buccal view (Table 7) the results for perimeter show the agreement to be in a range of 0.28 to 1.81 mm (1.04 to 6.88% respectively) within operators. The highest value in this range actually gave the lowest agreement value for its corresponding area measurement i.e. 0.94 mm^2 (1.90%).

Considering both buccal and occlusal views (Table 7 and 8), the worst agreements for area were 5.99 and 10.06 mm^2 (12.42 and 15.17%) that gave corresponding low values for perimeter discrepancies i.e. 0.42 and 0.37 mm (1.59 and 1.25% respectively). The mismatch in these results is a consequence of the methodology of the analysis programme calculating the area from the perimeter trace. Another possible reason was beacuse all tooth types were combined in determining the measurement error. Due to the discrepancies highlighted here, therefore, the area data should be viewed with caution. In the next test (pilot study 2) more attention was given for calibrating the scale prior the measurements as well as for tracing the perimeter by all operators, using additional cases. Furthermore, increasing the number of teeth measured allowed separation of results for individual tooth types (pilot study 3, to follow), so permitting less generalised results.

As one operator acquired the images, further validation of our new system will involve assessment of the imaging procedure in addition to measurement by same operator (see pilot study 3) and, in future, by multiple operators in order to facilitate comparison with manual method. More extensive tooth measurements were also assessed as will be shown later.

Conclusion:

The new system permits reproducible measurements for the teeth of dental study casts.

5.4.3. Validation Test 2 *(Pilot study 2)*

{Accurate tooth morphology measurement using a new image analysis system. Brook A H, Smith R N, Elcock C, Al-Sharood M H, Shah A A, Karmo M, Khalaf K and Robinson D L (1999). Journal of Dental Research, 78 (5): 1076}

Aim:

The objective of this study was to determine both the intra- and inter-operator reproducibility of tooth measurements aiming to test the validity of the new image analysis system.

Materials and Methods:

In this study, five more study models and one further operator were included. Thus, four operators including the investigator (operator 2) measured the teeth on ten sets of maxillary and mandibular dental casts (from this study population), on two separate occasions. The measurements obtained were for the same variables of pilot study 1 (MD, BL (OG), P and A). The investigator, according to the method discussed in previous chapter captured the buccal and occlusal images of all teeth.

Data analysis:

The limits of agreement (Bland and Altman 1986, Altman 1991) were calculated to determine intra- and inter-operator reproducibility between 1st and 2nd occasion measurements.

Results:

The results of the image analysis measurements for the four operators are shown in tables 9 and 10.

The tables display the worst scenarios of 95% limits of agreement and maximum percentage measurement error within and between the operators for each measurement in each view. The calculated limits of agreement showed the average agreement within operators ranged from 0.23-0.99 (or 1.7-2.9%) for buccal view images and 0.22-1.66 (1.6-2.6%) for occlusal view images. Average inter-operator assessment was greater with ranges of 0.57-7.24 (7.4-13.8%) and 0.66-9.61 (6.8-13.8) for buccal and occlusal views meaurements respectively.

Table 9: Intra- and inter-operator limits of agreement summary of buccal measurements. Table also shows percentage measurement error recorded within and between operators.

	Variable	Operator 1	Operator 2	Operator 3	Operator 4
Operator 1	MD	0.19 (2.3%)			
	OG	0.22 (2.9%)			
	P	0.41 (1.5%)			
	A	0.83 (1.6%)			
Operator 2	MD	0.56 (6.6%)	0.20 (2.3%)		
	OG	0.47 (6.1%)	0.19 (2.5%)		
	P	1.53 (5.6%)	0.40 (1.5%)		
	A	4.45 (8.6%)	1.16 (2.2%)		
Operator 3	MD	0.62 (7.2%)	0.54 (6.3%)	0.10 (1.2%)	
	OG	0.46 (5.9%)	0.40 (5.2%)	0.11 (1.5%)	
	P	1.21 (4.5%)	1.32 (4.9%)	0.46 (1.7%)	
	A	4.58 (8.9%)	4.78 (9.2%)	0.61 (1.2%)	
Operator 4	MD	0.83 (9.8%)	0.82 (9.6%)	0.73 (8.5%)	0.41 (4.8%)
	OG	0.73 (9.5%)	0.72 (9.4%)	0.66 (8.6%)	0.37 (4.8%)
	P	2.83 (10.4%)	2.64 (9.6%)	2.62 (9.6%)	0.55 (2.0%)
	A	10.28* (19.6%)	10.07* (19.1%)	9.29* (17.6%)	1.37 (2.5%)
Average Intra-operator Agreement	MD	0.23 (2.6%)			
	OG	0.23 (2.9%)			
	P	0.46 (1.7%)			
	A	0.99 (1.9%)			
Average Inter-operator Agreement	MD	0.68 (8.0%)			
	OG	0.57 (7.4%)			
	P	2.03 (7.4%)			
	A	7.24 (13.8%)			

*For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm^2). * Worst cases.*

Table 10: Intra- and inter-operator limits of agreement summary of occlusal measurements. Table also shows percentage measurement error recorded within and between operators.

	Variable	Operator 1	Operator 2	Operator 3	Operator 4
Operator 1	MD	0.20 (2.3%)			
	BL	0.23 (2.4%)			
	P	0.35 (1.2%)			
	A	1.35 (1.9%)			
Operator 2	MD	0.59 (6.8%)	0.23 (2.6%)		
	BL	0.64 (6.7%)	0.25 (2.7%)		
	P	1.96 (4.9%)	0.51 (1.7%)		
	A	7.26 (10.6%)	2.37 (3.5%)		
Operator 3	MD	0.64 (7.4%)	0.53 (6.1%)	0.09 (1.1%)	
	BL	0.56 (5.9%)	0.60 (6.3%)	0.12 (1.3%)	
	P	1.25 (4.2%)	1.52 (5.1%)	0.36 (1.2%)	
	A	5.88 (8.4%)	7.91 (11.4%)	0.82 (1.2%)	
Operator 4	MD	0.83 (9.6%)	0.73 (8.5%)	0.62 (7.1%)	0.36 (4.2%)
	BL	0.82 (8.5%)	0.85 (8.9%)	0.67 (7.0%)	0.37 (3.8%)
	P	2.79 (9.3%)	2.85 (9.5%)	2.38 (7.9%)	0.72 (2.4%)
	A	12.76* (18.3%)	13.40* (19.4%)	10.45* (14.9%)	2.09 (2.9%)
Average Intra-operator Agreement	MD	0.22 (2.6%)			
	BL	0.24 (2.5%)			
	P	0.48 (1.6%)			
	A	1.66 (2.4%)			
Average Inter-operator Agreement	MD	0.66 (7.6%)			
	BL	0.69 (7.2%)			
	P	2.04 (6.8%)			
	A	9.61 (13.8%)			

*For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm^2). * Worst cases.*

Discussion:

For buccal view measurement (MD, OG, P and A), the inter-operator limits of agreement and the percentage measurement errors show an average of 0.68 mm (8%), 0.57 mm (7.4), 2.03 mm (7.4%) and 7.24 mm^2 (13.8%) respecively (Table 9). The worst situations were the area measurements for operator 4 against operator 1, 2 and 3 (10.28, 10.07 and 9.29 mm^2 respectively). When the measurements of operator 4 were excluded, the average figure of inter-operator limits of agreement drops down to be 4.60 (8.9%).

The intra-operator limits of agreement on the other hand demonstrated much better averages as expected; 0.23 mm (2.6%), 0.23 mm (2.9%), 0.46mm (1.7%) and 0.99 mm^2

(1.9%) for same variables respectively. The worst case was 1.37 mm^2 (2.5%) for area measurement of operator 4.

For the occlusal view meaurements (Table 10), the inter-operator limits of agreement of MD, OG, P and A show an average of 0.66 mm (7.6%), 0.69 mm (7.2%), 2.04 mm (6.8%) and 9.61 mm^2 (13.8%) respectively. A similar conclusion was also revealed in the occlusal view meaurements in which the worst scenarios were the area measurements that all occured between operator 4 against operator 1, 2 and 3 (12.76, 13.40 and 10.45 mm^2 respectively). Excluding operator 4 measurement the area inter-operator limits of agreement improves to be 7.02 mm (10.1%).

The intra-operator limits of agreement, the average values were 0.22 mm (2.6%), 0.24 mm (2.5%), 0.48mm (1.6%) and 1.66 mm^2 (2.4%) for same variables respectively. The worst situations were 2.37 (3.5%) and 2.09 (2.9%) for area measurement of operator 2 and 4 respectively.

The analysis of data revealed good measurement agreements for MD, BL and OG variables while the perimeter fall in between area and these variables.

Next test will investigate individual tooth types when increasing the number of teeth involved, imaging repeatability can be assessed (pilot study 3).

Conclusion:

The overall results show that this new image analysis technique permits measurements on the computer screen for tooth dimensions with good levels of reproducibility for multiple operators. The results, therefore, further support the use of the new system.

5.4.4. Validation Test 3 *(Pilot study 3)*

{Reliability of a new image analysis technique in orthodontic research. Al-Sharood M H, Brook A H, Elcock C, Smith R N and Robinson D L (1999). European Journal of Orthodontics, 21(5): 569-570}

Aim:

In this study, the main objectives were to test the intra-operator reproducibitity of imaging and measurement procedures for different tooth types and to compare image analysis and manual technique measurements formally.

Materials and Methods:

Using the same 10 cases of previous study, three tooth types were examined further. The maxillary central incisors (N = 20), canines (N = 18) and first molar (N = 20) were re-imaged and measured from both buccal and occlusal views after one year from the 1st imaging occasion. Manual measurements of these teeth were also obtained on two separate occasion measurements. The investigator, according to the same guidelines reported earlier performed all the imaging and measurement procedures. The measurements obtained were also the same variables; MD, BL (OG), P and A for image analysis system and MD and BL for manual method.

Data analysis:

The limits of agreement were calculated to test intra-operator reproducibility between 1st and 2nd occasion measurements. Multiple comparisons of an F-test were used to compare tooth types for each variable by comparing two standard deviations of differences about zero (i.e. repeatability coefficients). One sample t-tests on paired absolute differences were utilised to test the differences between the two techniques for a particular variable.

Results:

1) Comparisons of image analysis reproducibility between tooth types:

The calculated limits of agreement for buccal and occlusal image analysis measurements for each tooth are shown in table 11. For each measurement per view the ratios of standard deviation differences about zero were tested in multiple comparisons of tooth type (every possible pair within a view for each measurement) and no significant differences were revealed at the 5% level.

The results of buccal view measurements revealed the following: For the MD the lowest figure of limits of agreement was for the molar (0.32 mm) and the highest was for canine (0.48 mm), while the incisor fall in between (0.39 mm). This suggests easier MD measurements to be made for molar and more difficult in the canine. Similar figures were shown for the OG for incisor (0.33 mm), canine (0.28 mm) and molar (0.29 mm).

For the perimeter, the limit values were 1.68, 1.01 and 1.40 respectively suggesting more difficulty in tracing the surface of incisor tooth than the molar, which is followed by the canines. The area demonstrated the highest figures in different teeth, 5.37, 3.97 and 4.54 mm^2 for incisor, canine and molar teeth respectively. The findings suggest that canine to be the easiest tooth to obtain area measurement.

The analysis of the occlusal view measurements revealed the following: For the MD, very similar figures of the limits were shown for the incisor, canine and molar (0.36, .034 and 0.36 mm, respectively). The canine tooth measurement, therefore, was as easy as the other variables when it is compared to the buccal view. Similar figures were also found for the BL for these teeth (limits, 0.41, 0.43 and 0.36 mm respectively) suggesting slightly easier measurements to be made for molar and the opposite for the canine.

Similar figures were shown for the perimeter 1.41, 1.34 and 1.56 mm respectively. On the other hand the analysis indicated that the molar tooth to be the most difficult tooth to measure its area (limits of 8.29 mm^2) and presented similar results for incisor and canine area measurement reproducibility (5.74 and 5.44 mm^2 respectively).

2) Comparisons reproducibility between methods:

The limits of agreement of measurements for image analysis and manual techniques are shown in table 12. One sample t-tests on paired absolute differences between measurements made on two occasions for both techniques revealed no significant differences in repeatability.

For the MDb, similar results for the image analysis and manual method were presented for the incisor by limits (0.39 and 0.32 mm respectively). The canine and molar teeth demonstrated differences between the two techniques. The canine tooth showed better MDb reproducibility in the manual than the new technique (0.48 and 0.29 respectively). The opposite picture was found for the molar (0.32 and .43 mm respectively).

For the MDo, the overall results suggest similar reproducibility for different teeth in both techniques. Moreover, the results indicate lower figures for the canine in the image analysis and molar in the manual technique (0.34 and 0.28 mm, respectively) as compared to the MDb. This would suggest easier mesiodistal measurements to be gained from the occlusal rather than from buccal aspect, for these two teeth.

For the BL, the worest scenario was related to the canine tooth in the image analysis technique (limits of 0.43 mm) as compared to the manual method (0.29 mm). The result was almost the same in both techniques for molar and fairly similar in the incisor tooth.

Table 11: Comparisons of image analysis reproducibility between tooth types. The intra-operator limits of agreement and proportion (in brackets) of average tooth dimension for image analysis measurements in buccal and occlusal views of different tooth types.

Variable	View	Incisor (n=20)		Canine (n=18)		Molar (n=20)	
MD	Buccal	0.39	(4.16)	0.48	(5.75)	0.32	(2.96)
	Occlusal	0.36	(3.18)	0.34	(4.08)	0.36	(3.20)
OG	Buccal	0.33	(3.21)	0.28	(2.89)	0.29	(5.30)
BL	Occlusal	0.41	(5.07)	0.43	(4.78)	0.36	(2.99)
P	Buccal	1.68*	(5.00)	1.01	(3.54)	1.40	(4.80)
	Occlusal	1.41	(5.04)	1.34	(4.87)	1.56	(3.98)
A	Buccal	5.37	(6.45)	3.97	(6.47)	4.54	(8.72)
	Occlusal	5.74	(9.93)	5.44	(9.47)	8.29*	(7.22)

*For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm^2). * Worst cases.*

Table 12: Comparisons of reproducibility between methods. The intra-operator limits of agreement of measurements and proportion (in brackest) of average tooth dimension for different techniques, teeth and views.

Variable	Technique	Incisor (n=20)		Canine (n=18)		Molar (n=18)	
MDb	Image Analysis	0.39	(4.16)	0.48*	(5.75)	0.32	(2.96)
	Manual	0.32	(3.44)	0.29	(3.56)	0.43*	(3.17)
MDo	Image Analysis	0.36	(3.81)	0.34	(4.08)	0.36	(3.20)
	Manual	0.30	(3.33)	0.36	(4.45)	0.28	(2.56)
BL	Image Analysis	0.41	(5.07)	0.43*	(4.78)	0.36	(2.99)
	Manual	0.32	(4.10)	0.29	(3.18)	0.35	(2.89)

*For each variable, the limits of agreement are +/- the figure shown and the unit is mm. * Worst cases.*

Discussion:

This pilot study is a continuation for previous studies aiming to investigate measurements of different tooth types and to test imaging reproducibility (Tables 11 and 12). None of these figures revealed significant differences for measurements taken in the 1st and 2nd image of the individual crown surface. The new technique permits repeatable measurements as obtained from double determination of imaging and measurement procedure (Table 11). The findings indicate that some measurements may be more difficult than others.

There was slight evidence ($0.05<p<0.06$) of a difference in repeatability for incisor perimeter measurements obtained buccally (1.68 mm) and molar area measurements obtained occlusally (8.29 mm^2), when compared with equivalent canine measurements (1.01 mm and 3.97 mm^2 respectively). Clinically, these figures do not indicate too big differences. The worst figures in MDb and BL were related to the canine (0.48 and 0.43 mm respectively), whereas the MDo and OG showed comparable results for different teeth.

In this study, the total errors of image analysis measurement consisted of errors resulting from imaging procedures and those resulting from measurement procedures. These errors, therefore, were expected to be larger than those of single occasion of imaging (as of previous pilot studies). The main reason for this difference is the orientation subjectivity of tooth surface during its imaging. Slight loss of model material can occur during 1st occasion of manual measurement. Any obvious loss however resulted in the tooth being excluded. The limits of agreement of measurements for each technique were shown in table 12. Comparing the techniques, the highest disagreement figures were related to the MDb dimensions i.e. 0.48 mm in image analysis for canine tooth and 0.43 mm in manual measurements for the molar. For the BL, the worst figure was 0.43 mm and 41 mm for the canine and incisor teeth respectively in the image analysis technique. Overall findings suggest comparable repeatability for the old and new techniques, at least for the tooth types selected.

Conclusion:

The results show that this new image analysis system allows reliable measurements of tooth morphology for different teeth. The findings, therefore, further support the use of this new technique. However, reproducibility of the whole procedures (imaging and measurements), for different teeth, by multiple operators should ideally be performed.

5.5. FURTHER RELIABILITY TEST

The above validation studies determined the intra- and inter-operator reproducibilty of four buccal and four occlusal measurement variables. The next investigation had been carried out to test reproducibility of the remaining measurement variables used in the study for other tooth types.

5.5.1. Aim

To determine repeatability of both imaging and measurements for other study variables of different teeth in both arches.

5.5.2. Materials and Methods

Determination of the errors was made from measurements obtained from two separate imaging occasions. Images of mandibular central incisors (n = 10), 2nd premolars (n = 10) and 1st molar (n = 10) and maxillary lateral incisors (n = 10) in addition to the maxillary central incisors, canines, molars of previous study, were captured by the investigator, twelve months later from the 1st occasion. The measurements were made using the same method reported earlier. The limits of agreement were calculated to evaluate the total errors of measurements.

5.5.3. Results

Table 13 demonstrates the calculated intra-operator limits of agreement findings of buccal view measurements, while table 14 displays the agreement for occlusal variables. For 95% of cases, the difference between the two measurements obtained on the same tooth was no more than +/- each of these figures shown. In light of these observations presented the limits of agreement for linear measurements (MD, OG, BL, D, BLm and BLd) of both buccal and occlusal views, showed the following worst scenarios:

The worst occlusal agreements found were for D measurements of U6 and BLd of L6 (0.61 mm) and for BL and MD measurements of L6 (0.59 and 0.54 mm respectively). The worst buccal repeatabilities were for D of U3 and U6 (0.57 and 0.54 mm respectively), for OG of L5 (0.50 mm) and for MD of U3 and U2 (0.48 and 0.46 mm respectively).

On the other hand, the best two figures were 0.23 and 0.24 mm for D measurements of L6 and L1 respectively (buccally) and 0.24 mm for BLm of L6 (occlusally).

For the perimeter, the worst repeatabilities found were for L6 and U1 (1.82 and 1.68 mm respectively) in buccal view and for the U6 and L6 (1.56 and 1.51 mm respectively) in occlusal view. On the other hand, U2 (occlusally) and L1 (buccally) presented the best two repeatabilities (0.50 and 0.64 mm respecively).

For the area measurements, on the other hand, the range of the agreements was 1.80 to 9.75 mm^2. The worst figures were for U6 and L6 (8.29 and 9.75 mm^2 respectively) in the occlusal view and for L6 (7.76 mm^2) in the buccal view. Whereas the best agreement were for U2 (occlusally) and for L1 (buccally) with 1.80 and 2.21 mm^2 values respectively.

None of the mean difference measurements were significant after Bonferroni adjustments for significance levels.

Table 13: The intra-operator limits of agreement for buccal view measurements of different teeth.

Variable	Maxillary Teeth				Mandibular Teeth		
	U1 (n=20)	U2 (n=10)	U3 (n=18)	U6 (n=18)	L1 (n=10)	L5 (n=10)	L6 (n=10)
MDb	0.39	0.46	0.48	0.32	0.25	0.33	0.38
OG	0.33	0.43	0.28	0.29	0.27	0.50	0.42
Db	0.47	0.37	0.57*	0.54*	0.24	0.49	0.23
Pb	1.68*	1.32	1.01	1.40	0.64	1.41	1.82*
Ab	5.37	4.57	3.97	4.54	2.21	4.78	7.76*

For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm^2).
*The standard deviation of the differences = +/- 50% of the limits of agreement value. * Worst cases.*

Table 14: The intra-operator limits of agreement for occlusal view measurements of different teeth.

Variable	Maxillary Teeth				Mandibular Teeth		
	U1 (n=20)	U2 (n=10)	U3 (n=18)	U6 (n=18)	L1 (n=10)	L5 (n=10)	L6 (n=10)
MDo	0.36	0.35	0.34	0.36	0.29	0.39	0.54
BL	0.41	0.42	0.43	0.36	0.37	0.47	0.59*
Do	0.45	0.41	0.53	0.61*	0.33	0.40	0.33
Po	1.41	0.50	1.01	1.56*	0.92	1.41	1.51*
Ao	5.74	1.80	5.44	8.29*	3.14	5.91	9.75*
BLm				0.54			0.24
BLd				0.34			0.61*

For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm²).
*The standard deviation of the differences = +/- 50% of the limits of agreement value. * Worst cases.*

5.5.4. Discussion

This test is a continuation for pilot study 3 aiming to investiagte reproducibility of imaging and measurement procedures for different tooth types using the image analysis techniue. The new teeth investigated were the mandibular central incisor, 2nd premolar and 1st molar and maxillary lateral incisors. In addition to the previous measurments (MD, OG, BL, P and A), the repeatability of D, BLm and BLd measurements were determined.

The results of limits of agreement (Tables 13 and 14) demonstrated the total errors as the observations were taken from two occasions of imaging and measurement procedures. Descriptive data revealed that for few paired linear measurements, the repeatability was exceeding the acceptable levels mentioned earlier (i.e. for some individual tooth in each view, 1 or 2 cases were found showing a range of 0.31-0.45 mm). The overall findings, from both buccal and occlusal view, suggest that the molar was the most difficult tooth to be investigated and the opposite was for the lower central incisor and upper lateral incisor.

With regard to sample size, ideally 20 teeth were the minimum size for investigating the repeatability. In this test, the time allowed investigation a range of tooth sizes (n = 10 -20) from both buccal and occlusal views and only teeth from normal dentitions. Part of the next chapter investigated the reproducibility of both imaging and measurement procedures but for teeth from abnormal (hypodontia) dentitions morphology i.e. anterior teeth from their buccal views. Finally, the observations generally indicate an improvement with time to perform both imaging and measurement procedures.

5.6. SUMMARY OF MEASUREMENT RELIABILITY

The reliability of measurements and validation of the new image analysis technique were investigated by a series of method error tests:

1) Assessment of the intra-operator reproducibility was made for three operators (pilot study 1) by double determination for buccal and occlusal variables (MDb, MDo, OG, BL, Ab, Pb, Ao and Po for image analysis). Five sets of dental models were investigated manually and with image analysis technique and one operator captured the images. The results revealed that the new system to be reproducible and comparable to the manual method. For the image analysis, the most difficult variable to be measured was the area, according to the limits of agreement.

2) Four operators carried out assessment of the intra- and inter-operator reproducibility (Pilot study 2). Another 5 sets were investigated (total 10 upper and 10 lower casts) to obtain measurements of the same variables above. The same operator performed imaging procedure. The overall results indicate reproducible technique and the intra-operator agreement was better than the inter-operator agreement, as expected. The most disagreement values were related to the area measurements, followed by the perimeter.

3) Assessment of the total errors, which include imaging and measurement procedures, for different tooth types (maxillary central incisor, canine and 1st molar), was also made by double determination for both image analysis and manual method (pilot study 3). One operator performed all the measurements for the above-mentioned variables, to determine the intra-operator repeatability. No significant differences were found between the measurements obtained by two techniques and between the occasions of measurements. For the image analysis, the biggest limits of agreement values were the occlusal area for the molar tooth and buccal perimeter for the incisor teeth. While, the canine appears to be the most difficult tooth to measure its MDb and BL as compared to the manual method.

4) A continuation test was also done for other tooth types (maxillary lateral incisor, mandibular central incisor, 2nd premolar and 1st molar) and additional variables were included (Db, Do, BLm and BLd) by one operator (section 5.5.). The overall findings were in parallel to the above tests. For the new teeth and variables included, the worst repeatability were for Db and Do of U3 and U6, BLm of U6, BLd for L6 and perimeter of L6. However, the figures of limits of agreement are not of much clinical significance.

Finally, the next chapter assesses reliability of measurements in hypodontia dentitions including tooth taper and its related variables. This will allow the evaluation of differences between measurements of normal and abnormal teeth.

Chapter 6

Determination Of Tooth Taper

6.1. INTRODUCTION

Hypodontia creates problems in orthodontic and restorative management. One is the morphology of the remaining teeth. Sometimes the anterior teeth which form are tapered in shape or microdont or both. Teeth with abnormal morphology require careful treatment planning to achieve desirable results. Tapering trait may be unilateral or bilateral. In addition, it has a range of severity in which it could be mild or severe, and it could affect one or more teeth.

A number of terms were used to describe this malformation. For instance, pyramidal, abnormal, degenerated, diminished in size, conical, peg-shaped, pointed, narrow, and elongated teeth (Rantanen 1956, Alvesalo and Portin 1969, Foster and Van Roey 1970, Sofaer et al. 1971, Lai and Seow 1989, Schalk-van der Weide 1992).

Peg shaping is usually related to the malformation of the upper lateral incisors. The literature indicates some link between tooth malformation and hypodontia. The aetiology of this phenomenon not yet been defined. However, a genetic basis may be involved in these conditions (Alvesalo and Portin 1969, Woolf 1971).

Its prevalence varies. Davies (1968) reported that 22 % of the hypodontia subjects had peg shaping of one or more teeth. According to Lai and Seow (1989), 8.9% of hypodontia subjects demonstrated this trait that was significantly different from the controls ($P<0.01$). A finding requiring further investigation is peg-shaped teeth that were significantly more common on the left side than the right (Sofaer et al. 1971).

Determination of anterior tooth taper is usually made in a subjective manner during clinical examination. The categories of conical, slightly conical and normal incisor have been used (Zeisz and Nuckols 1949, Schalk-van der Weide 1992). Establishing a method of quantification the degree of tapering is of relevance for aetiological studies. This is preferable to subjective categorical scoring as the measurements will have lower variance and therefore permit more powerful statistical analysis later i.e. comparing control verus hypodontia groups. This study investigates maxillary and mandibular incisor teeth.

6.2. DEVELOPMENT OF TAPER INDEX

A new method is proposed to quantify, on a continuous scale, the amount of tooth taper in the incisor teeth of both maxillary and mandibular arches.

6.2.1. Aim

To validate an index to quantify tooth taper for the incisor teeth.

6.2.2. Methodology

6.2.2.1. Imaging procedure

Using the new image analysis technique method discussed above, images of incisor teeth, on dental casts, were obtained. Each individual incisor was positioned on a calibrated stage and imaged from its buccal aspect (Figures 18-25 and 26-33 for maxillary and mandibular incisors respectively).

6.2.2.2. Measurement procedure

The MDb and OG dimensions were initially determined. Then, a series of tooth widths were determined, parallel to MDb, at fixed proportions along the OG (at 50, 56.25, 62.5, 68.75, 75, 81.25, 87.5, 93.75 percentiles) from the gingival margin (Figures 34 and 35 for maxillary and mandibular incisors respectively). The distance (Db) of the MDb from the incisal edge across the OG was also measured (Figure 12). A number of teeth (N = 20 for each tooth) was remeasured to assess reproducibility of the new method.

6.2.2.3. Visual scoring

All teeth were subjectively graded as normal (0), mild (1), moderate (2) and severe taper (3) by the investigater in double determinations and by three other dentists in single occasion to assess scoring agreement (Figures 18-25 and 26-33 for maxillary and mandibular incisors respectively).

6.2.3. Statistical Analysis

The initial question was to find a reliable scoring system, with a continuous scale, for the determination of tapering. Subjective scoring is not a precise way as it shows variation between and within individuals and is categorical in nature. Three approaches were tested:

1) The first one was to determine the best ratio of two fixed width measurements according to the following formula, for example:

$$\text{Tooth taper (by ratio)} = \frac{\text{MD at 50 \% of the OG length}}{\text{MD at 75\% of the OG length}}$$

2) The second method was to investigate the usefulness of using the proportion for Db dimension (i.e. the distance between the MDb to the incisal edge across the OG) to the whole OG dimension based on the formula, for example:

$$\text{Tooth taper (by proportion)} = \frac{\text{Db dimension}}{\text{OG dimension}}$$

3) The third one was to investigate combining the above methods according to the following formula:

Tooth taper = Ratio x k (Proportion).

Where k is an unknown constant. For example, the taper of two widths at 50 and 75 percentiles of the OG dimension would be: Tooth taper = MD at 50/75 x k (Db/OG)

Discriminant analysis was used to find the best ratio of two fixed width measurements to discriminate between subjective scorings. The method of limits of agreement was utilised to evaluate both intra-observer repeatability between the two occasions of measurements (No inter-observer reproducibility was determined for the measurements). While, Kappa analysis (standard and weighted) was used to determine both intra- and inter-observer scoring agreement. The standard Kappa counts the agreement between subjective scores as 1 for the consistent scores in the two occasions and 0 for inconsistent scores (Table 15). The weighted Kappa, on the other hand counts the closeness of the 2nd occasion score to the 1st one i.e. 1, 0.66, 0.33 and 0 for complete agreement, moderate, mild and no agreement respectively (Table 16).

Table 15: Standard Kappa method for calculating the agreement between the occasions of subjective scores for tooth taper.

	2nd Occasion of subjective scoring				
	Scores	0	1	2	3
	0	1	0	0	0
1st	1	0	1	0	0
Occasion	2	0	0	1	0
	3	0	0	0	1

Agreement and disagreement (1 and 0 respectively) between the two occasions of scoring.

Table 16: Weighted Kappa method for calculating the agreement between the occasions of subjective scores for tooth taper.

	2nd Occasion of subjective scoring				
	Scores	0	1	2	3
	0	1	0.66	0.33	0
1st	1	0.66	1	0.66	0.33
Occasion	2	0.33	0.66	1	0.66
	3	0	0.33	0.66	1

Agreement (1) and a range of disagreement (0 - 0.66) between the two occasions of scoring.

6.2.4. Findings

The initial materials and results were presented in the following pilot studies (6.3. and 6.4. to follow). A further test (6.4. to follow) was then conducted, after adding more incisor teeth, in which all final results were presented.

6.3. TAPER INDEX FOR MAXILLARY INCISORS *(Pilot study 4)*

{A new method for determination of anterior tooth taper. Al-Sharood M H, Robinson D L, Elcock C, Smith R N and Brook A H (1999). Journal of Dental Research, 78 (5): 1077}

6.3.1. Materials

From 50 subjects involved in this study (24 with hypodontia and 26 others with normal dentitions), images of 79 maxillary teeth (40 centrals and 39 laterals) were acquired and analysed by the investigator (Figures 18-25). To assess the measurement repeatability, 40 teeth (20 central and 20 lateral) were remeasured one month later.

6.3.2. Results

The ratio of tooth widths at 50:75 percentiles gave the best result discriminating between the subjective scores in 70 % of cases (Table 17).

The intra-observer limits of agreement for repeatability of measurement ranged from 0.18 to 0.30 mm (Table 18).

Standard Kappa values for agreement of taper scores were 0.93 (weighted 0.95) for intra-observer and 0.88 (weighted 0.95) for the average inter-observer tests (Tables 19 and 20 respectively).

6.4. TAPER INDEX FOR MANDIBULAR INCISORS *(Pilot study 5)*

{A new method for determination of lower anterior tooth taper. Al-Sharood M H, Robinson D, Elcock C, Smith R N and Brook A H (1999). International Journal of Paediatric Dentistry, 9 (Supplement 1): 104}

6.4.1. Materials

From study casts of 43 subjects involved in this study (28 hypodontia and 15 others with normal dentitions), images of 68 mandibular teeth (34 centrals and 34 laterals) were obtained and analysed by the investigator (Figures 26-33). To evaluate the repeatability of measurements, 40 teeth (20 central and 20 lateral) were remeasured one month later.

6.4.2. Results

Similarly to the upper teeth, the ratio of tooth widths at 50:75 percentiles gave the best result discriminating between the subjective scores in 92.6 % of cases (Table 17).

The limits of agreement for measurement repeatability ranged from 0.10 – 0.16 mm (Table 18).

Standard Kappa values for agreement of taper scores were 0.86 (weighted, 0.91) and 081 (weighted, 0.87) for the intra-operator and average inter-operator, respectively (Tables 19 and 20).

Subjective Scoring of Tooth Taper For Maxillary Incisors

Maxillary central incisor

Maxillary lateral incisor

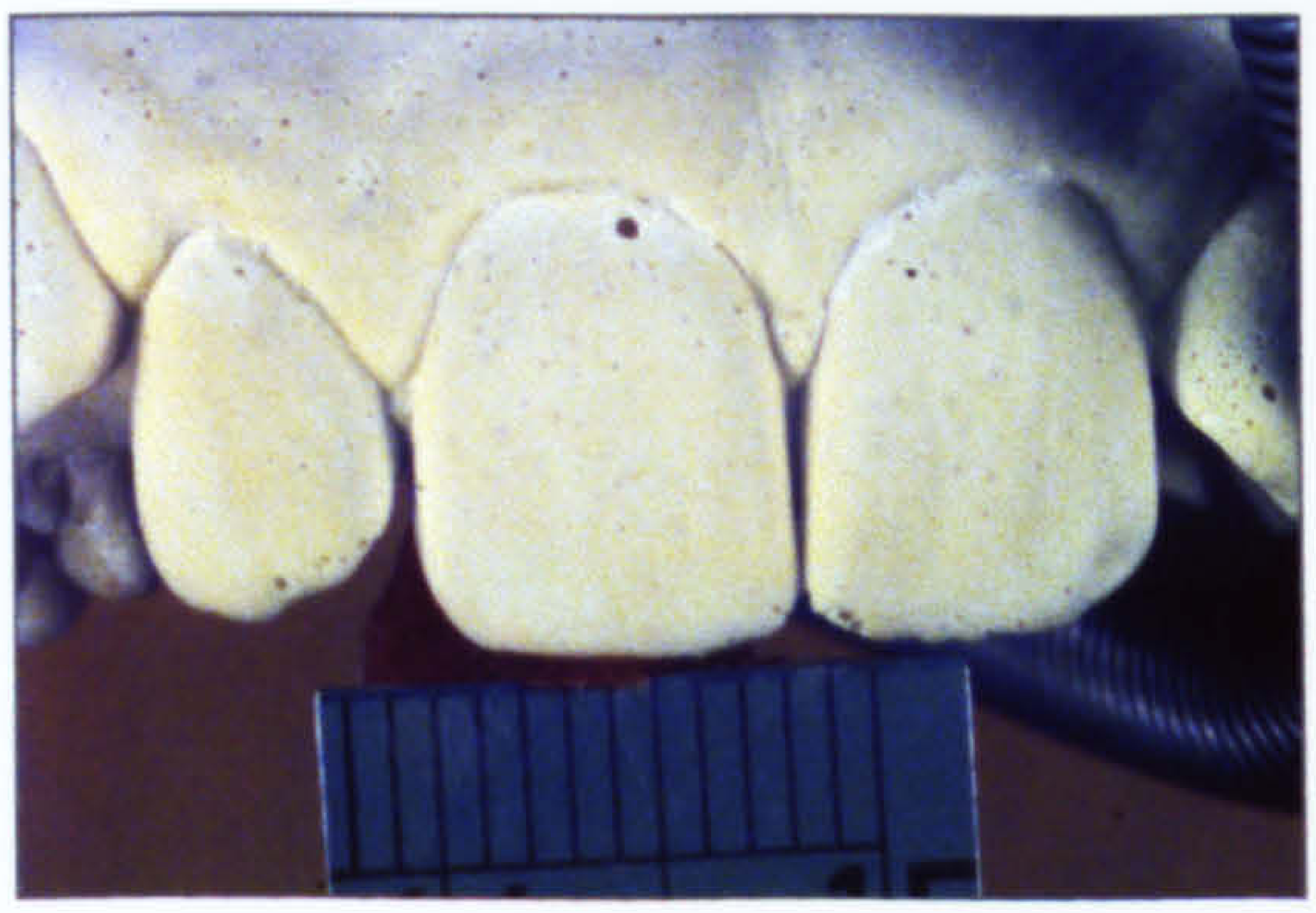


Figure 18

No taper
(0)

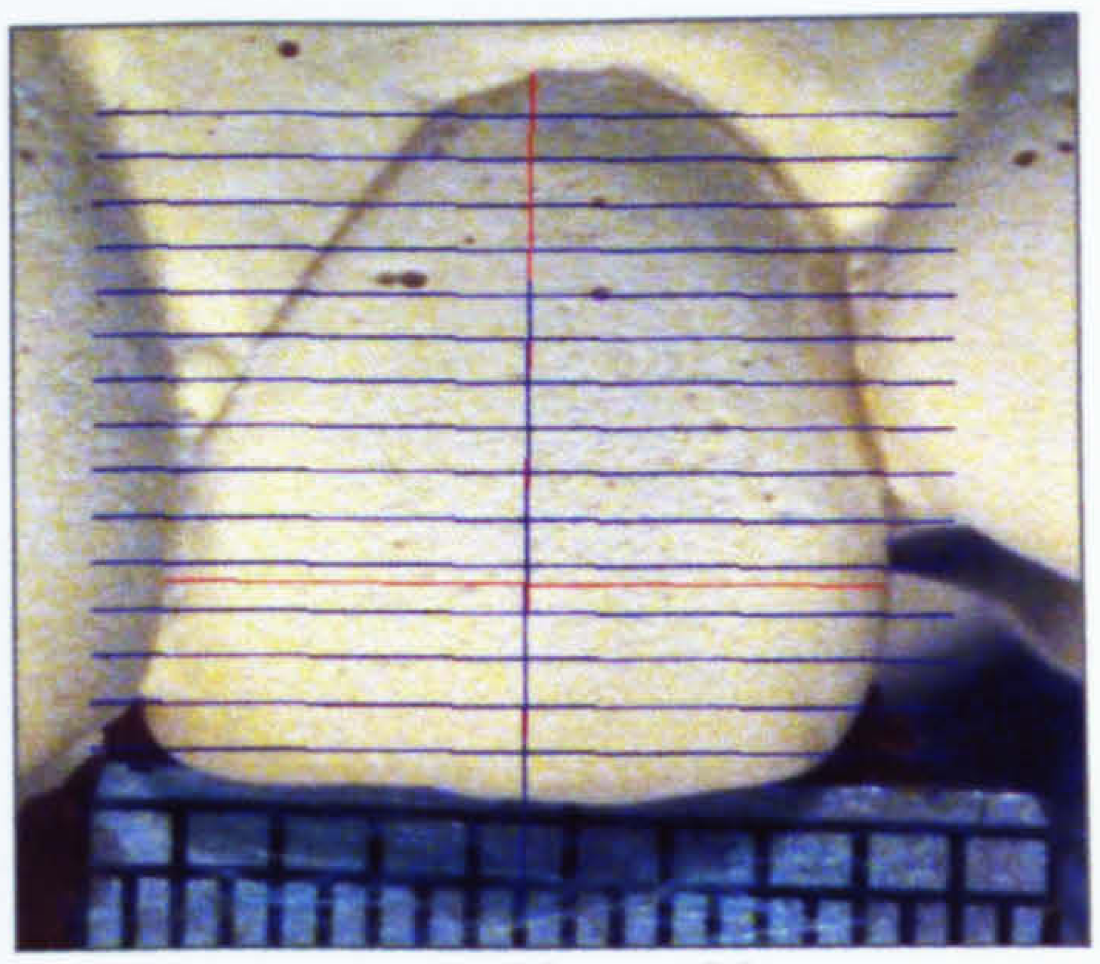


Figure 22

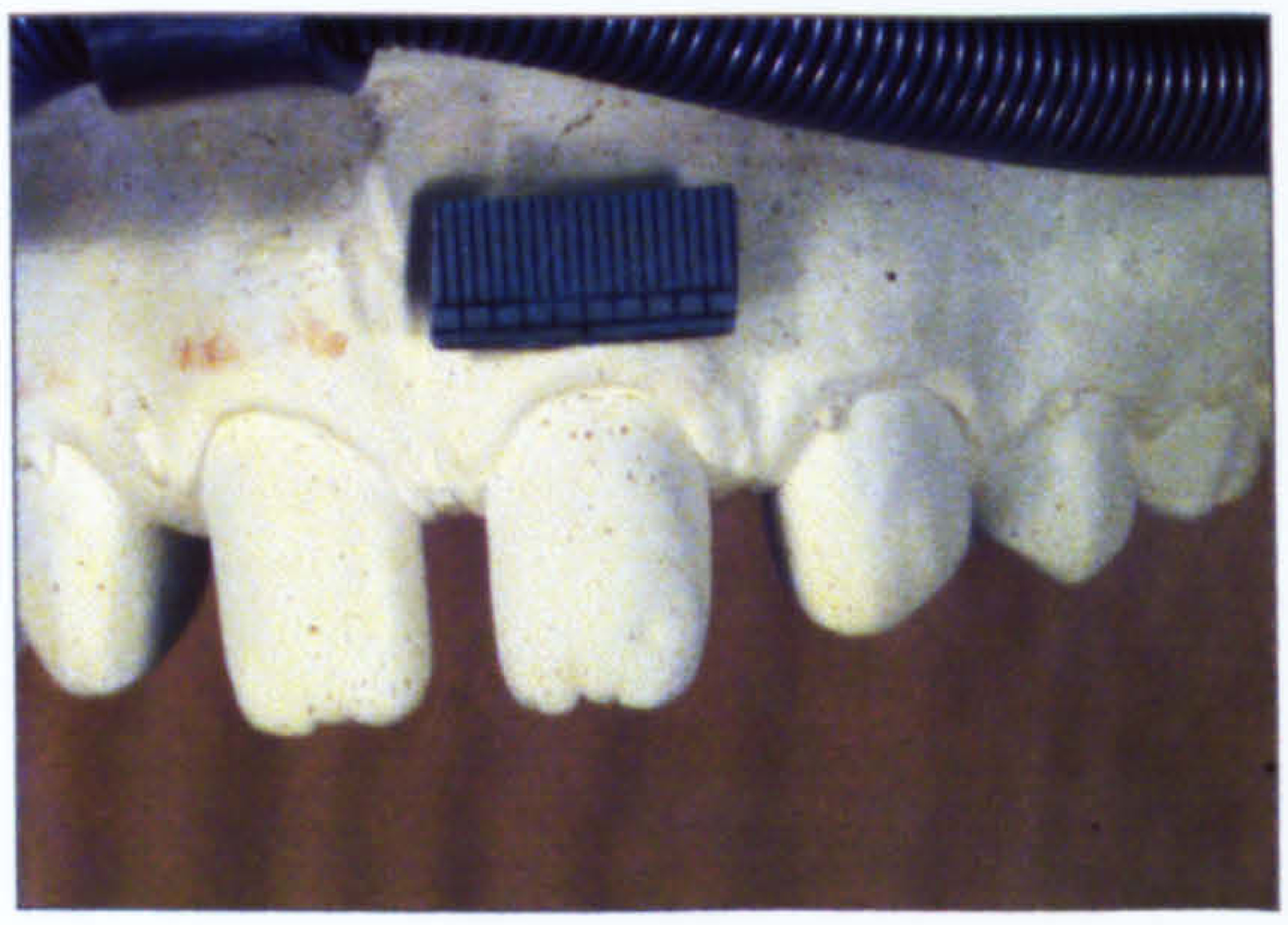


Figure 19

Mild
(1)

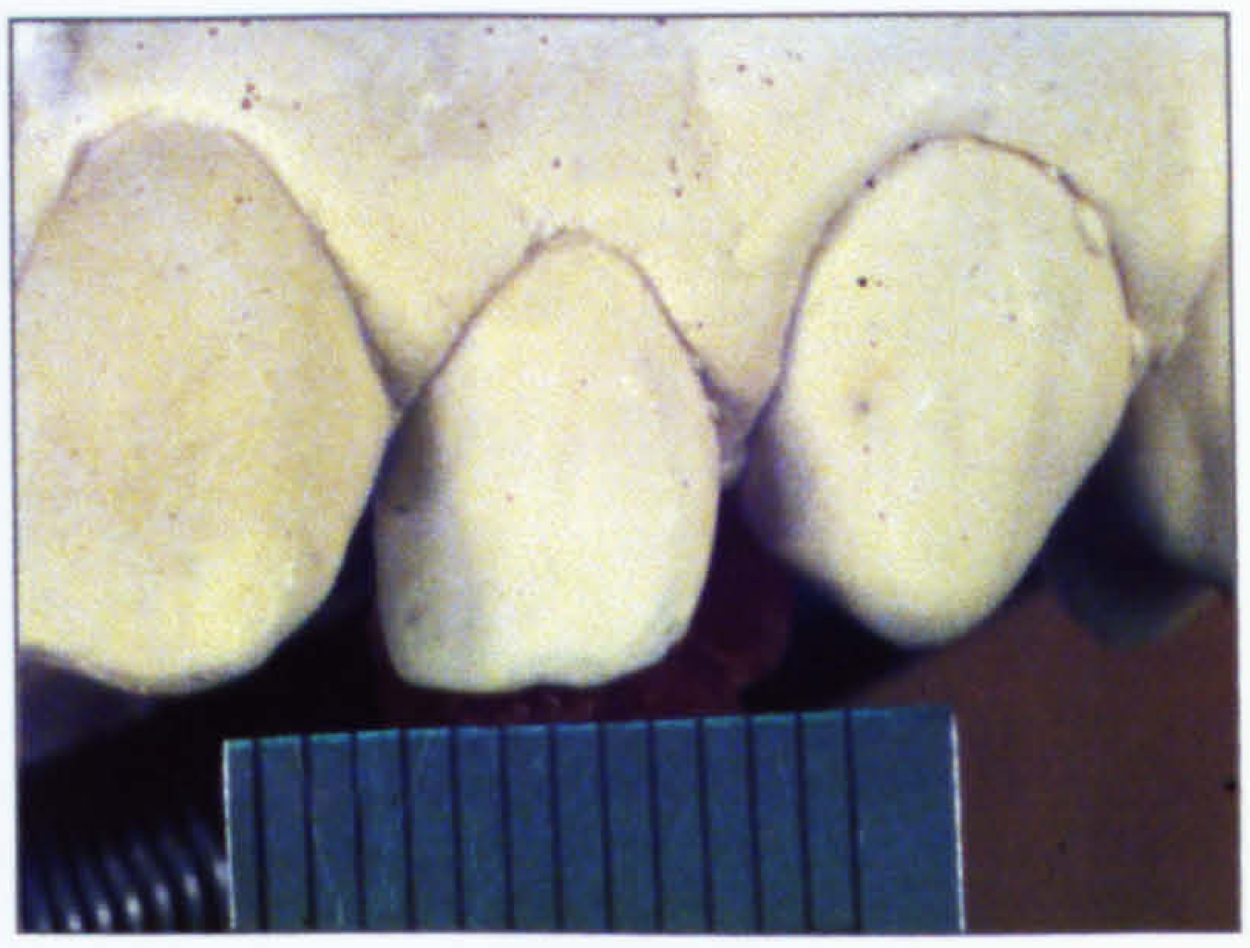


Figure 23

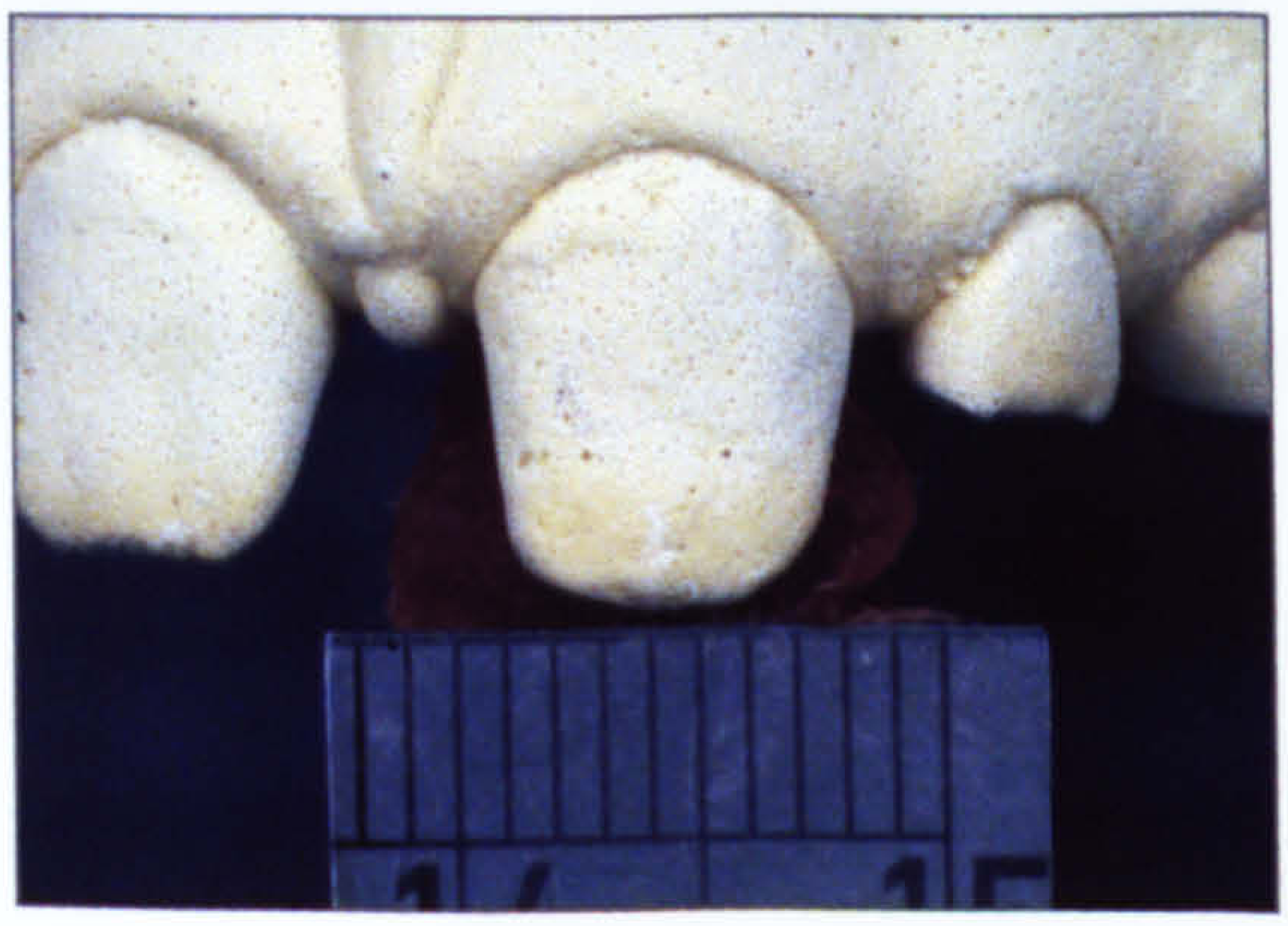


Figure 20

Moderate
(2)

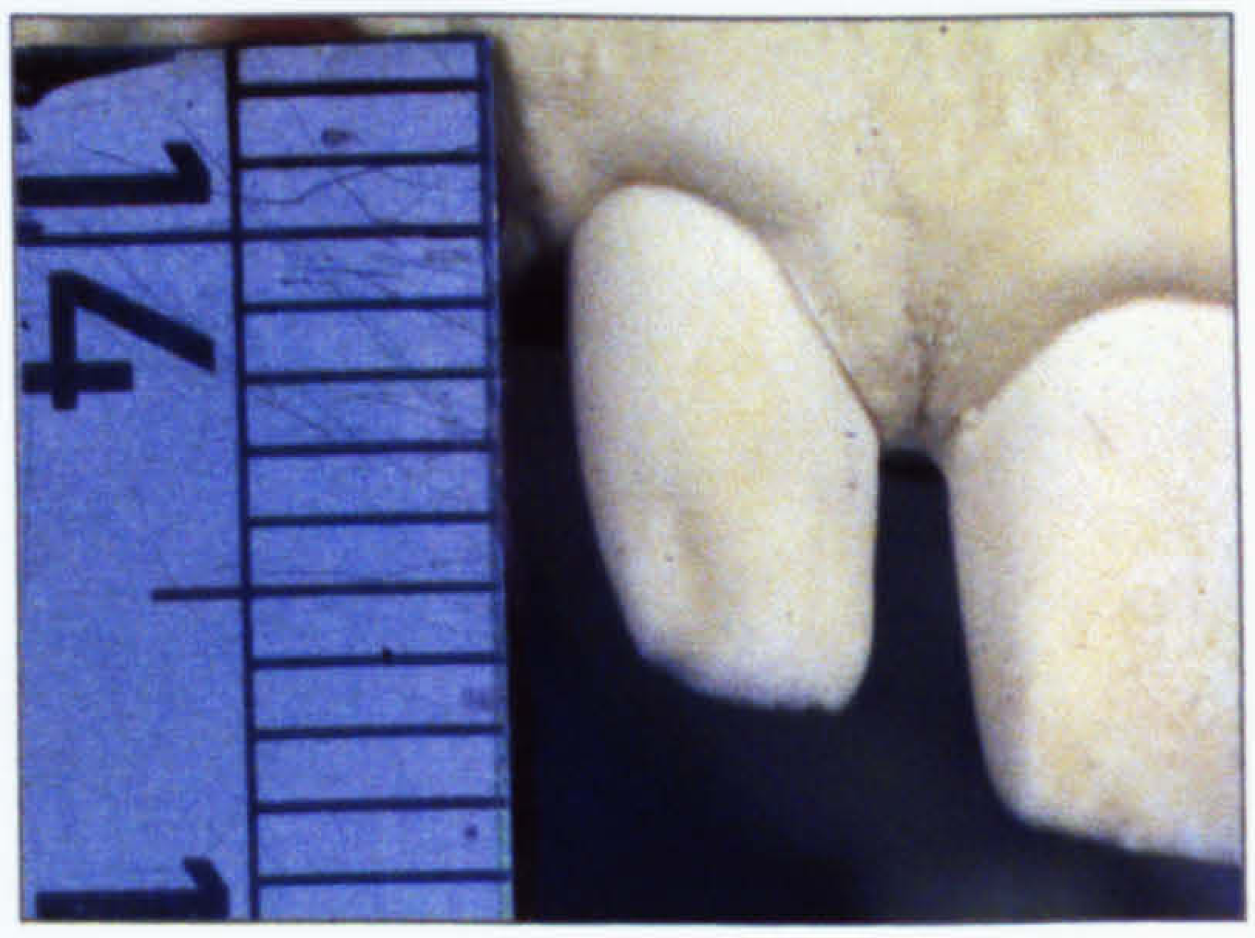


Figure 24

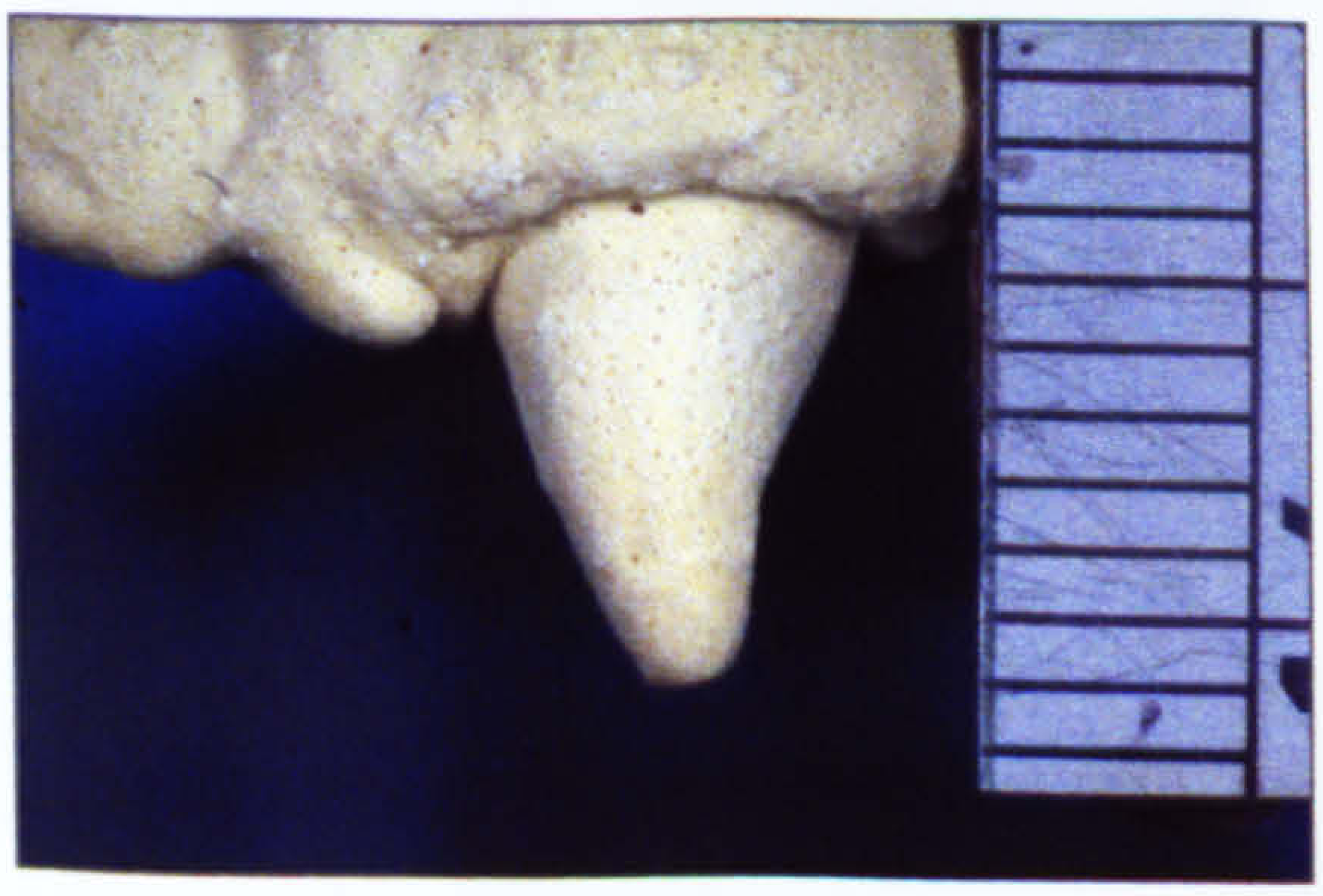


Figure 21

Severe
(3)

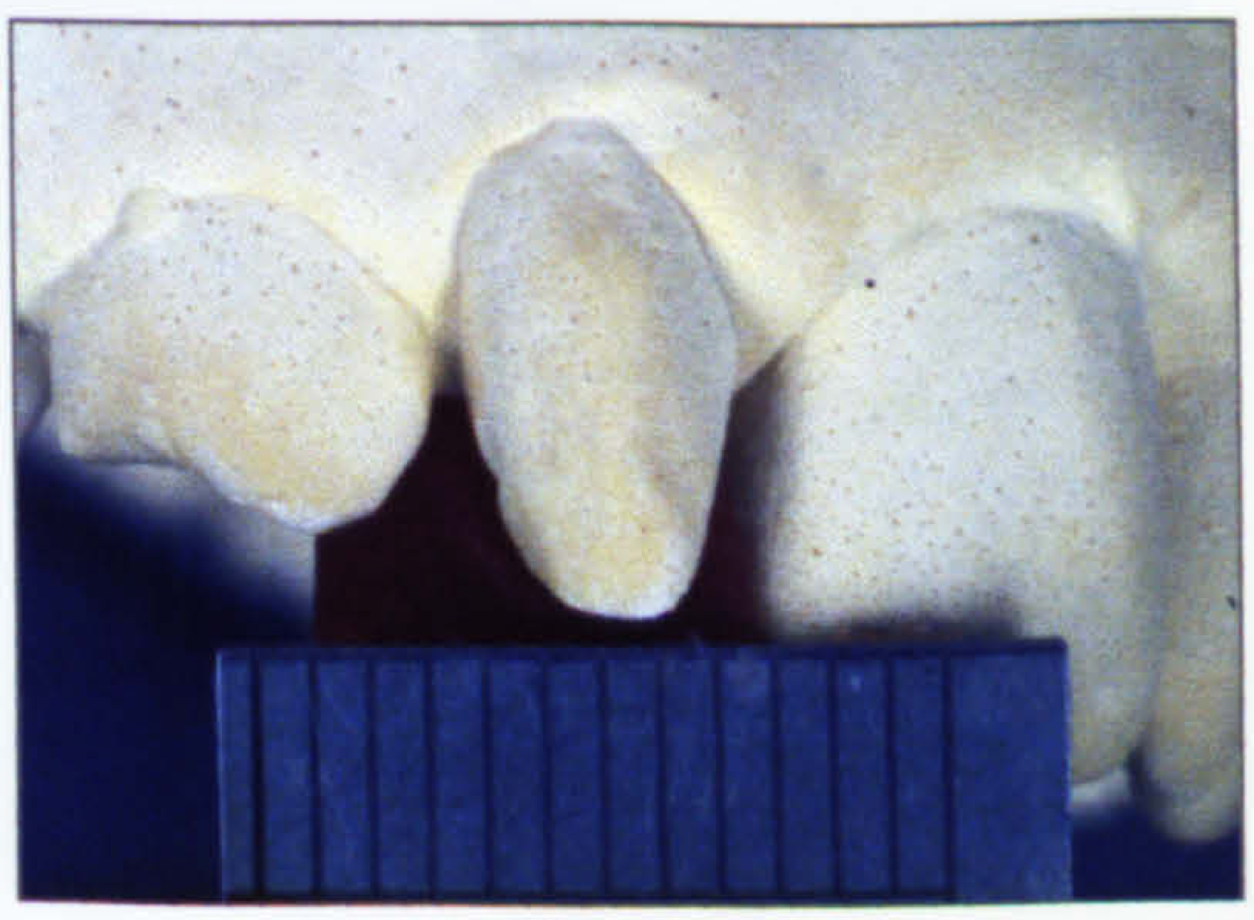


Figure 25

Figures 18-25: Subjective scoring for tooth taper suggests 0 for the normal shape, 1 for mild, 2 for moderate and 3 for severe tapering (Figures 18-21 for the central incisor and figures 22-25 for the lateral incisor teeth).

Subjective Scoring of Tooth Taper For Mandibular Incisors

Mandibular central incisor | ***Mandibular lateral incisor***

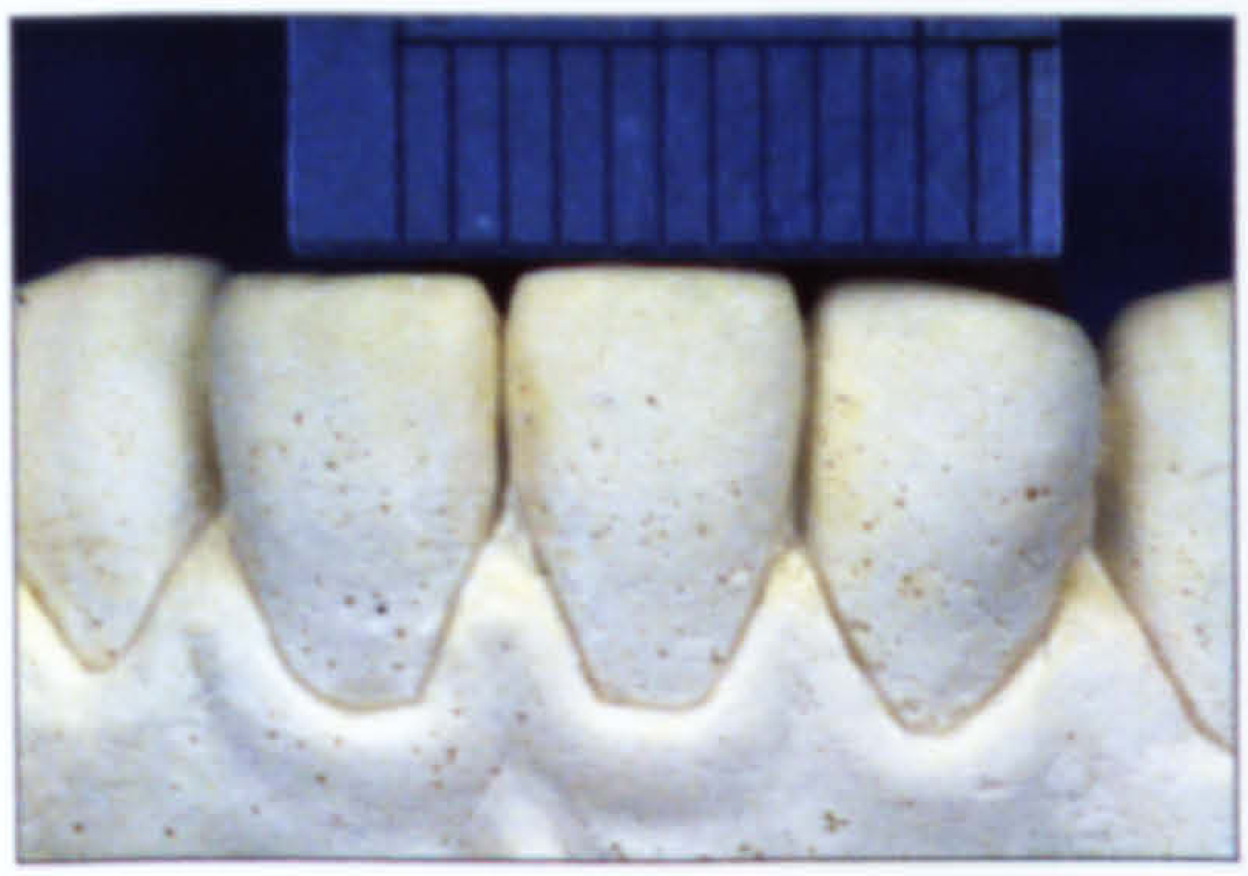


Figure 26

No taper (0)

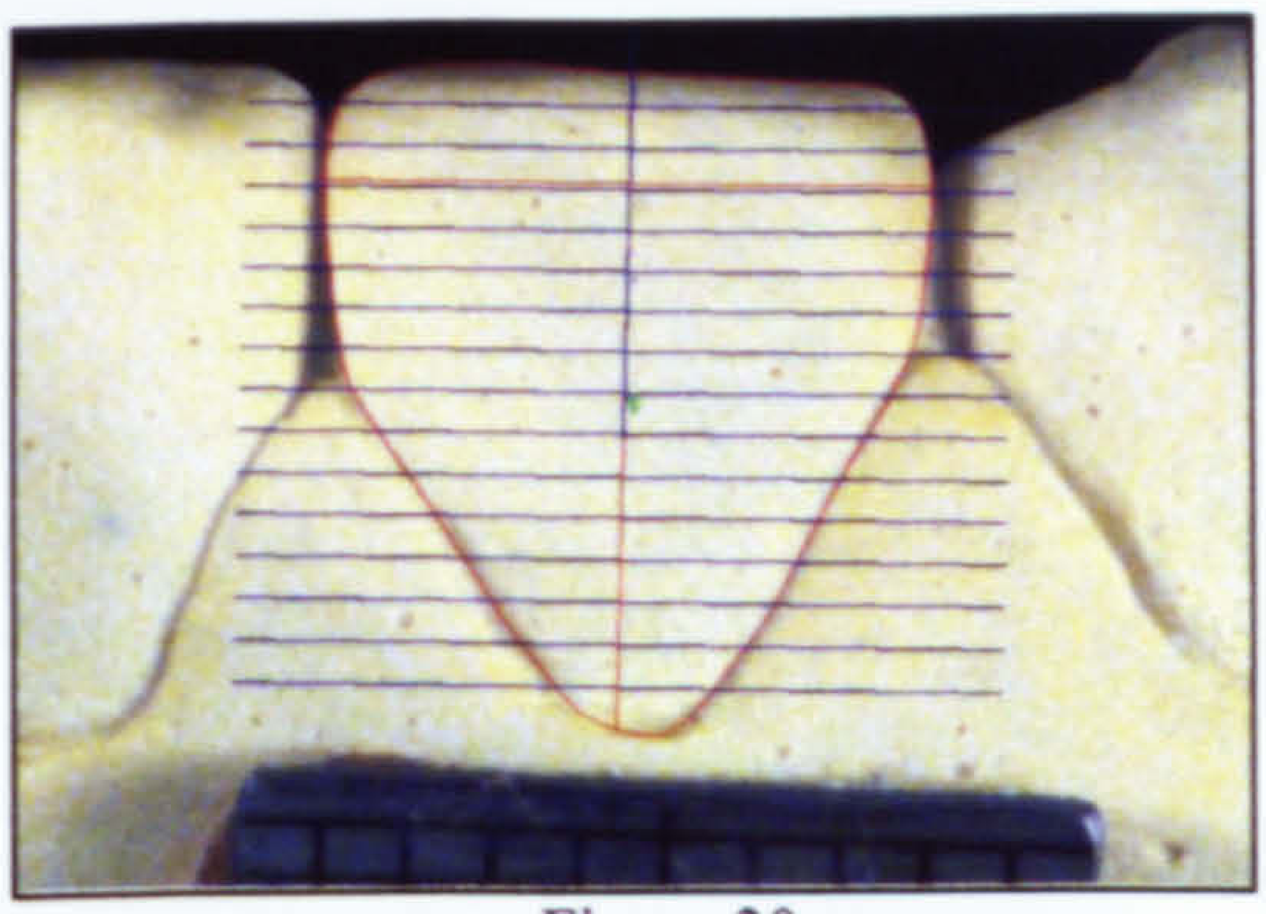


Figure 30

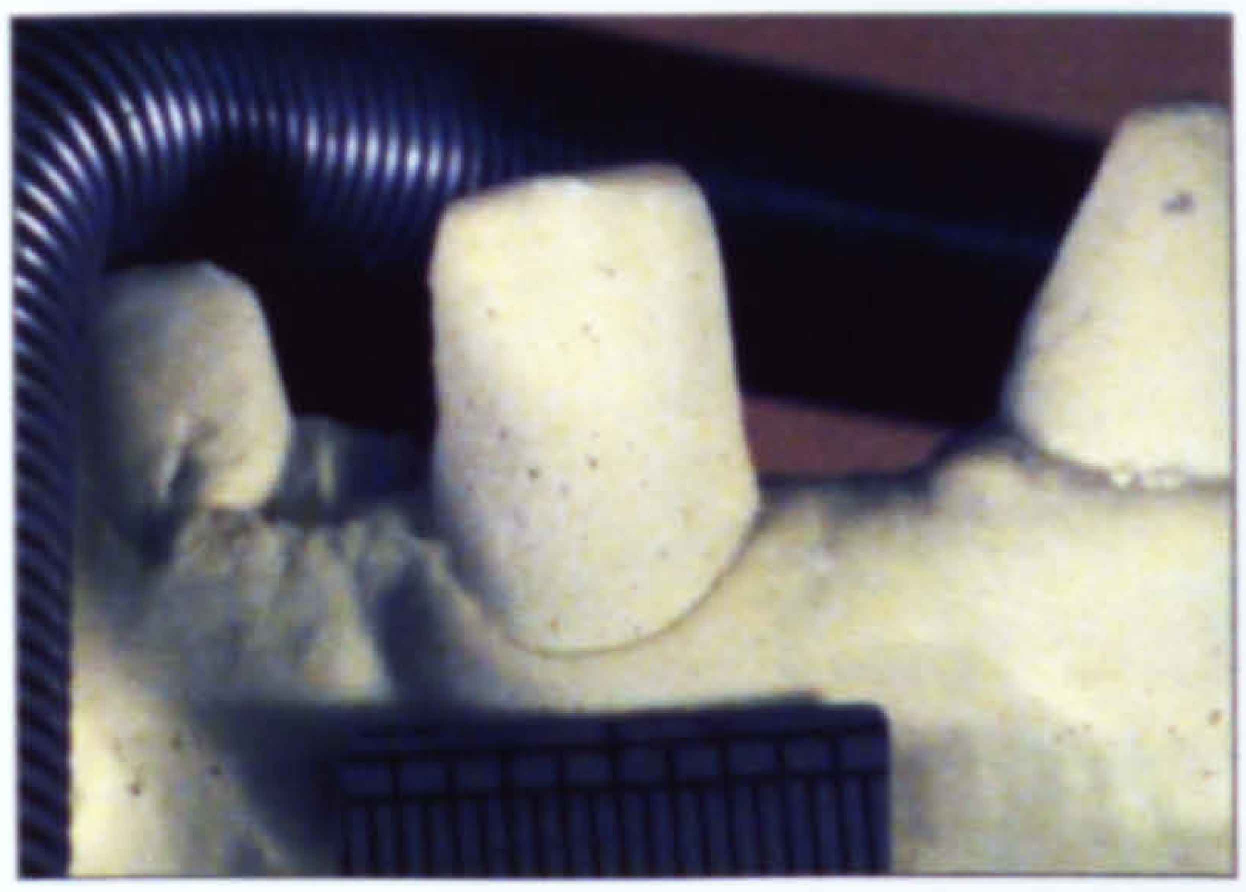


Figure 27

Mild (1)

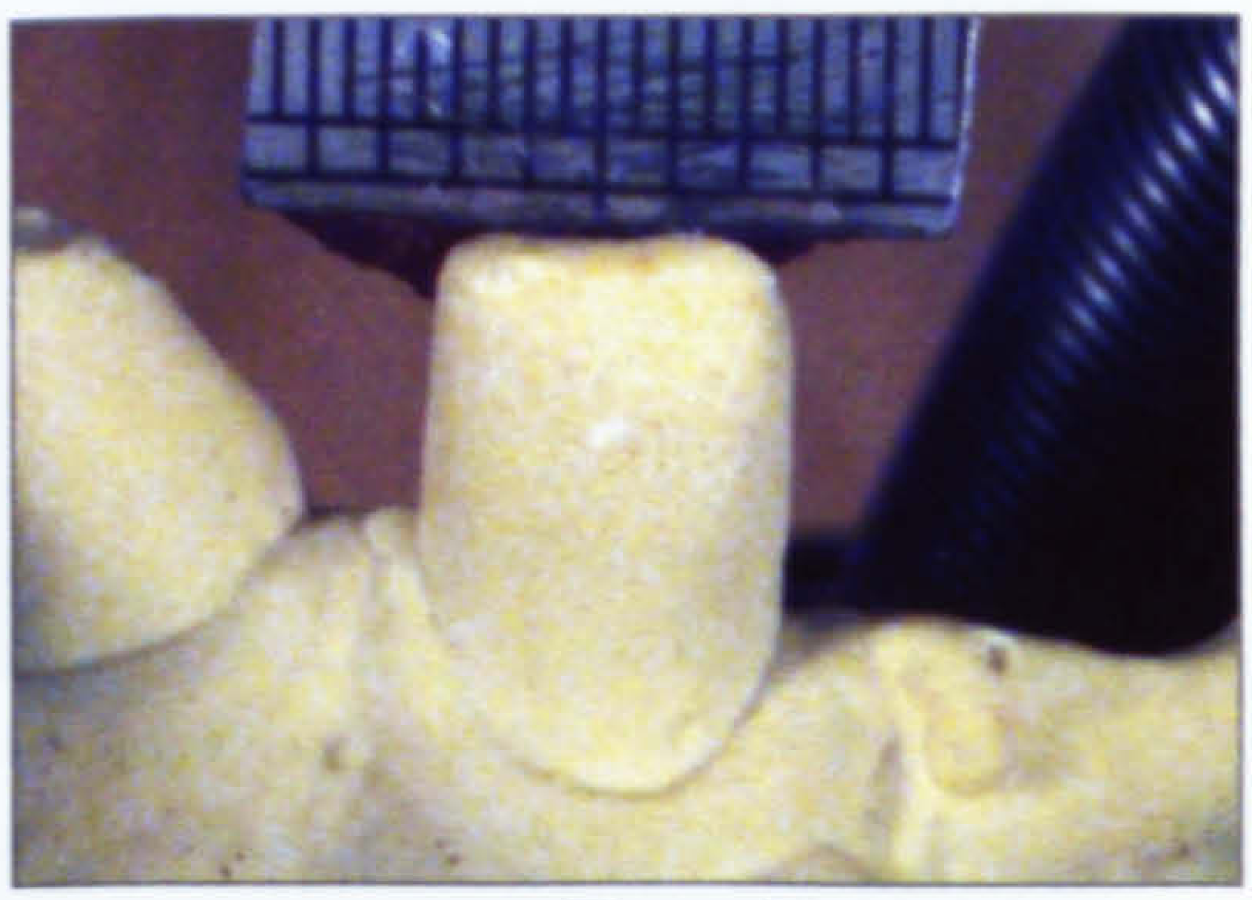


Figure 31

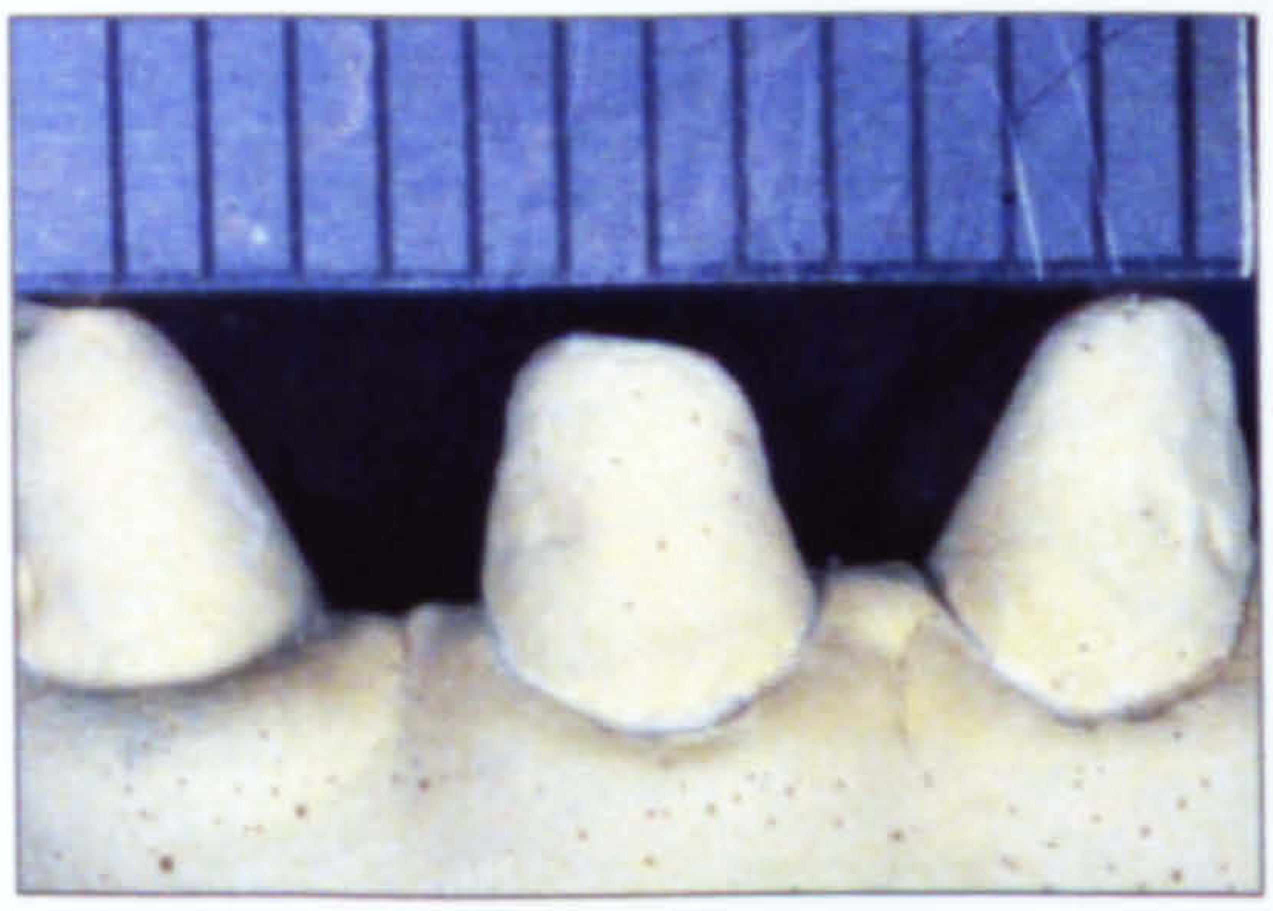


Figure 28

Moderate (2)

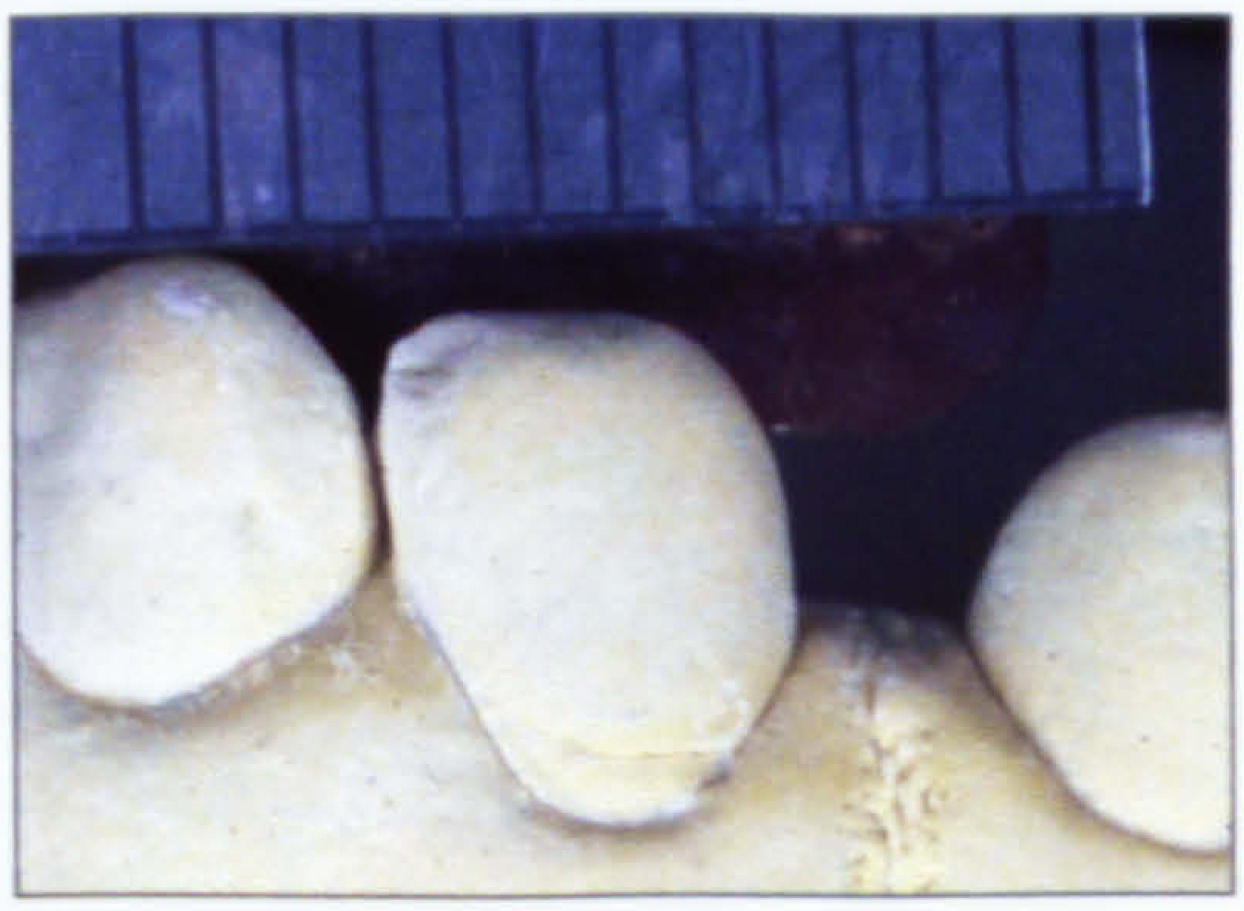


Figure 32

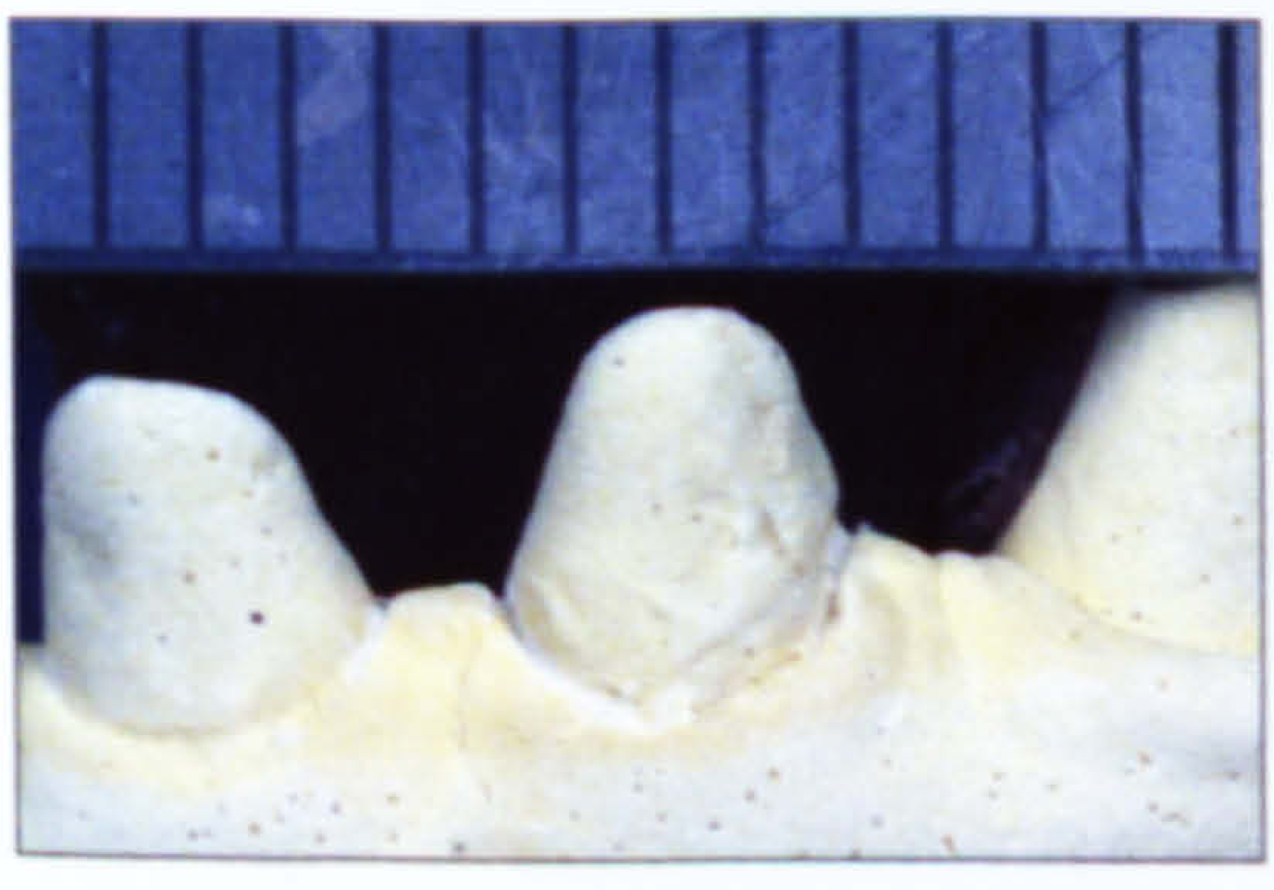


Figure 29

Severe (3)

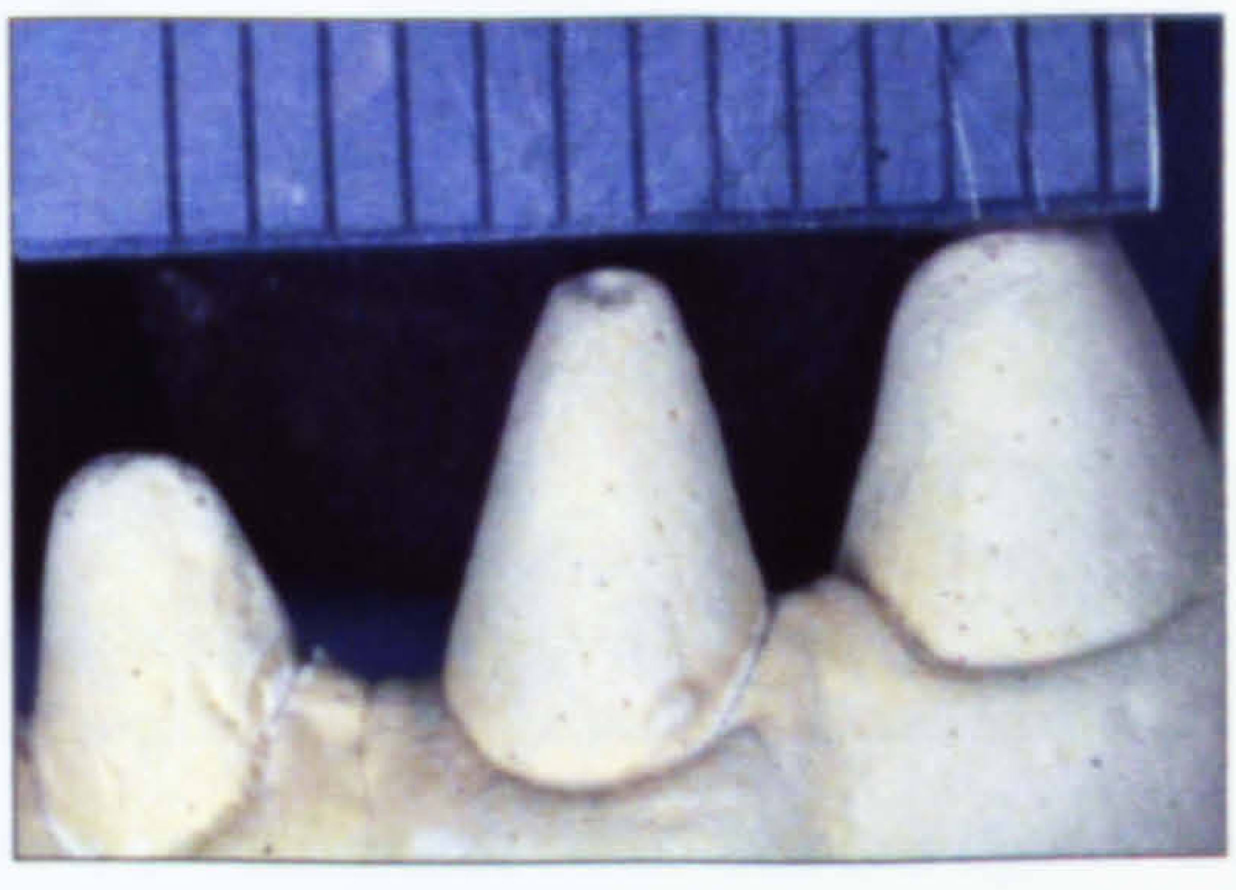


Figure 33

Figures 26-33: Subjective scoring for tooth taper suggests 0 for the normal shape, 1 for mild, 2 for moderate and 3 for severe tapering (Figures 26-29 for the central incisor and figures 30-33 for the lateral incisor teeth).

Measurement Technique of Tooth Taper Index

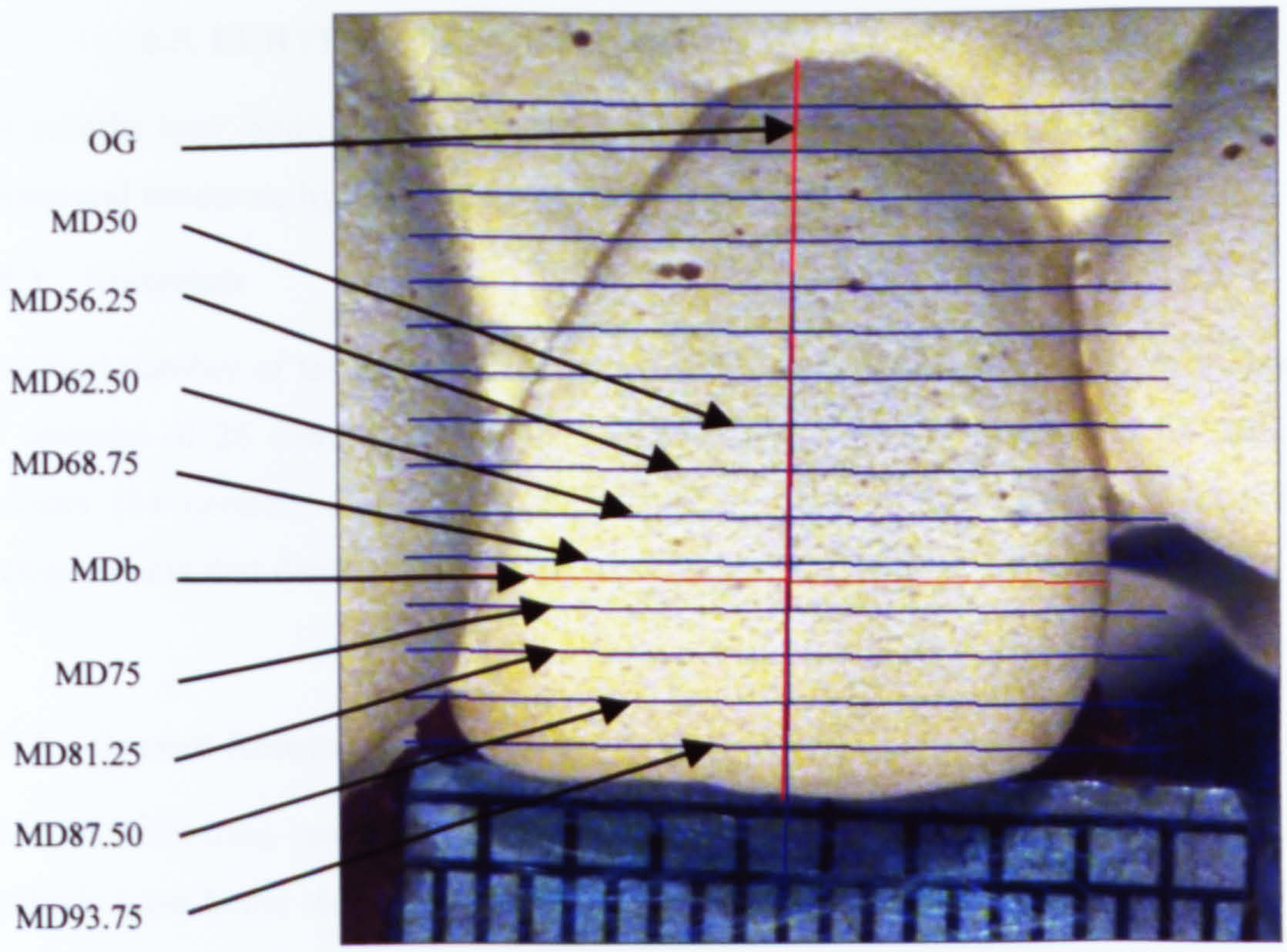


Figure 34: Taper index measurements of maxillary lateral incisor.

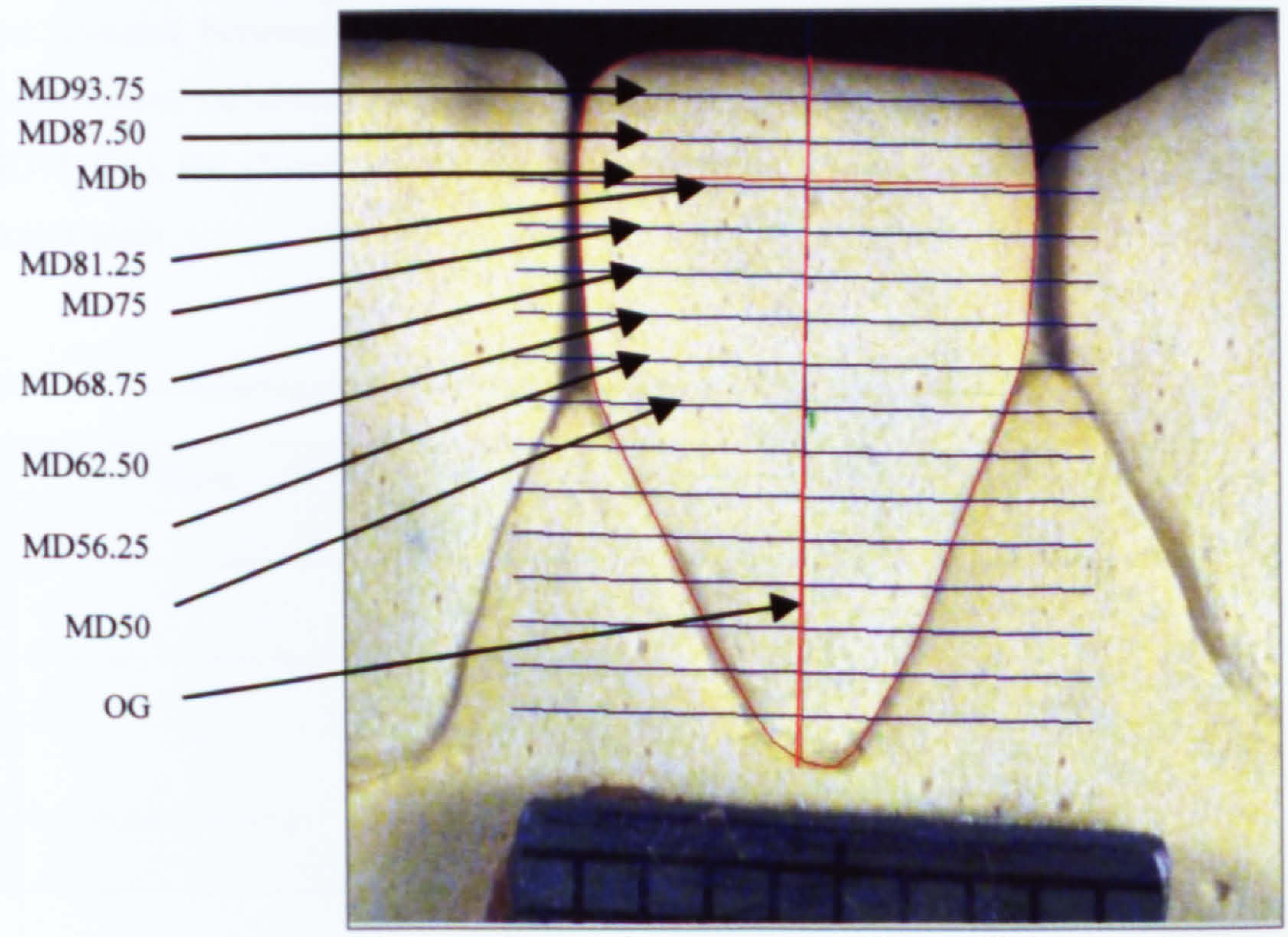


Figure 35: Taper index measurements for mandibular central incisor.

Figures 34 and 35: Measurement technique of the tooth taper index for incisor teeth. The two figures are examples for the maxillary and mandibular incisors respectively, and the measurements of tooth taper index were made by determining a series of mesiodistal dimensions at fixed proportions (6.25 percentiles) along, and perpendicular to, the occlusogingival dimension for the incisor teeth as shown in the figures. The Quantification of the degree of tapering in then made according to the ratio index: MD50/MD75.

6.5. FURTHER TEST FOR TAPER INDEX MEASUREMENT

Six months later, additional maxillary incisor teeth were investigated which demonstrated severe and moderate hypodontia scores.

6.5.1. Materials

The total number of teeth evaluated, therefore, was 94 maxillary incisors (47 centrals and 47 laterals) of 26 control and 33 hypodontia subjects in addition to the 68 mandibular incisors (34 centrals and 34 laterals). The aim was to further test the reliability of measurements that determine the tooth taper index.

6.5.2. Overall Results

The discrimination results were demonstrated in table 17 and revealed the 1st and 3rd methods were better than the 2nd method in discriminating between taper scores given by the first operator (the investigator) for upper and lower teeth. No siginificant difference was revealed between the 1st and 3rd methods. Since, the 1st method consists of two measurement variables (MD50, MD75) and the 3rd one of three measurements (MD50, MD75, Db), the 1st one was chosen in the main study to quantify the amount of taper for incisor teeth.

Table 17: Discriminating results for different methods quantifying tooth taper.

Teeth	Discrimination Success Between Taper Scores	
	Method	Success %
Maxillary Incisors (n = 94)	1	70.10
	2	58.50
	3	75.50
Mandibular Incisors (n = 68)	1	92.60
	2	85.30
	3	94.10

The success rate of discimination results revealed that the ratio 50:75 percentiles was the best method out of the three proposed methods in that it discriminates between taper grades in 92.60 and 70.10 percentages of cases for mandibular and maxillary incisors teeth respectively. The discriminate success was lower in the 2nd method while the 3rd method was as high as the 1st method according to the findings shown in table 17.

The findings of measurement repeatability (Table 18) and subjective scoring (Tables 19 and 20) revealed the same conclusion reported in pilot studies 4 and 5. A good agreement within operator and between operators was shown for subjective scoring. Those scores that did not agree obviously limit the correct discrimination percentages. In light of this subjective disagreement, the successful discriminations were still high (70.10 to 92.60%). Looking back for the scoring disagreements revealed that they occurred in borderline cases.

Table 18: Intra-observer limits of agreement results for repeatability of taper index measurements.

Variables	Maxillary Incisors		Mandibular Incisors	
	Centrals (n = 20)	Laterals (n = 20)	Centrals (n = 20)	Laterals (n = 20)
MDb	0.25	0.22	0.12	0.15
OG	0.30	0.25	0.13	0.12
Db	0.20	0.18	0.16	0.15
MD50	0.22	0.22	0.13	0.14
MD75	0.25	0.27	0.10	0.13

For each variable, the limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of the differences = +/- 50% of the limits of agreement value.

Table 19: Intra-observer Kappa statistical results for subjective agreement of taper scores.

Kappa Statistics	Maxillary Incisors (n = 94)	Mandibular Incisors (n = 68)
Standard	0.93	0.86
Weighted	0.95	0.91
Proportion Correctly Classified	0.95	0.94

Table 20: Inter-observer Kappa statistical results for subjective agreement of taper scores.

Standard Kappa Statistics For Observers	Maxillary Incisors (n = 94)	Mandibular Incisors (n = 68)
Average Standard Kappa	0.88	0.81
Average Weighted Kappa	0.95	0.87
Average Proportions Correctly Classiffied	91.50	90.20

6.5.3. Discussion

The minimum width measurement at 50 % of tooth proportion avoided the inclusion of the gingival margin as a tooth width boundary. The ratio at 50:75 percentiles had been demonstrated as the most suitable method of the three investigated to discriminate between subjective taper scores. The findings in the mandibular teeth were slightly exceeding those of the maxillary teeth to quantify the tapering of the incisor teeth.

The data analysis revealed a good intra- and inter-observer agreement for subjective taper scoring according Kappa statistics (standard and weighted kappa).

The reliability of measurements was high in both pilot studies, which further counts for validating this method. It also supports validation of the new image analysis technique in general, as it was applied on abnormal tooth shapes. However, this conclusion was based on measurements obtained by only one operator and ideally the reliability of measurements should be determined for multiple operators. The next test (section 6.6.) evaluated the method reliability for another operator.

This new method removes the need for subjective grading of tooth taper so reducing difficulties in borderline cases. Accordingly, it permits scientific comparisons in aetiological studies as hypodontia, and could aid orthodontic and restorative treatment planning.

6.5.4. Conclusion

The findings support the use of this index (ratio of 50:75 percentiles) as a new method to determine the degree of tooth taper.

6.6. MEASUREMENTS OF OTHER VARIABLES IN TAPERED TEETH

For the incisor teeth only, the measurements including the actual tooth taper index variable (MD50/MD75) as well as the remaining buccal view measurements used in the main study were further investigated. The measurements as obtained from two separate imaging occasions by the same investigator were compared. In addition, a second operator performed the measurements to allow inter-observer reproducibility evaluation.

6.6.1. Aim

To determine intra- and inter-reliability of measurements for abnormal shaped teeth and to assess if there is any specific problem associated with procedures.

6.6.2. Materials and Methods

A total of 30 teeth including maxillary lateral incisors (N = 15) and mandibular central incisors (N = 15) were re-imaged 16 months later and measured by the investigator to determine the intra-observer repeatability. Applying the same method procedure, another operator, to determine the inter-observer reproducibility, also obtained the measurements.

6.6.3. Data analysis

For the intra-observer repeatability, the intra-limits of agreement were calculated to assess measurement repeatability between 1st and 2nd imaging occasions. Whereas, both the inter-limits of agreement and the inter-class correlation coefficient (ICC) were determined for the inter-observer reproducibility. The ICC for intra-case was not utilised because the aim was to assess variations between operators; this can be achieved by the inter-class correlation coefficient.

The ICC was calculated according to the following formula:

$$\text{ICC} = \frac{\text{Variation in measurements between teeth}}{\text{Total variation in measurements}}$$

$$= \frac{\text{Variation in measurements between teeth}}{\text{Variation between teeth + Variation between operators + Variation in errors}}$$

6.6.4. Results and Discussion

Table 21 shows findings of the intra-observer limits of agreement of measurements. With the exception of the area measurements, the data generally indicates that the maxillary lateral incisors are more difficult than the mandibular central incisors to measure. This appears due to wider variation associated with the maxillary lateral incisors than the mandibular central incisor and this is confirmed by higher values of limits of agreement. Considering both maxillary and mandibular teeth, the following conclusions are made and compared to the findings of normal teeth of the same types:

For MDb and OG, the agreement values ranged between 0.29 and 036 mm and were comparable to that of normal teeth measurements, which showed a range of 0.25 to 0.46 mm respectively (Table 13).

For Db measurements, the worst figure was 0.53 mm (for the maxillary laterals) as compared to 0.37 mm for the same but normal tooth (Table 13). This suggests, in tapered teeth, the determination of the MDb location (occlusogingivally) is more difficult than the determination of its value.

For MD25, MD50 and MD75, with the exception of MD75 of Maxillary laterals (0.47 mm), the measurement agreement was ranging between 0.15 and 0.36 mm. The figures were slightly better for the mandibular tooth than the maxillary.

For taper index, the results revealed 0.05 limits of agreemens value for the mandibular central incisor and 0.12 for maxillary lateral incisor.

The perimeter demonstrated a limits range of 0.48 to 0.60 mm with better repeatability than in normal teeth (see table 13).

For the area, the repeatability was better for the maxillary teeth (1.81 mm^2) than for the mandibular (9.78 mm^2). With the exception of the area finding for the mandibular central incisor, the figures were generally better than that of normal teeth (see table 13). Clinically, the figures of these limits of agreement appear to be insignificant.

Table 21: The intra-observer limits of agreement for various buccal measurements of taperd teeth.

Variable	Maxillary Laterals (n = 15)		Mandibular Centrals (n = 15)	
	SD of differences	Limits of agreement	SD of differences	Limits of agreement
MDb	0.18	0.36	0.14	0.29
OG	0.18	0.36	0.18	0.35
Db*	0.26	0.53	0.21	0.42
MD25	0.17	0.34	0.12	0.25
MD50	0.23	0.47	0.11	0.22
MD75	0.18	0.36	0.08	0.15
Pb	0.30	0.60	0.24	0.48
Ab	0.91	1.81	4.89	9.78
Taper Index (MD50/MD75)	0.06	0.12	0.03	0.05

For each variable, the limits of agreement are +/- the figure shown and the unit is mm (for area, mm²).
SD is the standard deviation about zero.

Tables 22 and 23, on the other hand, demonstrate the findings of both inter-observer limits of agreement and inter-class correlation coefficient for maxillary lateral and mandibular lateral incior teeth respectively.

For the maxillary teeth (Table 22), the worst limits of agreement for linear measurements were for Db measurements (-1.21 and 1.40 mm for lower and upper limit respectively) and showed small mean differences (0.09 mm) but a wide standard deviation (0.65 mm). This was also revealed by a small ICC value (0.61 or 60%) when compared with rest of measurements, suggesting that to be the most difficult variable to be measured.

The OG measurements demonstrated the 2nd worst reproducibility (–1.05 and 1.75 mm respectively) but presented a quite good ICC value (0.93), suggesting a good reporducibility. The rest (MDb, MD25, MD50 and MD75) presented an overall range of -0.23 to 0.74 mm for lower limits and 0.20 to 0.64 mm for upper limits of agreement (0.91 to 0.99 for the ICC).

For the perimeter, the lower and upper limits were –1.59 and 1.64 mm respectively while the ICC value was 0.96 suggesting a good reproducibility. A similar conclusion was also found for area measurements (-1.93 and 3.86 mm^2 for lower and upper limits of agreement and 0.98 for ICC).

Table 22: The inter-observer limits of agreement and inter-class correlation coefficient for various buccal measurements of maxillary lateral inciors.

Variable	Inter-limits of agreement for U2 (n = 15)				ICC
	Mean difference	SD of differences	Lower limit	Upper limit	
MDb	0.12	0.26	-0.41	0.64	0.95
OG	0.35	0.70	-1.05	1.75	0.93
Db*	0.09	0.65	-1.21	1.40	0.61
MD25	-0.10	0.32	-0.74	0.54	0.91
MD50	0.08	0.27	-0.46	0.63	0.95
MD75	-0.02	0.11	-0.23	0.20	0.99
Pb	0.02	0.81	-1.59	1.64	0.96
Ab	0.97	1.45	-1.93	3.86	0.98
Taper Index (MD50/MD75)	0.03	0.07	-0.11	0.16	0.81

SD is the standard deviation about the mean difference.

Table 23: The inter-observer limits of agreement and inter-class correlation coefficient for various buccal measurements of mandibular central inciors.

Variable	Inter-limits of agreement for L1 (n = 15)				ICC
	Mean difference	SD of differences	Lower limit	Upper limit	
MDb	0.06	0.28	-0.49	0.61	0.93
OG	0.06	0.61	-1.15	1.28	0.88
Db*	-0.17	0.92	-2.01	1.67	0.78
MD25	-0.06	0.17	-0.40	0.28	0.98
MD50	-0.10	0.11	-0.32	0.12	0.98
MD75	-0.02	0.14	-0.29	0.25	0.99
Pb	-0.17	0.62	-1.40	1.06	0.98
Ab	1.14	4.82	-8.50	10.78	0.82
Taper Index (MD50/MD75)	-0.01	0.03	-0.08	0.05	0.97

* *SD is the standard deviation about the mean difference.*

For the mandibular teeth (Table 23), the overall figures were slightly better than those for the maxillary teeth. The following linear measurements (MDb, MD25, MD50 and MD75) demonstrated a range of -0.29 to 0.49 mm for the lower limits and 0.12 and 0.61 mm for the upper limits respectively (the range was 0.93 to 0.99 for the ICC). The worst figures were for Db measurements (-2.01 and 1.67 mm for lower and upper limit respectively). However, it showed a better ICC-value of 0.78 as compared to 0.61 for the maxillary teeth. Again, the OG measurements demonstrated the 2nd worst reproducibility (−1.15 and 1.28 mm respectively), although the ICC value was high (0.88) suggesting a good reproducibility.

For tooth taper index measurement, the upper and lower limits of agreement were 0.05 and – 0.08 respectively and ICC assessment was 0.97.

For the perimeter, the reproducibility was quite good (the lower and upper limits were -1.40 and 1.06 mm respectively while the ICC value was 0.98). For area measurements, the results were −8.50 and 10.78 mm^2 for the lower and upper limits of agreement and 0.82 for ICC with acceptable overall measurements.

6.6.5. Conclusions

Reproducibility of measurements for maxillary lateral incisor and mandibular central incisor teeth with abnormal morphology was determined for intra- and inter-operator assessments and the findings revealed the following conclusions:

1. An overall similar measurement reliability for these teeth to normal teeth.
2. Comparable measurement reliability for teeth with normal and tapered morphology of the same tooth types. The perimeter and area showed better repeatability than that in normal teeth.
3. Reliability of measurements for tooth taper index value was high. This, further support the use of the method as well as the technique in main study.

Chapter 7

Results

7.1. DISTRIBUTION OF STUDY POPULATION

The following describes the distributions of hypodontia and control subjects involved in the study. The patterns of tooth absence in the study sample subjects are also described according to two variables; the severity and location of tooth missing.

7.1.1. Sample Size and Subdivisions

The study sample subdivision frequencies are described in table 24. The table shows that the groups and subgroups are matched for frequency (40 subjects for each group and 20 subjects for each subgroup). Female severe hypodontia subgroup involves an extra case than the others (N = 21), therefore, 41 subjects represent the severe hypodontia group.

Table 24: The number and subdivisions of study subjects.

Gender	Controls	Mild Hypodontia	Moderate Hypodontia	Severe Hypodontia	Total
Males	20	20	20	20	80
Females	20	20	20	21	81
Total	40	40	40	41	161

7.1.2. Age Distribution

The age distribution of study sample is presented in table 25. The range, mean and standard deviation were calculated for each subgroup and group as well as the totals. All the ages demonstrated here were obtained according to the dates of the pretreatment impressions of subject dentitions. The table shows that the groups and subgoups were similarly distributed for age means ranging between 14 to 14.45 years and 13.47 to 14.79 years respectively. The findings of standard deviations, on the other hand indicate differences for groups and subgroups of 1.36 to 4.82 years and 1.15 to 4.94 years respectively, the moderate and severe hypodontia groups demonstrating the widest standard deviations. The overall minimium, maximum, mean and standard deviation of the study sample to be 9.58, 34, 14.24 years and 2.99 years respectively.

Table 25: The age distribution of study subjects.

Gender	Ages	Controls	Mild Hypodontia	Moderate Hypodontia	Severe Hypodontia
Males	Minimum	12.08	11.75	9.58	9.67
	Maximum	16.58	18.42	32.17	23.33
	Mean	14.51	14.62	14.70	14.79
	SD	1.15	1.60	4.94	2.80
Females	Minimum	11.50	12.08	10.58	10.50
	Maximum	17.42	18.00	34.00	25.00
	Mean	13.49	14.15	14.20	13.47
	SD	1.39	1.52	4.81	3.11
Group Total	Minimum	11.50	11.75	9.58	9.67
	Maximum	17.42	18.42	34.00	25.00
	Mean	14.00	14.38	14.45	14.11
	SD	1.36	1.56	4.82	3.00
Overall Total	Minimum	9.58			
	Maximum	34.00			
	Mean	14.24			
	DS	2.99			

All ages are in years. SD = Standard deviation.

7.1.3. Distribution According to Severity of Hypodontia

Table 26 demonstrates the detail of the frequency of different tooth absence patterns in male and female subjests. The findings revealed a similar distribution for mild and moderate hypodontia subgroups as compared with severe subgroups. Male subjects have not shown the absence of 9, 13, 16, 18 or 19 teeth as females. Females, on the other hand, have not shown the absence of 10, 11, 12 or 21 teeth as males.

7.1.4. Distribution According to Locations of Hypodontia

The distribuation of the subjects according to tooth types affected by hypodontia is shown in table 27. Each subject may be found in more than one tooth absence type. The commonest three tooth types affected by congenital tooth absence were maxillary lateral incisors and the maxillary and mandibular 2nd premolars.

Table 26: Frequency of hypodontia subjects according to the severity of tooth absence.

Group	Tooth absence	Frequency in males		Frequency in females	
	No.	*No.*	*%*	*No.*	*%*
Mild hypodontia	1	8	40	7	35
	2	12	60	13	65
Moderate hypodontia	3	8	40	7	35
	4	7	35	9	45
	5	5	25	4	20
Severe hypodontia	6	3	15	3	15
	7	4	20	5	25
	8	2	10	3	15
	9	0	0	2	10
	10	3	15	0	0
	11	3	15	0	0
	12	2	10	0	0
	13	0	0	2	10
	14	1	5	2	10
	15	1	5	1	5
	16	0	0	1	5
	17	0	0	0	0
	18	0	0	1	5
	19	0	0	1	5
	20	0	0	0	0
	21	1	5	0	0

Table 27: Frequency of hypodontia subjects according to the location of tooth absence.

Absent tooth	Mild Hypodontia		Moderate Hypodontia		Severe Hypodontia	
	Male	*Female*	*Male*	*Female*	*Male*	*Female*
U1			1		1	
U2	16	11	13	7	13	16
U3			4	1	12	5
U4			3	2	10	14
U5		2	8	15	14	21
U6					2	4
U7				1	10	6
L1		3	3	4	11	10
L2					6	7
L3					4	2
L4				2	9	9
L5	4	6	9	14	16	20
L6					1	3
L7		1	1	3	11	7
Total of absence types	2	5	8	9	14	13

7.2. COMBINING RIGHT AND LEFT MEASUREMENTS

The aim was to decide whether to use the average of bilateral measurements in the main analysis or to analyse them independently (discussed earlier in section 4.5.1.). The ICC of each measurement variable, in all tooth types, was calculated to assess the information lost by averaging right and left measurements, according to the formula (1-R). The bigger the ICC-value, the smaller the information lost. The ICC-values (%) were determined for all buccal and occlusal measurement variables:

7.2.1. Buccal Variables

The findings of buccal view variables are shown in tables 28 and 29 for maxillary and mandibular teeth, respectively. For tooth taper and Db the ICC figures were small suggesting keeping separate bilateral measurements in the main anlaysis. For Pb of U7, CIBM1 of U6 and CIBM2 of U7 and L6 the figures (59, 58, 58 and 57% respectively) were considered acceptable, as the rest of variables, to combine bilateral measurements and use their averages.

7.2.2. Occlusal Variables

The results of occlusal view variables for maxillary and mandibular teeth are demonstrated on tables 30 and 31, respectively. For CIOM2 and Do the ICC figures were small suggesting separating bilateral measurements in the main anlaysis. For CIOM1 of U4, U7, L5 and L7 the figures (58, 58, 59 and 57% respectively) were considered acceptable, as the rest of variables, to combine bilateral measurements and use their averages.

Table 28: The assessment results of combining bilateral measurements for buccal variables of upper teeth. All these ICC-values are in %.

Variable	U1	U2	U3	U4	U5	U6	U7
MDb	94	93	94	91	90	83	73
OG	88	77	83	82	65	71	66
Pb	95	90	89	89	77	82	59*
Ab	94	90	92	90	73	83	62
Db	71	46*	71	50*	39*	50*	56*
CIBM1	81	76	70	65	68	58*	61
CIBM2	78	68	68	60	62	64	58*
MD25	75	71					
MD50	91	91					
MD75	89	93					
Taper	22*	57*					

* *Suggests separating right and left sides in the main analysis, U = Upper.*

Table 29: The assessment results of combining bilateral measurements for buccal variables of lower teeth. All these ICC-values are in %.

Variable	L1	L2	L3	L4	L5	L6	L7
MDb	86	90	92	93	88	88	82
OG	88	82	87	77	78	74	64
Pb	91	90	91	87	92	84	80
Ab	88	89	92	88	89	82	72
Db	54*	60	66	63	65	52*	65
CIBM1	80	73	78	68	69	65	64
CIBM2	63	72	65	64	70	57*	68
MD25	62	68					
MD50	71	80					
MD75	81	89					
Taper	56*	53*					

* *Suggests separating right and left sides in the main analysis, L = Lower.*

Table 30: The assessment results of combining bilateral measurements for occlusal variables of upper teeth. All these ICC-values are in %.

Variable	U1	U2	U3	U4	U5	U6	U7
MDo	95	94	93	87	92	85	77
BL	91	90	92	94	94	88	79
Po	97	95	95	95	95	88	85
Ao	97	95	94	91	95	93	82
Do	62	55*	59*	73	74	54*	64
CIOM1	79	66	80	58*	73	68	58*
CIOM2	49*	4*	15*	53*	59*	33*	55*
BLm						85	75
BLd						83	73

** Suggests separating right and left sides in the main analysis, U = Upper.*

Table 31: The assessment results of combining bilateral measurements for occlusal variables of lower teeth. All these ICC-values are in %.

Variable	L1	L2	L3	L4	L5	L6	L7
MDo	92	93	90	91	90	89	92
BL	86	86	89	91	94	86	79
Po	94	94	95	94	97	94	90
Ao	95	94	94	93	96	93	91
Do	69	55*	53*	55*	68	58*	31*
CIOM1	70	72	73	76	59*	62	57*
CIOM2	60	40*	33*	36*	57*	19*	28*
BLm						81	81
BLd						80	76

** Suggests separating right and left sides in the main analysis, L = Lower.*

Summary of combining right and left measurements

Assessment of the amount of information lost by combining bilateral measurements revealed:

1) *High ICC-values for most of measurement variables. This suggests using the average in the main analysis, after combining the right and left measurements.*
2) *Four variables demonstrated low ICC-values in most of the teeth that suggested separating the bilateral measurements to perform their main analysis (buccally: tooth taper and Db and occlusally: the Do and CIOM2 variables).*

7.3. MAIN STUDY FINDINGS

7.3.1. Presentation of Findings

The effect of the two independent factors, the severity of hypodontia and gender, on each dependent measurement variable was statistically analysed using the two-way ANOVA. Measurements of eleven buccal and nine occlusal variables were obtained and analysed for different teeth. There are 266 variables in total in this dataset.

Since the study investigates multiple measurement variables of different teeth, one variable (tooth taper) has been chosen, as an example, to demonstrate various interpretations of the statistical results with more detail.

For the rest of variables, the focus will be directed to the main findings. Plots for significant subgroup interactions and summary tables are also presented. Descriptive and comparative figures are all tabulated in appendices 1-19, for reference when details are required. Two and three decimal places were used to present all descriptive figures and p-values respectively.

Because Bonferroni adjustment of 266 variables is very conservative, all the corrected p-value figures that are $P2 \leq 0.10$ are considered as the main conclusive findings (reported as bold and underlined text) and are discussed in detail. On the other hand, originally significant p-values that are $P1 \leq 0.00375$ are also considered, in light of the conservative adjustment, as secondary conclusions (reported as bold text) since final adjusted p-values will still be $P2 < 1$ after multiplying by 266. Whereas, other significant findings that did not retain significance after final adjustments ($P2 \geq 1$) are reported briefly and p-values are quoted as $P2 = 1$, the reader is therefore asked to refer to tables of the appendices for statistical details.

7.3.2. Tooth Taper Findings *(Pilot study 6)*

{Tooth-taper in Hypodontia and control subjects. Al-Sharood M H, Robinson D, Elcock C and Brook A H (2000). Presented at the BSDR meeting, Lancaster, April 2000, Abstract No. 068}

This variable is related to the incisor teeth only. Bilateral teeth were tested separately according to the conclusions of the ICC assessment. Thus, eight maxillary and mandibular incisor teeth were individually considered.

7.3.2.1. Tooth 11 (Maxillary right central incisor)

The descriptive and comparative data were demonstrated in tables 32-34. Two-way plots (Figures 36 and 37) convey this information and provide a visual comparison between groups and genders. There is a suggested general trend in tapering with severe hypodontia group > moderate > mild and control groups. Each point indicates the estimated mean of tooth taper for each subgroup. Figure 36 shows comparisons between gender at different severities and figure 37 compares severity within genders.

Two-way ANOVA reveals significant interaction (P = 0.075) between severity groups and genders, indicating that differences between groups were different for males and females and also evident on 2-way plots. Comparisons between groups must therefore consider males and females separately. Multi-subgroup comparison tests (P1) suggest significant differences between the female severe hypodontia subgroup and the other three female subgroups (see table 34). But, only two of these remained significant after final adjustment of significance levels (P2), to allow for multiple comparisons. These were between severe subgroup and the control (P2 = 0.003) and mild (P2 = 0.001). For the difference between severe and modertae subgroups, P2 = 0.475. **Thus, in females, the mean of tooth taper value in severe hypodontia group was found to be larger than the control mean and mild hypodontia mean.** **There was some evidence of a difference with the moderate group as well (since P1 = 0.002 and P2 = 0.475).**

The differences between tooth taper mean in female severe hypodontia group (1.04) and control mean (0.99) is 0.05 and with mild hypodontia mean (0.98) is 0.06 (Table 34). See tables 32 and 33 for other descriptive and comparative figures.

Descriptive data (Table 32) suggests a similar pattern for the males although the differences between groups were not significant.

Table 32: Descriptive statistics of tooth taper for tooth 11.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	1.00	0.03	20
	Female	0.99	0.02	19
	Total	0.99	0.02	39
Mild hypodontia	Male	0.99	0.03	18
	Female	0.98	0.04	20
	Total	0.98	0.03	38
Moderate hypodontia	Male	0.99	0.03	19
	Female	1.00	0.04	20
	Total	1.00	0.03	39
Severe hypodontia	Male	1.02	0.04	20
	Female	1.04	0.05	21
	Total	1.03	0.05	41
Total	Male	1.00	0.03	77
	Female	1.00	0.04	80
	Total	1.00	0.04	157

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 33: Two-way ANOVA of tooth taper for tooth 11.

Source	Significance
GROUP	0.000
GENDER	0.348
GROUP * GENDER	0.075

Table 34: Multiple comparisons of tooth taper for tooth 11.

(I) SUBGRP	(J) SUBGRP	Mean Difference (I-J)	P1 (sig x 16)	P2 (P1 x 266)
Male control	M.mild	0.01	1.000	1.000
	M.moderat	0.00	1.000	1.000
	M.severe	-0.02	1.000	1.000
	F.control	0.01	1.000	1.000
Male mild	M.moderat	-0.01	1.000	1.000
	M.severe	-0.03	0.161	1.000
	F.mild	0.00	1.000	1.000
Male moderate	M.severe	-0.02	0.866	1.000
	F.moderat	-0.01	1.000	1.000
Male severe	F.severe	-0.03	0.173	1.000
Female control	F.mild	0.00	1.000	1.000
	F.moderat	-0.01	1.000	1.000
	F.severe	-0.05	0.000*	0.003*
Female mild	F.moderat	-0.02	1.000	1.000
	F.severe	-0.06	0.000*	0.001*
Female moderate	F.severe	-0.04	0.002*	0.475

M = male, F = female. P1 = Bonferroni corrected significance levels accounting for 16 multi-subgroup comparisons. P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

Figure 36: Estimated means of tooth taper for tooth 11. The table demonstrates gender comparisons at different severities of hypodontia.

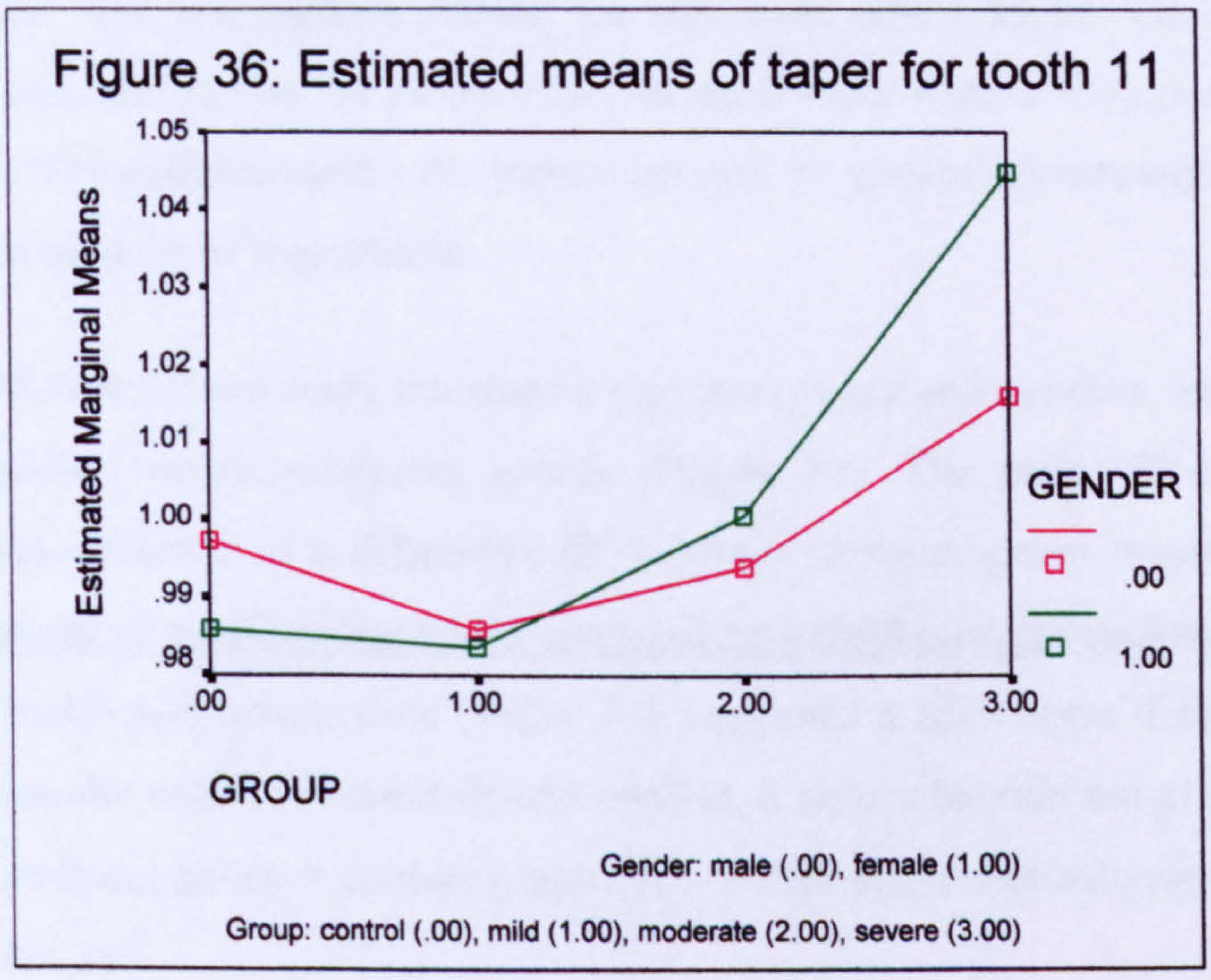
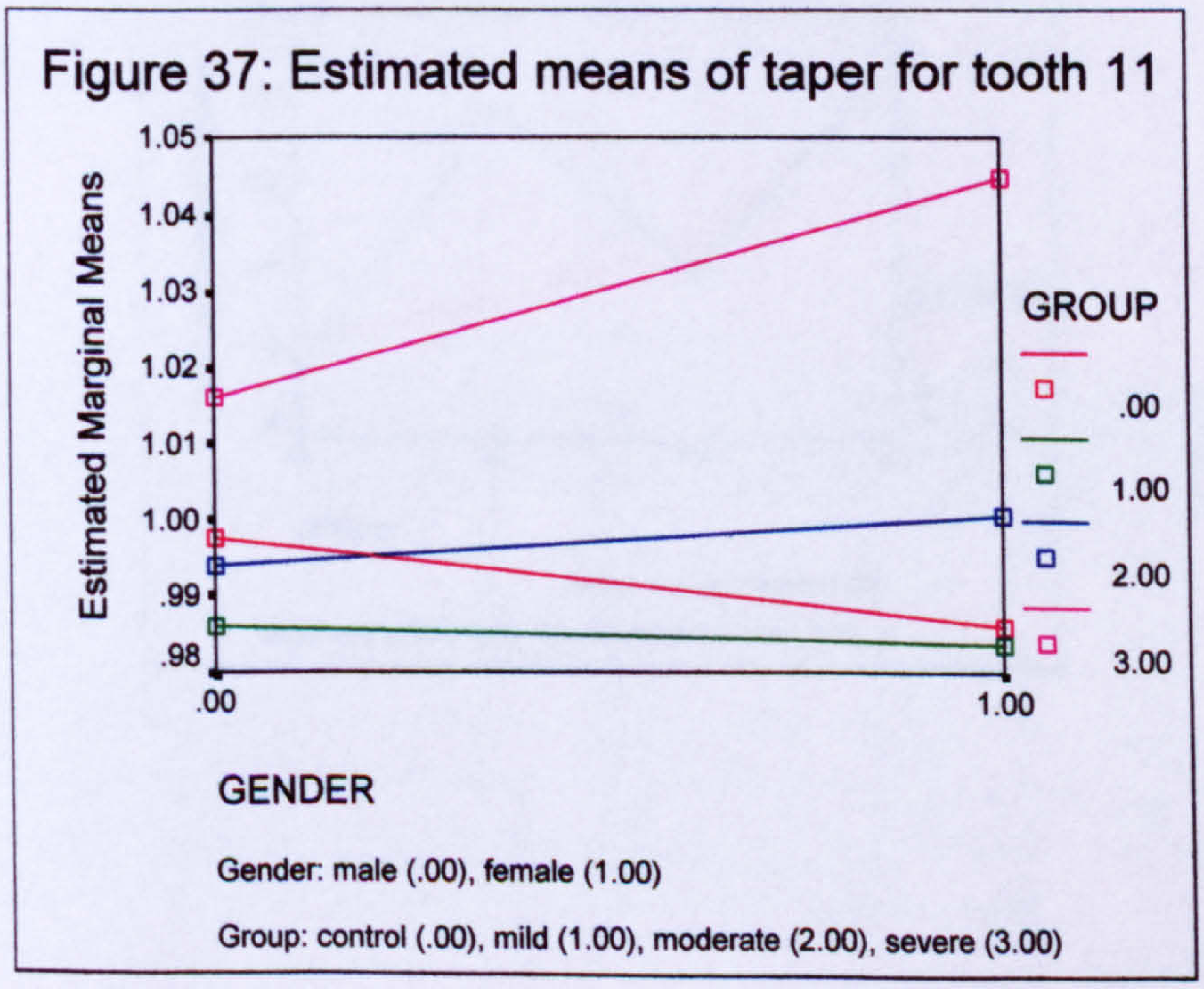


Figure 37: Estimated means of tooth taper for tooth 11. The table demonstrates severity comparisons within genders and conveys the same information of table 36.



7.3.2.2. Tooth 21 (Maxillary left central incisor)

The descriptive and comparative results are shown in tables 35-37. Descriptive data (Table 35) demonstrates that the group mean values of taper were 0.98 (control subjects), 1.02 (mild), 1.00 (moderate) and 1.05 (severe group), the general picture suggesting taper increases with severity of hypodontia.

Two-way ANOVA did not show interaction between groups and genders, and so genders may be combined when comparing groups (Figure 38). The main effect (Table 36) revealed slight evidence of a difference (P = 0.092) between group means. **<u>However, final adjustment of significance levels revealed no significant differences.</u>** Before the adjustment, multi-comparison tests (Table 37) suggested a significant difference (P1 = 0.079) between the combined controls and combined severe hypodontia group (tapering of severe hypodontia group > control group). No overall difference between genders was revealed (Table 36).

Figure 38: Estimated means of taper for tooth 21

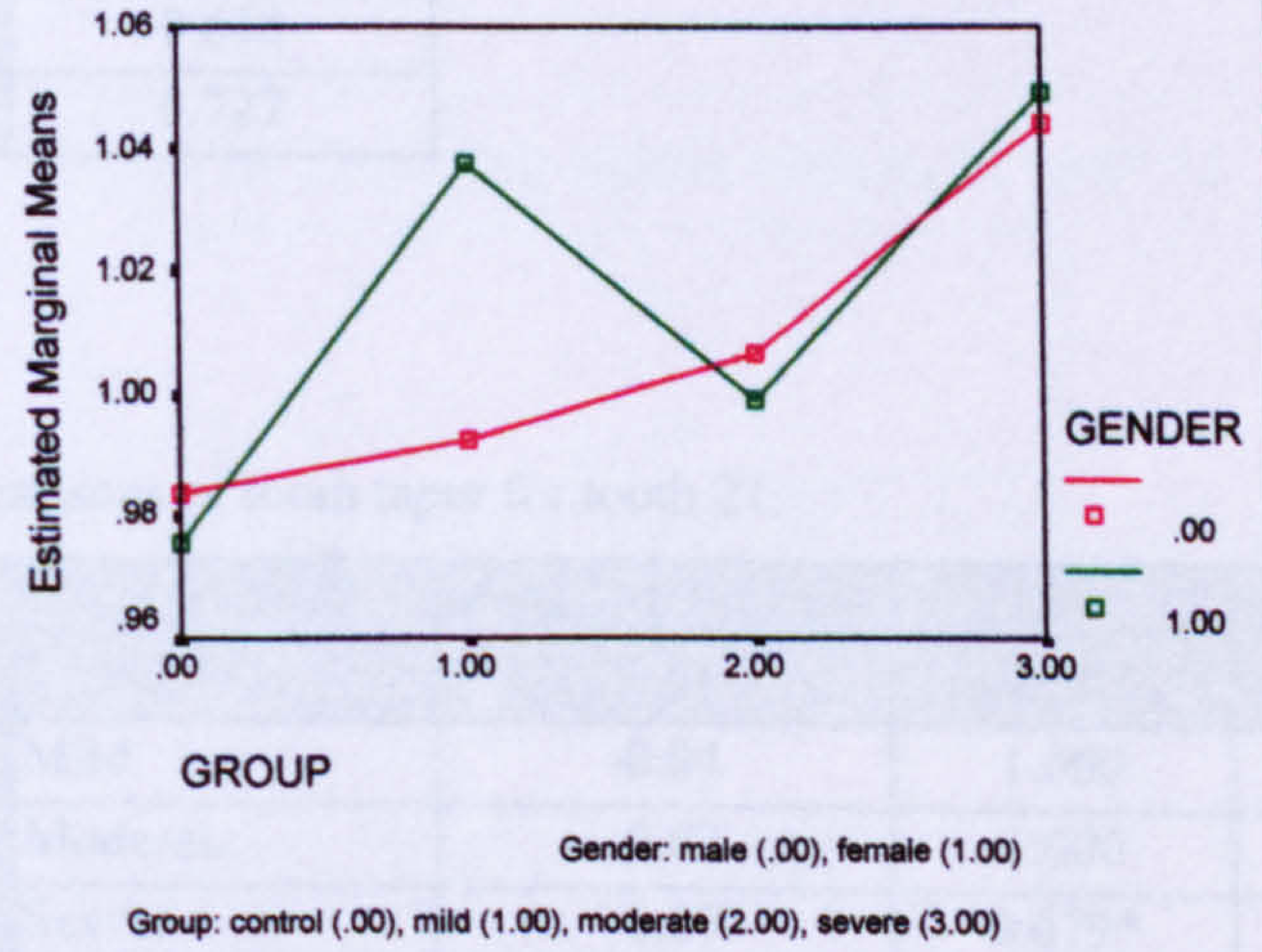


Table 35: Descriptive statistics of tooth taper for tooth 21.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.98	0.04	20
	Female	0.98	0.03	19
	Total	0.98	0.03	39
Mild hypodontia	Male	0.99	0.03	18
	Female	1.04	0.29	20
	Total	1.02	0.21	38
Moderate hypodontia	Male	1.01	0.03	20
	Female	1.00	0.04	20
	Total	1.00	0.04	40
Severe hypodontia	Male	1.04	0.14	19
	Female	1.05	0.05	21
	Total	1.05	0.10	40
Total	Male	1.01	0.08	77
	Female	1.02	0.15	80
	Total	1.01	0.12	157

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 36: Two-way ANOVA of tooth taper for tooth 21.

Source	Significance
GROUP	0.092
GENDER	0.648
GROUP * GENDER	0.727

Table 37: Multiple comparisons of tooth taper for tooth 21.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	P1 (Sig x 6)	P2 (P1 x 266)
Controls	Mild	-0.04	1.000	1.000
	Moderate	-0.02	1.000	1.000
	Severe	-0.07	0.079*	1.000
Mild hypodontia	Moderate	0.01	1.000	1.000
	Severe	-0.03	1.000	1.000
Moderate hypodontia	Severe	-0.04	0.590	1.000

P1 = Bonferroni corrected significance levels accounting for 6 multi-group comparisons.
P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.3. Tooth 12 (Maxillary right lateral incisor)

The descriptive and comparative data are shown in tables 38-40. Polts generally demonstrate that taper in severe and moderate group being > mild > control groups.

No interactions between groups and genders were found, so genders are combined (Figure 39). **Significant diference (P = 0.000) between group means was found (Table 39). A smaller tooth taper value was found in control group than in each of the severe and moderate hypodontia groups.**

The differences between controls (mean = 0.98) and each of severe (mean = 1.11) and moderate (mean = 1.10) hypodontia groups to be 0.13 amd 0.12 respectively (Table 40).

A difference between control and mild hypodontia group tooth taper means was suggested but failed to retain significance after final adjustment of the significnace levels (P1 = 0.026, P2 > 1.000, tooth taper in mild hypodontia group > control group).

In addition to a difference in groups a consistent difference between genders (P = 0.005) was also suggested of size 0.05, which applies across groups, but also failed to retain significance after final adjustment (P2 >1.000). See table 38 and 40 for detail.

Figure 39: Estimated means of taper for tooth 12

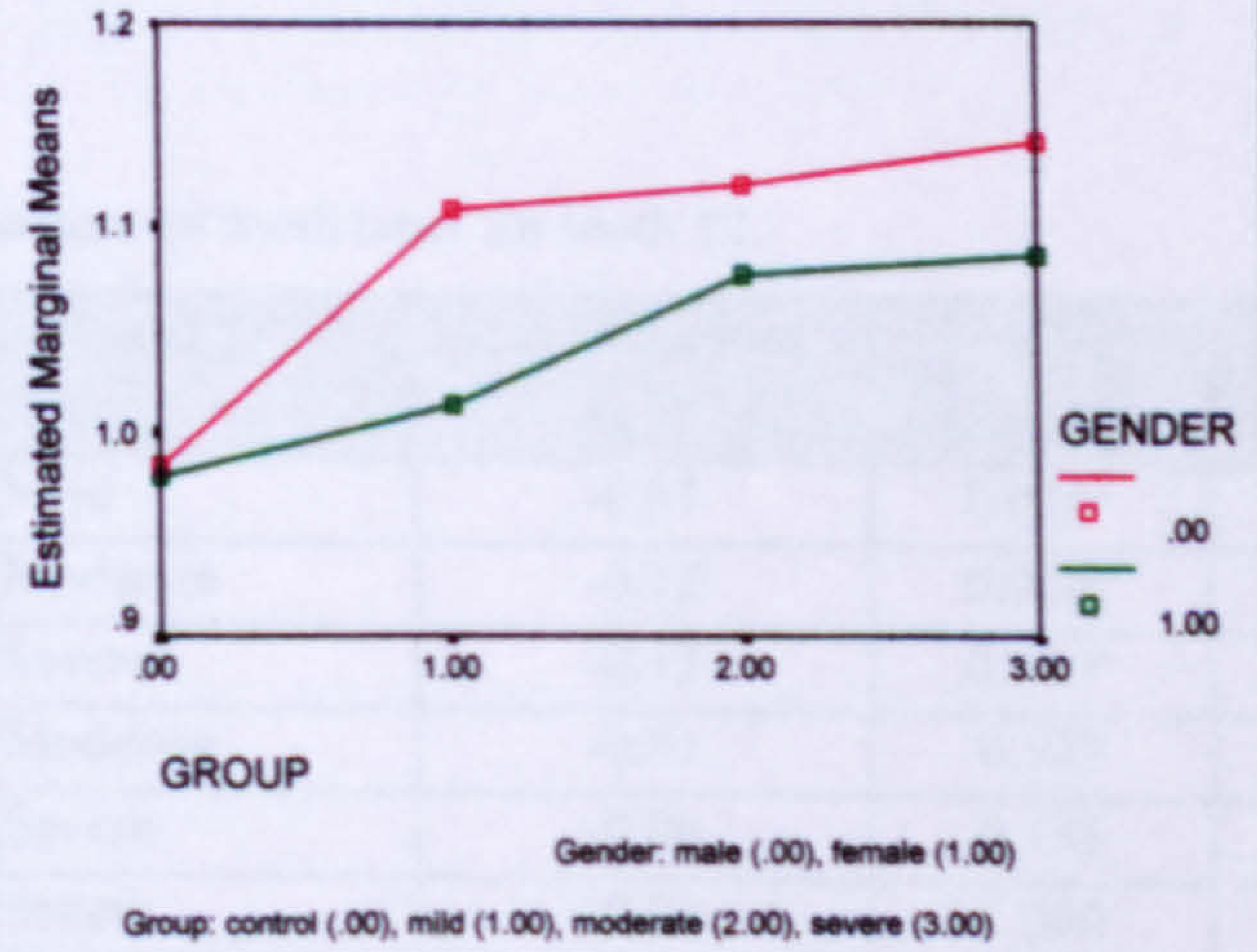


Table 38: Descriptive statistics of tooth taper for tooth 12.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.98	0.05	12
	Female	0.98	0.05	17
	Total	0.98	0.05	29
Mild hypodontia	Male	1.11	0.12	6
	Female	1.01	0.06	10
	Total	1.05	0.10	16
Moderate hypodontia	Male	1.12	0.09	10
	Female	1.08	0.07	11
	Total	1.10	0.08	21
Severe hypodontia	Male	1.14	0.11	7
	Female	1.08	0.09	8
	Total	1.11	0.10	15
Total	Male	1.08	0.11	35
	Female	1.03	0.08	46
	Total	1.05	0.09	81

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 39: Two-way ANOVA of tooth taper for tooth 12.

Source	Significance
GROUP	0.000
GENDER	0.005
GROUP * GENDER	0.311

Table 40: Multiple comparisons of tooth taper for tooth 12.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	P1 (Sig x 6)	P2 (P1 x 266)
Controls	Mild	-0.07	0.026*	1.000
	Moderate	-0.12	0.000*	0.001*
	Severe	-0.13	0.000*	0.001*
Mild hypodontia	Moderate	-0.05	0.323	1.000
	Severe	-0.06	0.138	1.000
Moderate hypodontia	Severe	-0.01	1.000	1.000

P1 = Bonferroni corrected significance levels accounting for 6 multi-group comparisons.
P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.4. Tooth 22 (Maxillary left lateral incisor)

The descriptive and comparative data are presented in tables 41-43. Statistical analysis revealed the same trend of tooth 12. Descriptive data demonstrates that taper in severe, moderate and mild hypodontia groups > control group.

No interactions between groups and genders were found and so genders are combined (Figure 40). **<u>Significant diference (P = 0.000) between group means found (Table 41). A smaller tooth taper value was found in control group than in each severe and moderate hypodontia group.</u>**

The differences between controls (mean = 0.97) and each of severe (mean = 1.09) and moderate (mean = 1.08) hypodontia groups to be 0.11 amd 0.10 respectively (Table 43).

A difference between control and mild hypodontia group tooth taper means was suggested (P1 = 0.003, mild hypodontia group > control group) but failed to retain significance after final adjustment of the significnace levels (P2 = 0.698).

In addition, a consistent difference between genders (P = 0.040) was also found of size 0.02, which applies in each group, but also failed to retain significance after final adjustment (P2 > 1.000). For further detail, see tables 41 and 43.

Figure 40: Estimated means of taper for tooth 22

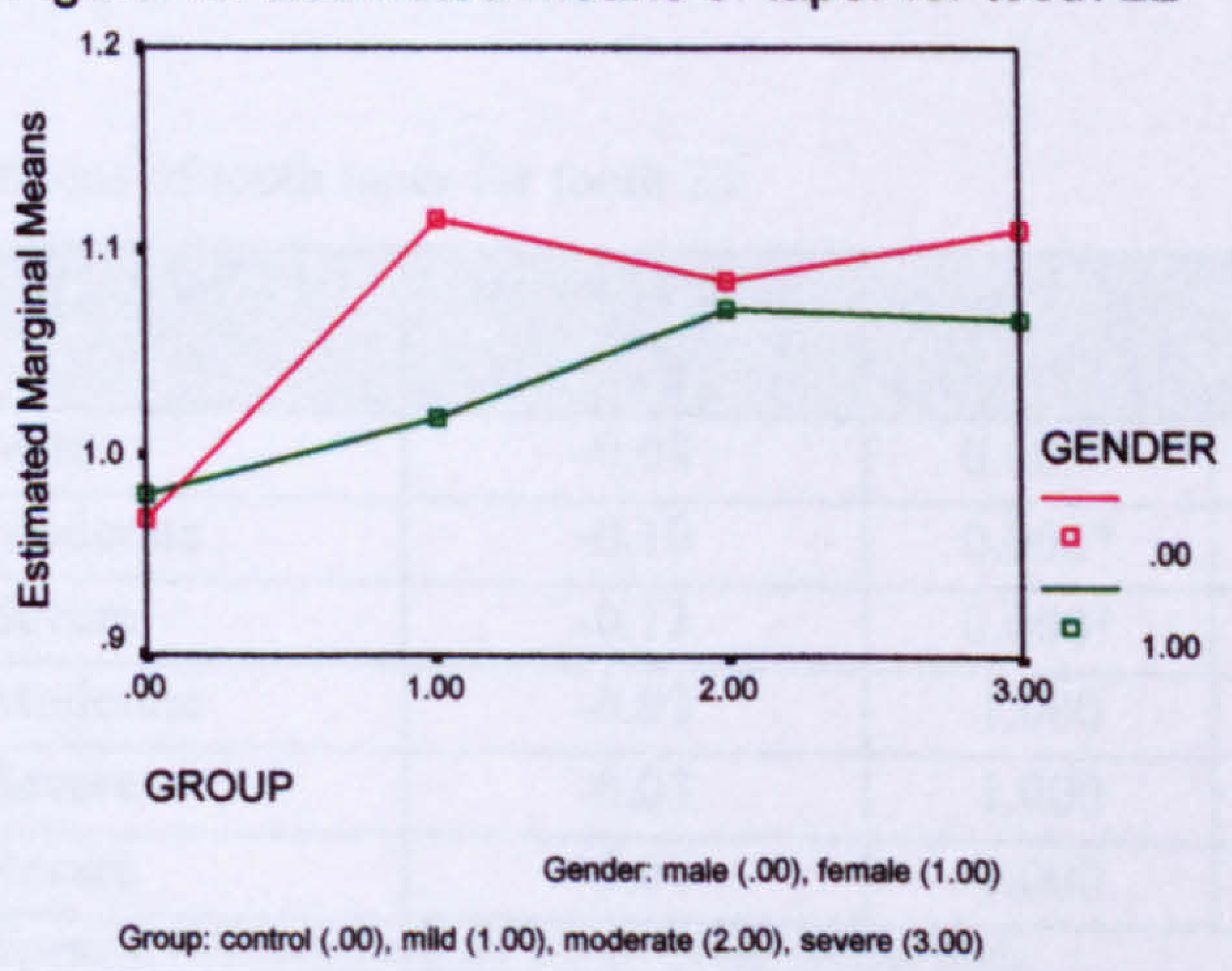


Table 41: Descriptive statistics of tooth taper for tooth 22.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.97	0.08	14
	Female	0.98	0.04	17
	Total	0.97	0.06	31
Mild hypodontia	Male	1.12	0.10	7
	Female	1.02	0.04	12
	Total	1.05	0.08	19
Moderate hypodontia	Male	1.09	0.10	11
	Female	1.07	0.09	14
	Total	1.08	0.09	25
Severe hypodontia	Male	1.11	0.06	6
	Female	1.07	0.08	7
	Total	1.09	0.07	13
Total	Male	1.05	0.11	38
	Female	1.03	0.07	50
	Total	1.04	0.09	88

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 42: Two-way ANOVA of tooth taper for tooth 22.

Source	Significance
GROUP	0.000
GENDER	0.040
GROUP * GENDER	0.108

Table 43: Multiple comparisons of tooth taper for tooth 22.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	P1 (Sig x 6)	P2 (P1 x 266)
Controls	Mild	-0.08	0.003*	0.698
	Moderate	-0.10	0.000*	0.002*
	Severe	-0.11	0.000*	0.033*
Mild hypodontia	Moderate	-0.02	1.000	1.000
	Severe	-0.03	1.000	1.000
Moderate hypodontia	Severe	-0.01	1.000	1.000

P1 = Bonferroni corrected significance levels accounting for 6 multi-group comparisons.
P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.5. Tooth 31 (Mandibular left central incisor)

The descriptive and comparative data were demonstrated in tables 44-46 and figure 41. The analysis indicated significant interaction ($P = 0.022$) between hypodontia groups and genders indicating that differences between groups were different for males and females. Significant differences between female severe hypodontia subgroup and other female subgroups (**control: P1 = 0.001, mild: P1 = 0.003** and moderate hypodontia: P1 = 0.014) were suggested i.e. severe > the others, **but did not retain significance after adjustment, P2 = 0.314, 0.781 and > 1.000 respectively**).

The differences between tooth taper mean in female severe hypodontia group (0.99) and control mean (0.91) is 0.07, with mild hypodontia mean (0.92) is 0.07 and moderate hypodontia (0.92) is 0.06 (Table 46). For further detail, see tables 44 and 46.

For males, no significant difference across groups was found.

Figure 41: Estimated means of taper for tooth 31

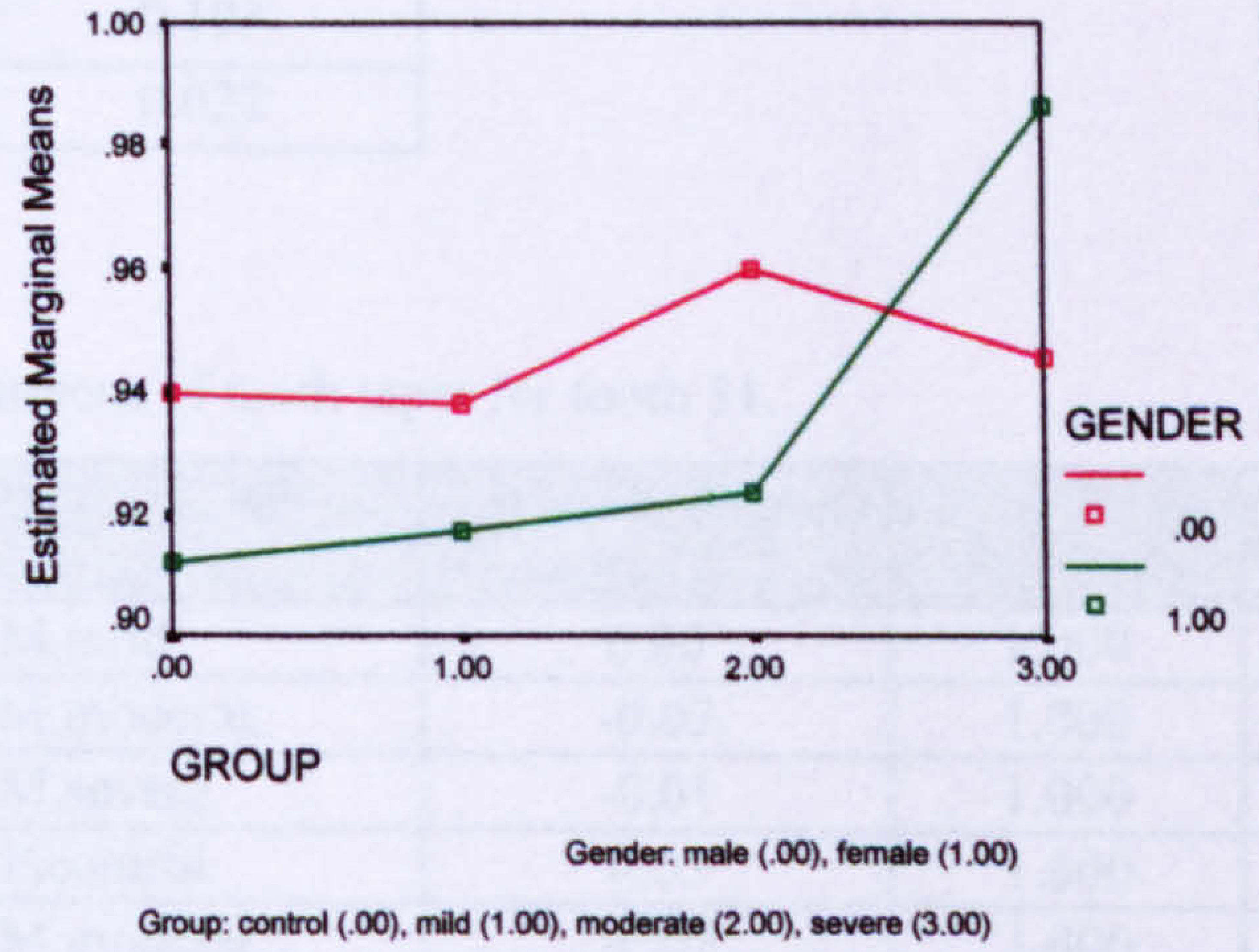


Table 44: Descriptive statistics of tooth taper for tooth 31.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.94	0.04	16
	Female	0.91	0.04	17
	Total	0.93	0.04	33
Mild hypodontia	Male	0.94	0.05	19
	Female	0.92	0.04	18
	Total	0.93	0.05	37
Moderate hypodontia	Male	0.96	0.06	16
	Female	0.92	0.03	16
	Total	0.94	0.05	32
Severe hypodontia	Male	0.95	0.05	10
	Female	0.99	0.05	10
	Total	0.97	0.05	20
Total	Male	0.95	0.05	61
	Female	0.93	0.05	61
	Total	0.94	0.05	122

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 45: Two-way ANOVA of tooth taper for tooth 31.

Source	Significance
GROUP	0.009
GENDER	0.193
GROUP * GENDER	0.022

Table 46: Multiple comparisons of tooth taper for tooth 31.

(I) SUBGRP	(J) SUBGRP	Mean Difference (I-J)	P1 (Sig x 16)	P2 (P1 x 266)
Male control	M.mild	0.00	1.000	1.000
	M.moderat	-0.02	1.000	1.000
	M.severe	-0.01	1.000	1.000
	F.control	0.03	1.000	1.000
Male mild	M.moderat	-0.02	1.000	1.000
	M.severe	-0.01	1.000	1.000
	F.mild	0.02	1.000	1.000
Male moderate	M.severe	0.01	1.000	1.000
	F.moderat	0.04	0.424	1.000
Male severe	F.severe	-0.04	0.763	1.000
Female control	F.mild	-0.01	1.000	1.000
	F.moderat	-0.01	1.000	1.000
	F.severe	-0.07	0.001*	0.314
Female mild	F.moderat	-0.01	1.000	1.000
	F.severe	-0.07	0.003*	0.781
Female moderate	F.severe	-0.06	0.014*	1.000

M = male, F = female. P1 = Bonferroni corrected significance levels accounting for 16 multi-subgroup comparisons. P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.6. Tooth 41 (Mandibular right central incisor)

The descriptive and comparative data were demonstrated in tables 47-49 and figure 42. Descriptive data (Table 47) and plots (Figure 42) indicated tapering, in general, in severe hypodontia group > moderate > mild > control group, however, only for females there were differences as discussed above.

Statistical findings were in agreement to those of tooth 11.

Significant interaction (P = 0.014) between severity groups and genders, indicating that differences between groups were different for males and females (Table 48). **Only in female, the mean value of tooth taper value in severe hypodontia group was found to be larger than the control mean and mild hypodontia mean.**

Multi-subgroup comparison tests suggested a difference between moderate and severe hypodontia group tooth taper (P1 = 0.037, taper in severe > moderate) but did not retain significance after adjustment (P2 > 1.000). See table 49.

Tooth taper found to be 0.09 smaller in female control (mean 0.91) and 0.08 smaller in mild hypodontia (mean 0.92) when compared to 1.00 in severe category. See tables 47 and 49 for further detail.

Figure 42: Estimated means of taper for tooth 41

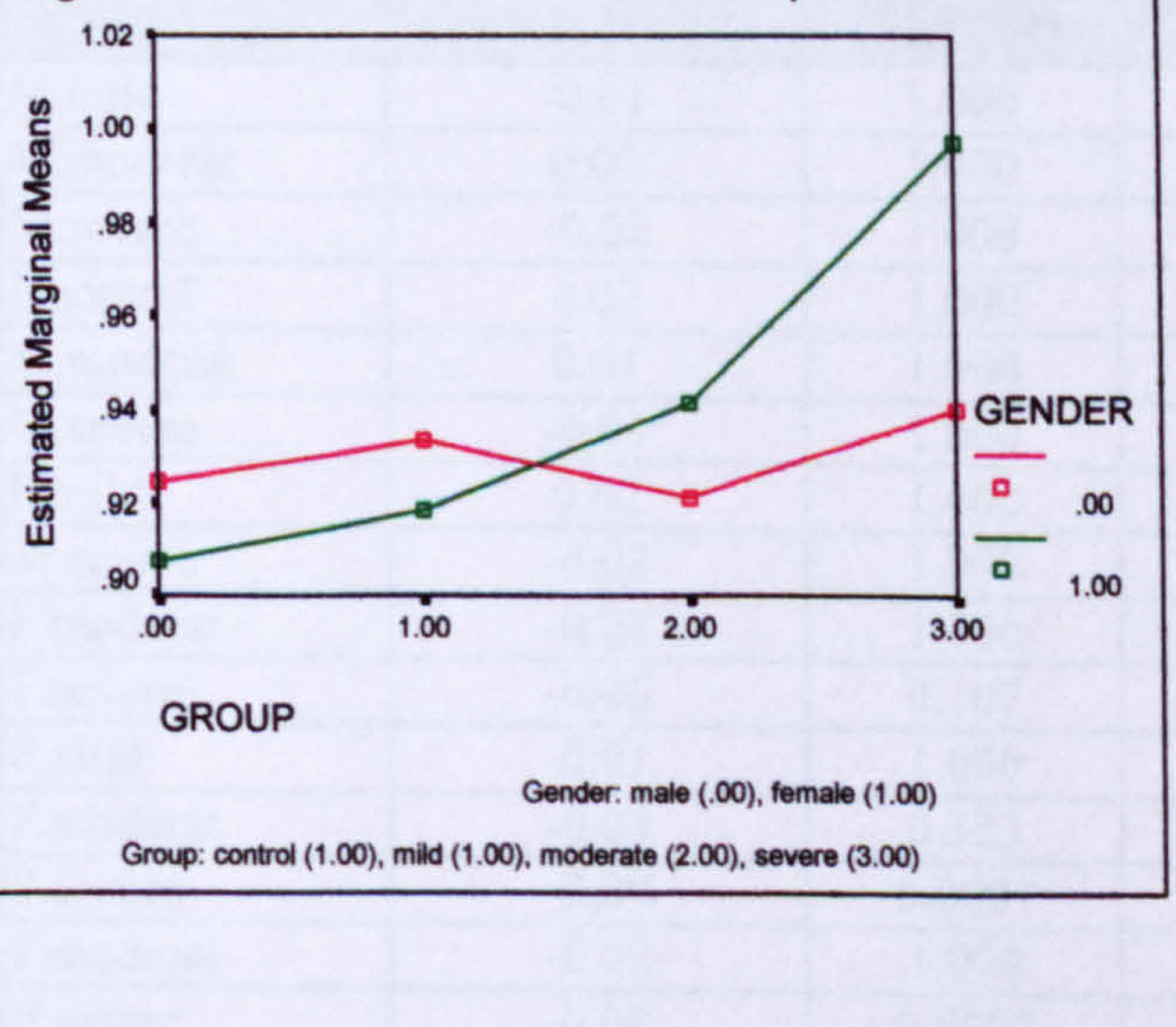


Table 47: Descriptive statistics of tooth taper for tooth 41.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.92	0.03	18
	Female	0.91	0.04	19
	Total	0.92	0.04	37
Mild hypodontia	Male	0.93	0.04	17
	Female	0.92	0.05	19
	Total	0.93	0.05	36
Moderate hypodontia	Male	0.92	0.05	15
	Female	0.94	0.05	16
	Total	0.93	0.05	31
Severe hypodontia	Male	0.94	0.06	9
	Female	1.00	0.04	12
	Total	0.97	0.06	21
Total	Male	0.93	0.04	59
	Female	0.93	0.06	66
	Total	0.93	0.05	125

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 48: Two-way ANOVA of tooth taper for tooth 41.

Source	Significance
GROUP	0.001
GENDER	0.204
GROUP * GENDER	0.014

Table 49: Multiple comparisons of tooth taper for tooth 41.

(I) SUBGRP	(J) SUBGRP	Mean Difference (I-J)	P1 (Sig x 16)	P2 (P1 x 266)
Male control	M.mild	-0.01	1.000	1.000
	M.moderat	0.00	1.000	1.000
	M.severe	-0.02	1.000	1.000
	F.control	0.02	1.000	1.000
Male mild	M.moderat	0.01	1.000	1.000
	M.severe	-0.01	1.000	1.000
	F.mild	0.02	1.000	1.000
Male moderate	M.severe	-0.02	1.000	1.000
	F.moderat	-0.02	1.000	1.000
Male severe	F.severe	-0.06	0.107	1.000
Female control	F.mild	-0.01	1.000	1.000
	F.moderat	-0.03	0.523	1.000
	F.severe	-0.09	0.000*	0.003*
Female mild	F.moderat	-0.02	1.000	1.000
	F.severe	-0.08	0.000*	0.048*
Female moderate	F.severe	-0.06	0.037*	1.000

M = male, F = female. P1 = Bonferroni corrected significance levels accounting for 16 multi-subgroup comparisons. P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.7. Tooth 32 (Mandibular left lateral incisor)

The descriptive and comparative data are demonstrated in tables 50-52 and figure 43. Two-way ANOVA did not show interaction between groups and genders, so the differences between groups do not depend on gender. **Significant differences (P = 0.000) between group means were found (Table 51). Each of control and mild hypodontia groups demonstrated less taper value than the severe group. An evidence for a difference between moderate and severe group was also suggested (P1 = 0.004, P2 = 0.919, taper in severe hypodontia group > in moderate hypodontia group).** One other difference between moderate hypodontia group and control group was suggested but failed to retain significance after final adjustment (P1 = 0.040, P2 > 1.000, taper in moderate hypodontia group > in control group). For detail, see tables 50-52.

The difference between combined severe group mean (1.00) and combined control group (mean 0.92) = 0.07 and with combined mild hypodontia group (mean 0.93) = 0.06 (Tables 50 and 52).

Figure 43: Estimated means of taper for tooth 32

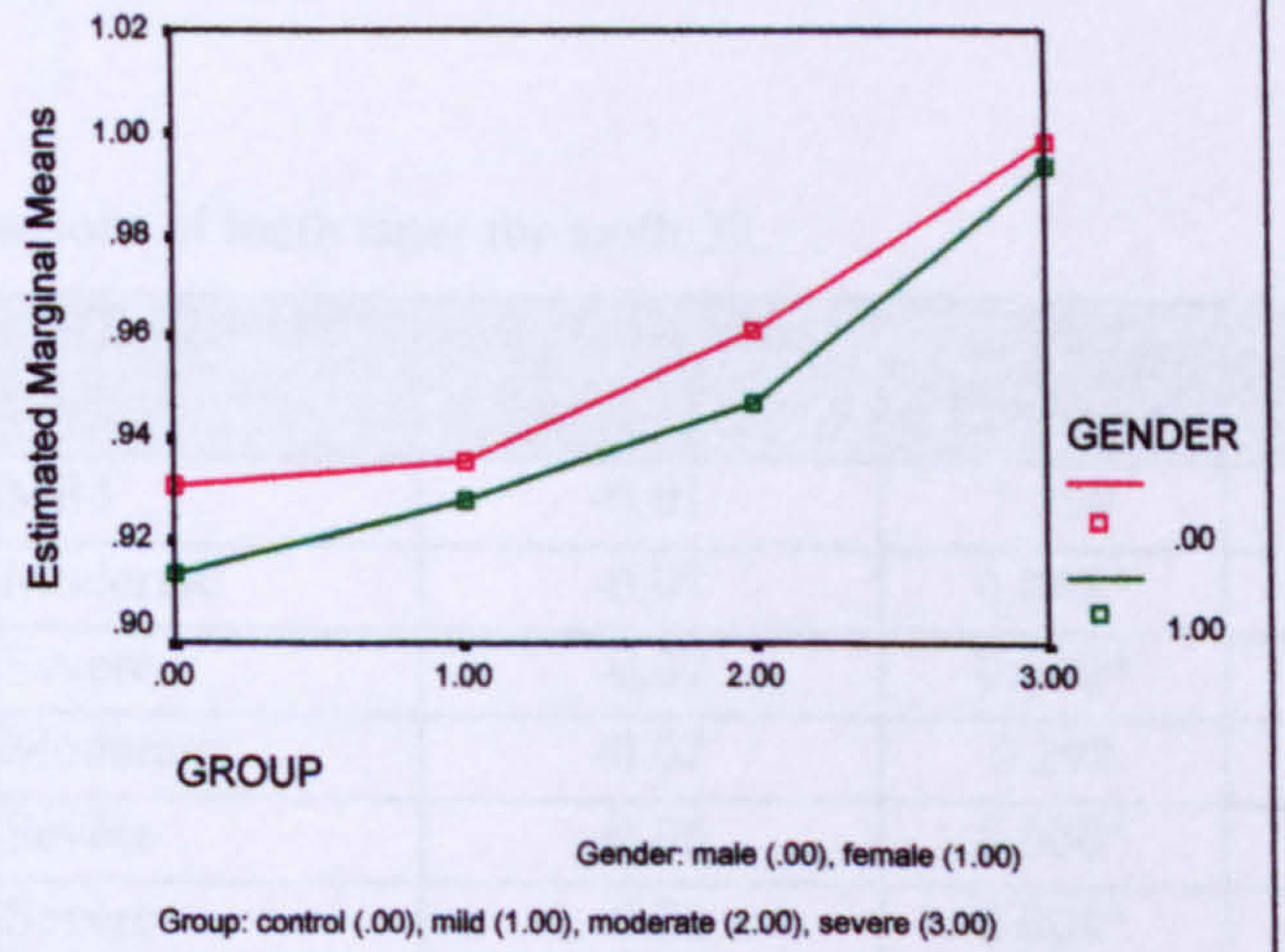


Table 50: Descriptive statistics of tooth taper for tooth 32.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.93	0.033	15
	Female	0.91	0.045	16
	Total	0.92	0.040	31
Mild hypodontia	Male	0.94	0.032	18
	Female	0.93	0.042	17
	Total	0.93	0.037	35
Moderate hypodontia	Male	0.96	0.043	17
	Female	0.95	0.055	18
	Total	0.95	0.049	35
Severe hypodontia	Male	1.00	0.076	14
	Female	0.99	0.037	13
	Total	1.00	0.059	27
Total	Male	0.95	0.053	64
	Female	0.94	0.053	64
	Total	0.95	0.053	128

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 51: Two-way ANOVA of tooth taper for tooth 32.

Source	Significance
GROUP	0.000
GENDER	0.198
GROUP * GENDER	0.958

Table 52: Multiple comparisons of tooth taper for tooth 32.

(I) GROUP	(J) GROUP	Mean Difference (I-J)	P1 (Sig x 6)	P2 (P1 x 266)
Controls	Mild	-0.01	1.000	1.000
	Moderate	-0.03	0.040*	1.000
	Severe	-0.07	0.000*	0.000*
Mild hypodontia	Moderate	-0.02	0.294	1.000
	Severe	-0.06	0.000*	0.001*
Moderate hypodontia	Severe	-0.04	0.004*	0.919

P1 = Bonferroni corrected significance levels accounting for 6 multi-group comparisons.
P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.8. Tooth 42 (Mandibular right lateral incisor)

The descriptive and comparative data were demonstrated in tables 53-55 and figure 44. Significant interaction (P = 0.002) between severity groups and genders, indicating that differences between groups were different for males and females (Table 54). **Only in females, the mean value of tooth taper in severe hypodontia group was found to be larger than the mean of each of the control, mild and moderate hypodontia.**

Tooth taper found to be 0.15 smaller in female control (mean 0.90), 0.13 smaller in mild hypodontia (mean 0.92) and 0.11 smaller in moderate hypodontia (mean 0.94), each compared to 1.05 in female severe group.

Finally, a difference in tooth taper between genders was suggested in severe hypodontia group but this also failed to retain significance after final adjustment (P1 = 0.019, P2 > 1.000, female tooth taper > male tooth taper). See tables 53 and 55 for further descriptive detail.

Figure 44: Estimated Means of taper for tooth 42

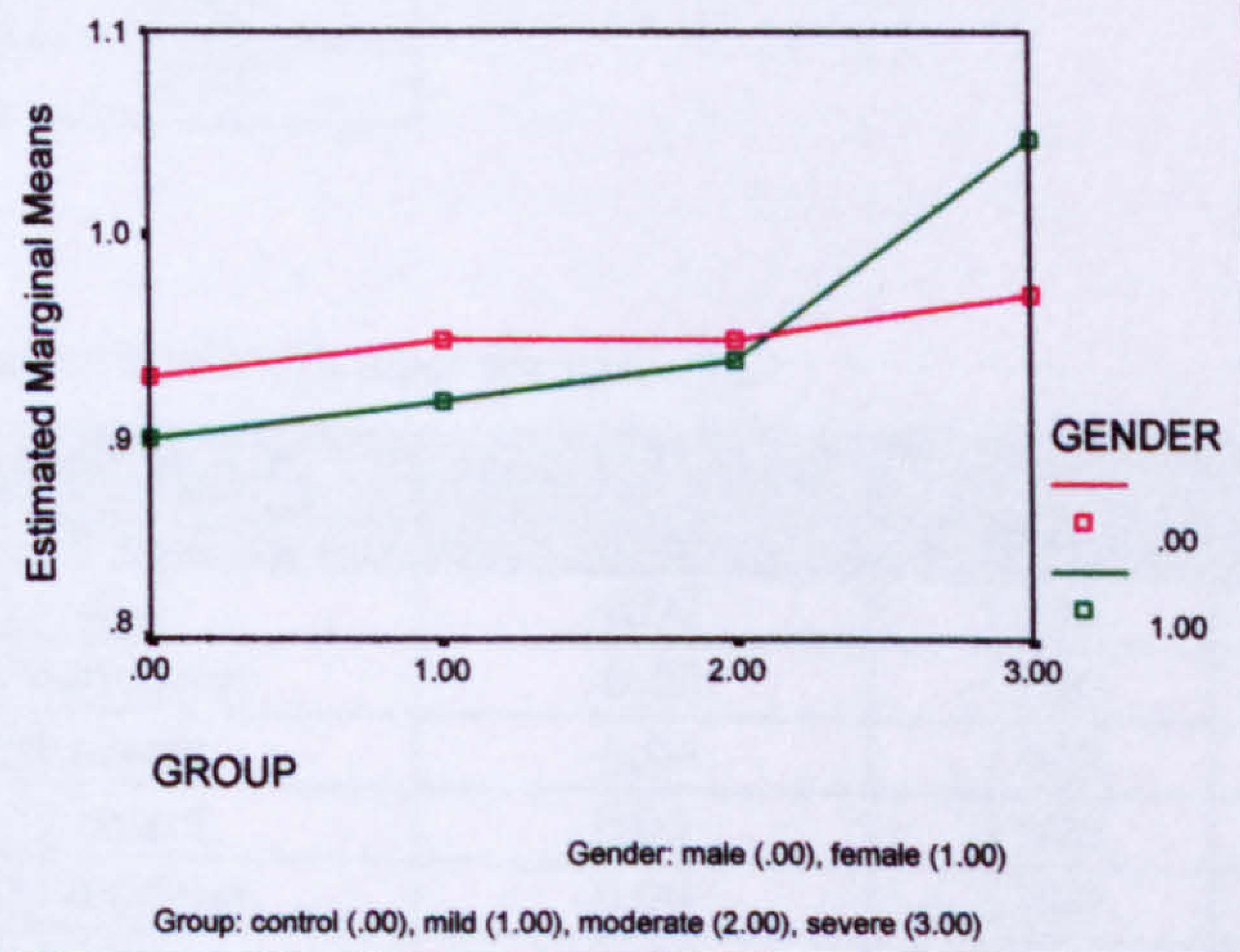


Table 53: Descriptive statistics of tooth taper for tooth 42.

GROUP	GENDER	Mean	Std. Deviation	N
Controls	Male	0.93	0.05	15
	Female	0.90	0.04	16
	Total	0.91	0.05	31
Mild hypodontia	Male	0.95	0.03	18
	Female	0.92	0.06	17
	Total	0.93	0.05	35
Moderate hypodontia	Male	0.95	0.04	15
	Female	0.94	0.06	17
	Total	0.94	0.05	32
Severe hypodontia	Male	0.97	0.05	14
	Female	1.05	0.13	15
	Total	1.01	0.10	29
Total	Male	0.95	0.04	62
	Female	0.95	0.09	65
	Total	0.95	0.07	127

Std. Deviation = Standard deviation, N = Number of teeth investigated.

Table 54: Two-way ANOVA of tooth taper for tooth 42.

Source	Significance
GROUP	0.000
GENDER	0.904
GROUP * GENDER	0.002

Table 55: Multiple comparisons of tooth taper for tooth 42.

(I) SUBGRP	(J) SUBGRP	Mean Difference (I-J)	P1 (Sig x 16)	P2 (P1 x 266)
Male control	M.mild	-0.02	1.000	1.000
	M.moderat	-0.02	1.000	1.000
	M.severe	-0.04	1.000	1.000
	F.control	0.03	1.000	1.000
Male mild	M.moderat	0.00	1.000	1.000
	M.severe	-0.02	1.000	1.000
	F.mild	0.03	1.000	1.000
Male moderate	M.severe	-0.02	1.000	1.000
	F.moderat	0.01	1.000	1.000
Male severe	F.severe	-0.08	0.019*	1.000
Female control	F.mild	-0.02	1.000	1.000
	F.moderat	-0.04	1.000	1.000
	F.severe	-0.15	0.000*	0.000*
Female mild	F.moderat	-0.02	1.000	1.000
	F.severe	-0.13	0.000*	0.000*
Female moderate	F.severe	-0.11	0.000*	0.012*

M = male, F = female. P1 = Bonferroni corrected significance levels accounting for 16 multi-subgroup comparisons. P2 = Final (overall) Bonferroni adjusted significance levels for testing multiple variables (N = 266).

7.3.2.9. Summary of tooth taper findings

The results of tooth taper analysis for all the maxillary and mandibular incisor teeth are summarised as follows:

1) *When the measurements of genders were analysed separately due to significant interaction for teeth 11, 31, 41 and 42; multi-subgroup comparison tests revealed that the taper value in severe hypodontia group was statistically greater than in moderate, mild hypodontia and control groups. For tooth 42, male severe hypodontia also showed less tooth taper value than female severe hypodontia.*
   But, final adjustment for the significance levels revealed:

   In tooth 42, all the above findings retained significance except the difference between genders in the severe hypodontia group.
   In teeth 11 and 41, only the control and mild hypodontia groups were significantly different from the severe hypodontia group.
   In tooth 31, none of the above findings retain significance.
   These significant findings were related to female subjects only.

2) *When genders were combined for teeth 12, 21, 22 and 32; multi-group comparison tests revealed that the degree of tooth taper in hypodontia groups was greater than in control group and increased with an increase in the severity of hypodontia:*
   Tooth 21, significant difference was found between severe hypodontia and control subjects but did not retain significance after final adjustment.
   Teeth 12 and 22, significant differences were found between each hypodontia group (mild, moderate severe) and control group but the difference between the mild hypodontia and control groups was unretained.
   Tooth 32, there were significant difference between control group and each of moderate and severe hypodontia group, however, only the difference between severe and control groups had retained significance. Severe group showed significantly greater taper than each of mild and moderate hypodontia groups, however, only the difference between the mild and severe groups had retained significance after final adjustment.

7.3.3. Mesiodistal Measurements From Buccal Aspect

The main statistical results for mesiodistal dimension of buccal view measurement (MDb) data in all tooth types are summarised in table 56. Further details of descriptive data of group and subgroup means and differences are shown in appendix 1, tables 1-42. The following are the main findings.

Genders analysed separately:

Significant interactions were found for teeth L2, L3 and L5 (see table 56 for p-values and figures 45-47) indicating that differences between groups were different for males and females.

For L2, L3 and L5 in males: MDb mean value in each hypodontia group was found to be smaller than the control mean, but hypodontia groups did not (generally) differ amongst themselves.

A difference between mild and severe MDb dimensions of L2 was suggested (M1 > M3) but did not retain significance after final adjustment of significance levels (Table 56).

For L2: Difference between male control mean MDb (6.41 mm) and mild hypodontia group (mean, 5.68 mm) = 0.73 mm, with moderate group (mean, 5.37 mm), difference = 1.04 mm and with severe group (mean, 5.13), difference = 1.28 mm.

For L3: MDb dimension found to be 0.98 mm smaller in mild male hypodontia group (mean, 6.71 mm), 1.14 mm smaller in moderate group (mean, 6.55 mm) and 1.21 mm smaller in severe group (mean, 6.48 mm), each compared to 7.69 mm in male control group.

For L5: Difference between male control mean MDb (7.62 mm) and mild hypodontia group (mean, 6.87 mm) = 0.75 mm, with moderate group (mean, 6.42 mm), difference = 1.20 mm and with severe group (mean, 6.48), difference = 1.14mm.

For L2, L3 and L5 in females: Only in L2, the severe hypodontia group MDb mean was found to be smaller than the control mean. There are evidence for differences between control and each of mild hypodontia group (for L3 and L5) and severe group (for L3): F0 > each of those. For detail, see table 56 and tables of appendix 1.

Differences were found between female control and each of the mild and moderate means for L2, between control and moderate hypodontia group means for L3 and between control and severe hypodontia group for L5 (F0 > each of these). However, none of these differences retained significance after final adjustment (Table 56).

For L2: MDb dimension found to be 0.76 mm smaller in female severe hypodontia (mean, 5.32 mm) than female control group (mean, 6.08 mm). The rest of subgroup means and differences are shown in appendix 1 tables.

Finally, for L3: a difference between genders was suggested in the control groups (M0>F0) but this also failed to retain significance after final adjutment (see appendix 1 if details are of interest).

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. **Significant differences between group means were found for all other tooth types: U1, U2, U3, U4, U5, U6, U7, L1, L4, L6 and L7** (see table 56 for p-values).

With the exception of L7 in the above list, each hypodontia group MDb was found to be smaller than the control group. However, for all but one type, the MDb dimensions of hypodontia groups did not differ among themselves. For U1, statistically smaller MDb dimensions were detected in the severe group when compared to the mild and moderate groups.

A difference between control and mild hypodontia group means was suggested for L7 (control > mild) but failed to retain significance after final adjustment (Table 56 shows p-value).

For U1: Difference between control mean MDb (9.26 mm) and mild hypodontia group (mean, 8.43 mm) = 0.83 mm, with moderate group (mean, 8.24 mm), difference = 1.02 mm and with severe group (mean, 7.80 mm), difference = 1.46 mm. Difference between severe hypodontia MDb mean and mild group = 0.63 mm and with moderate group, difference = 0.43 mm.

For U2: MDb dimension found to be 1.62 mm smaller in mild hypodontia group (mean, 5.65 mm), 1.50 mm smaller in moderate group (mean, 5.77 mm) and 1.64 mm smaller in severe group (mean, 5.63 mm), each compared to 7.27 mm in control group.

For U3: MDb dimension found to be 0.91 mm smaller in mild hypodontia group (mean, 7.49 mm), 1.00 mm smaller in moderate group (mean, 7.40 mm) and 1.26 mm smaller in severe group (mean, 7.14 mm), each compared to 8.40 mm in control group.

For U4: MDb dimension found to be 0.65 mm smaller in mild hypodontia group (mean, 6.72 mm), 0.92 mm smaller in moderate group (mean, 6.45 mm) and 0.94 mm smaller in severe group (mean, 6.43 mm), each compared to 7.37 mm in control group.

For U5: MDb dimension found to be 0.74 mm smaller in mild hypodontia group (mean, 6.32 mm), 0.93 mm smaller in moderate group (mean, 6.13 mm) and 0.83 mm smaller in severe group (mean, 6.23 mm), each compared to 7.06 mm in control group.

For U6: MDb dimension found to be 0.60 mm smaller in each mild and moderate hypodontia group (mean, 10.12 mm) and 0.92 mm smaller in severe group (mean, 9.80 mm), each compared to 10.72 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.24 mm (M>F), which applies in each group, but did not retain significance (The differences between groups for male and female are the same since no interaction was revealed for this tooth).

For U7: MDb dimension found to be 0.81 mm smaller in mild hypodontia group (mean, 9.65 mm), 0.82 mm smaller in moderate group (mean, 9.64 mm) and 1.05 mm smaller in severe group (mean, 9.41 mm), each compared to 10.46 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.31 mm (M>F), which applies in each group but with unretained significance.

For L1: MDb dimension found to be 0.60 mm smaller in mild hypodontia group (mean, 5.16 mm), 0.59 mm smaller in moderate group (mean, 5.17 mm) and 0.75 mm smaller in severe group (mean, 5.01 mm), each compared to 5.76 mm in control group.

For L4: MDb dimension found to be 0.74 mm smaller in mild hypodontia group (mean, 6.82 mm), 0.84 mm smaller in moderate group (mean, 6.72 mm) and 0.93 mm smaller in severe group (mean, 6.63 mm), each compared to 7.56 mm in control group.

For L6: MDb dimension found to be 0.92 mm smaller in mild hypodontia group (mean, 10.59 mm), 0.77 mm smaller in moderate group (mean, 10.74 mm) and 0.89 mm smaller in severe group (mean, 10.62 mm), each compared to 11.51 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.23 mm (M>F), which applies in each group before final adjustment.

For L7: Only a consistent difference between genders was found of size 0.41 mm (M>F), which applies in each group before final adjustment.

The reader is asked to refer to appendix 1 tables if the details are needed.

Summary of MDb findings

The analysis results for the mesiodistal measurements for all maxillary and mandibular teeth, obtained from the buccal view (MDb) are summarised as follows:

1) *When the measurements of genders were analysed separately for teeth L2, L3 and L5; multi-subgroup comparison tests and final adjustment of significance levels revealed:*
   For males, the MDb mean values in each hypodontia group were statistically less than in the control group.
   For females, only in L2 the MDb mean values in severe hypodontia were statistically less than control group.

2) *When the measurements of genders were combined for teeth U1, U2, U3, U4, U5, U6, U7, L1, L4, L6 and L7; multi-group comparison tests with final adjustment of the significance levels revealed:*
   The MDb mean in each hypodontia group was statistically smaller than in the control group for these teeth, except L7.
   The measurements of severe hypodontia group were also statistically smaller than the measurements of mild and moderate hypodontia groups for tooth U1.

Table 56: Summary results of mesiodistal measurements from buccal aspect (MDb)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.018
	Gender		0.323	0.908	0.364	0.481	0.869	0.019	0.036	0.372	0.773	0.000	0.360	0.482	0.063	0.009
	Group & Gender		0.788	0.787	0.659	0.441	0.362	0.413	0.481	0.865	0.011	0.042	0.886	0.070	0.258	0.345
Multi-group comparisons	0	1	**	**	**	**	**	**	**	**			**		**	*
		2	**	**	**	**	**	**	**	**			**		**	
		3	**	**	**	**	**	**	**	**			**		**	
	1	2														
		3	**													
	2	3	**													
Multi-subgroup comparisons	Mo	M1									**	**		**		
		M2									**	**		**		
		M3									**	**		**		
	F0	F1									*	(*)		(*)		
		F2									*	*				
		F3									**	(*)		*		
	M1	M2														
		M3									*					
	F1	F2														
		F3														
	M2	M3														
	F2	F3														
	M0	F0										*				
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 1 tables.

Figure 45: Estimated Means of MDb for tooth L2

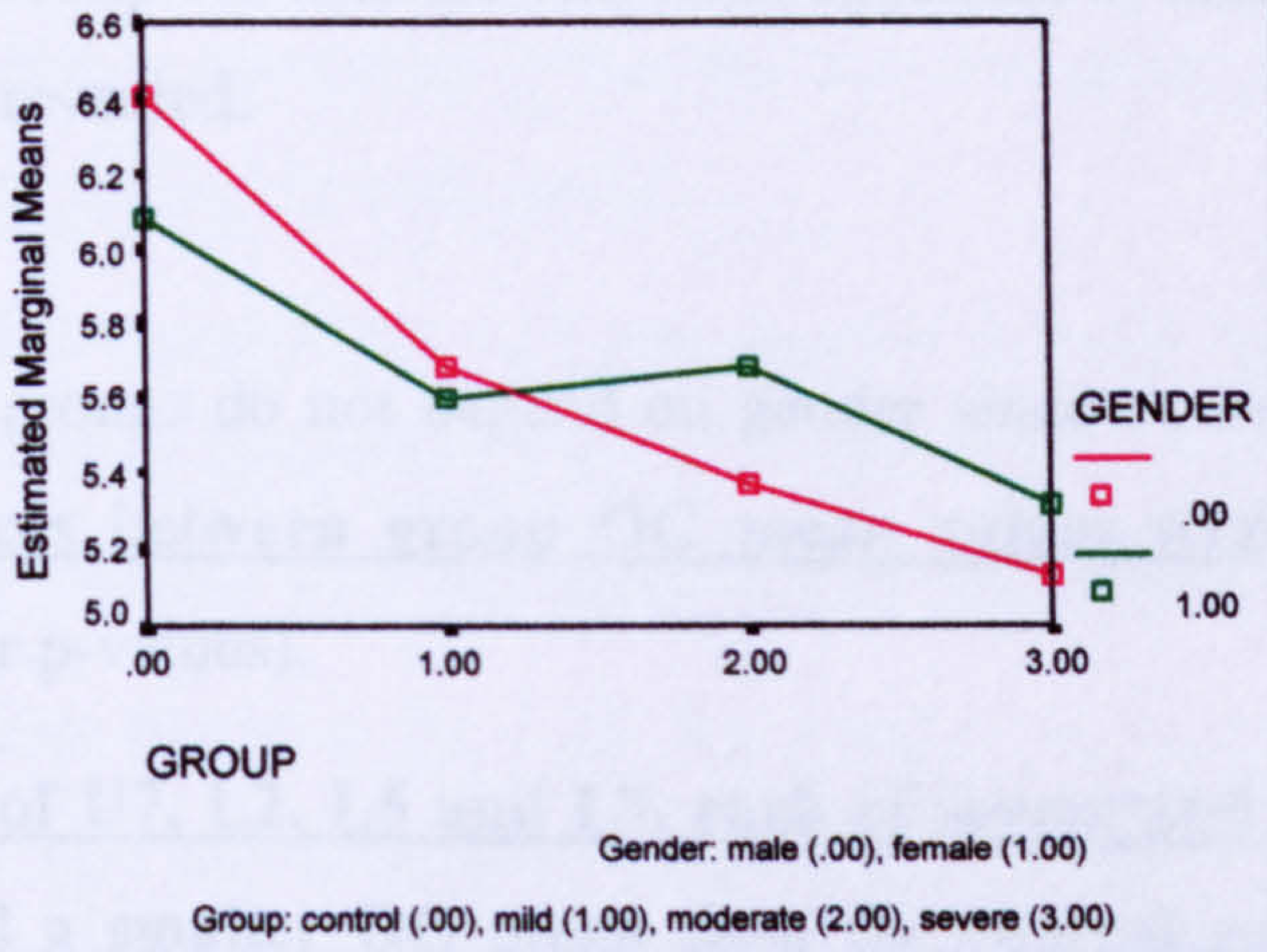


Figure 46: Estimated Means of MDb for tooth L3

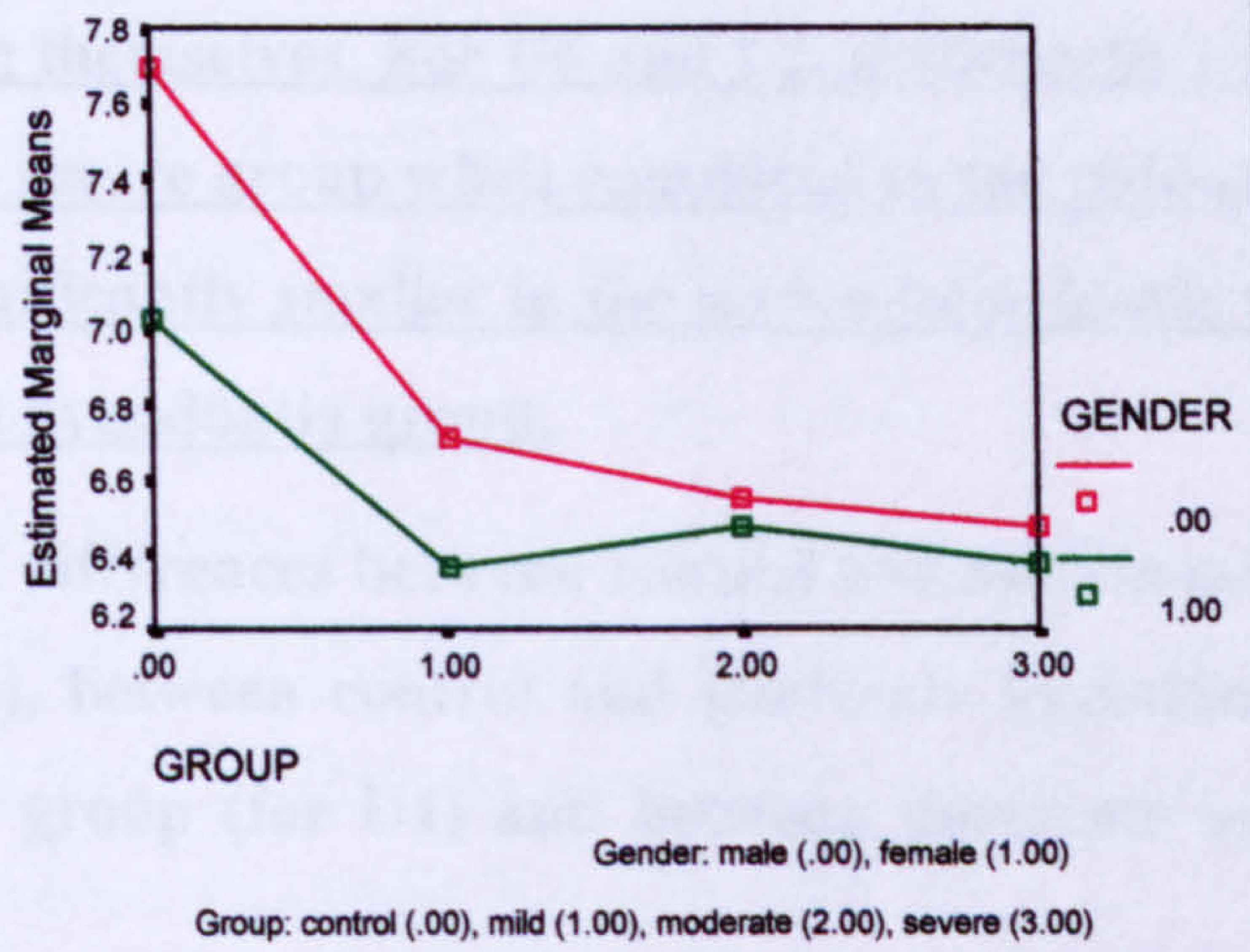
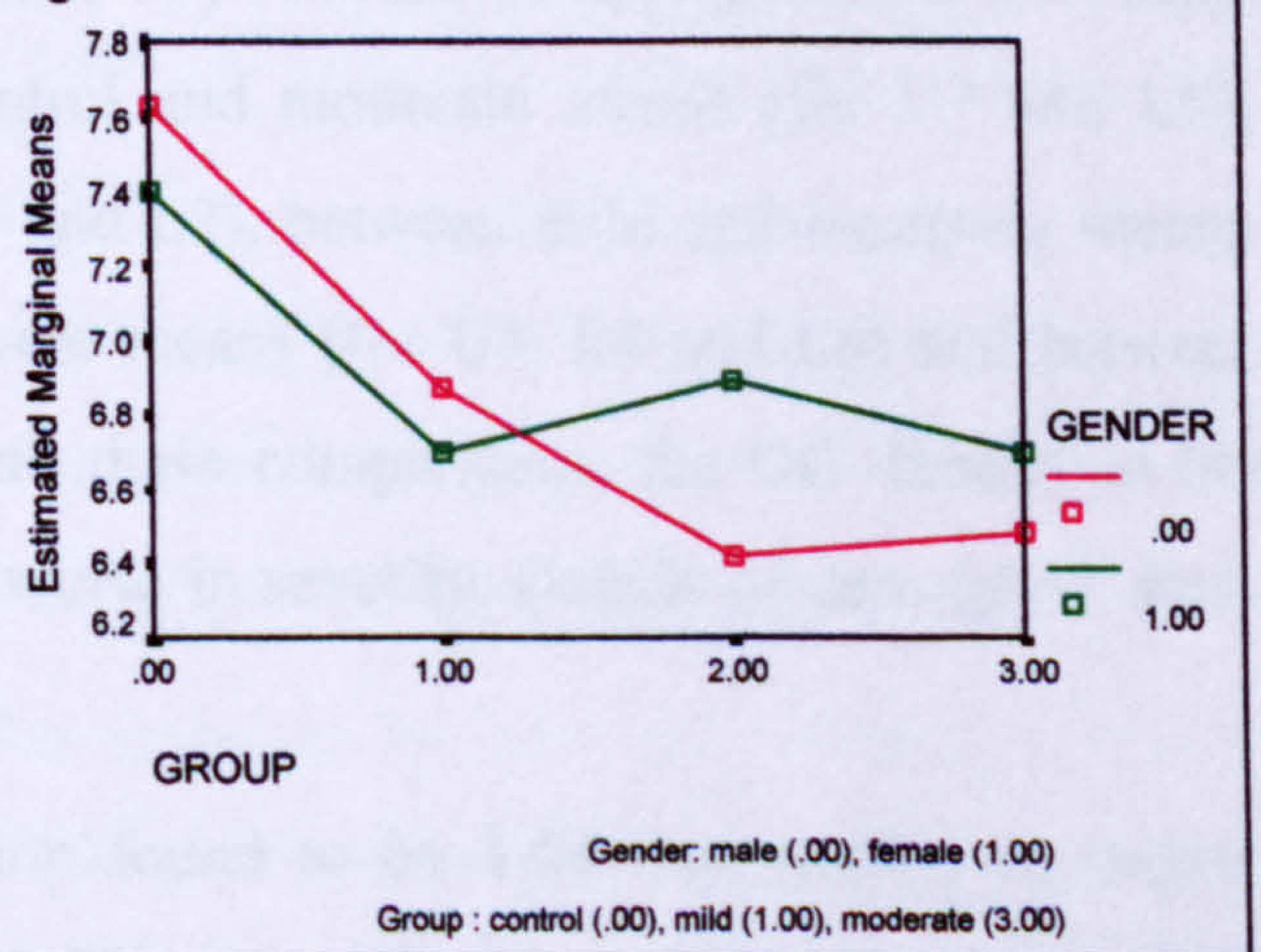


Figure 47: Estimated Means of MDb of tooth L5



7.3.4. Occlusogingival (OG) Measurements

The analysis of occlusogingival measurement data of different teeth was summarised in table 57. Details of descriptive data are shown in appendix 2, tables 1-42. The following are the main findings revealed:

Genders combined:

Differences between groups do not depend on gender since no interaction was revealed. Significant differences between group OG mean values were found for all tooth types (see table 57 for p-values).

With the exception of U7, L2, L5 and L7, each of severe and moderate hypodontia group demonstrated a smaller OG mean than the control group. For U2 and U3, mild hypodontia group OG was also found to be smaller than control group. However, for all the above but one type, the OG dimensions of hypodontia groups did not differ among themselves. For U6 and L2, statistically smaller OG dimensions were detected in the severe group when compared to the mild group. For L2, the OG mean value was significantly smaller in the severe hypodontia group than in each of the control and mild hypodontia group.

There is evidence of differences between control and mild hypodontia group (for U4, U6, U7, L3 and L4), between control and moderate hypodontia (for L2), between mild and moderate group (for U1) and between moderate and severe hypodontia group (for U6).

Differences were also suggested but failed to retain significance after final adjustments of significance levels (Table 57) between control and mild OG means (for U1, U5, L1, L5 and L6), between control and moderate means (for U7 and L5), between control and severe means (for U7 and L7), between mild and moderate means (for U5, L4 and L6), between mild and severe means (for U3, L4 and L6) and between moderate and severe means (for U1). For all these comparisons, the OG dimension becoming smaller as the hypodontia is getting worse in severity. Details of descriptive data are shown in table 57 and appendix 2 tables.

For U1: OG dimension found to be 1.08 mm smaller in moderate hypodontia group (mean 8.92 mm) and 1.66 mm smaller in severe group (mean, 8.34 mm), each compared to 10.00 mm in control group.

For U2: OG dimension found to be 1.36 mm smaller in mild hypodontia group (mean, 6.74 mm), 1.26 mm smaller in moderate group (mean, 6.84 mm) and 1.48 mm smaller in severe group (mean, 6.62 mm), each compared to 8.10 mm in control group. In addition to a difference in groups, a consistent difference between genders was suggested of size 0.43 mm (M>F), which applies in each group.

For U3: OG dimension found to be 1.27 mm smaller in mild hypodontia group (mean, 8.04 mm), 1.75 mm smaller in moderate group (mean, 7.56 mm) and 1.93 mm smaller in severe group (mean, 7.38 mm), each compared to 9.31 mm in control group.

For U4: OG dimension found to be 1.38 mm smaller in moderate hypodontia group (mean, 6.07 mm) and 1.26 mm smaller in severe group (mean, 6.19 mm), each compared to 7.45 mm in control group.

For U5: OG dimension found to be 1.17 mm smaller in moderate hypodontia group (mean, 5.03 mm) and 0.82 mm smaller in severe group (mean, 5.38 mm), each compared to 6.20 mm in control group. In addition to a difference in groups, a consistent difference between genders was suggested of size 0.24 mm (M>F), which applies in each group.

For U6: OG dimension found to be 0.58 mm smaller in moderate hypodontia group (mean, 4.65 mm) and 1.07 mm smaller in severe group (mean, 4.16mm), each compared to 5.23 mm in control group. The mean of severe hypodontia was 0.70 mm smaller than than mild group mean (mean, 4.86 mm). In addition to a difference in groups, a consistent difference between genders was suggested of size 0.24 mm (M>F), which applies in each group.

For L1: OG dimension found to be 0.97 mm smaller in moderate hypodontia group (mean, 7.45 mm) and 1.59 mm smaller in severe group (mean, 6.83 mm), each compared to 8.42 mm in control group.

For L2: OG dimension found to be 1.24 mm smaller in severe group (mean, 6.94 mm) than control group (mean, 8.18 mm). The mean value of severe hypodontia was 0.88 mm smaller than than mild group mean value (7.82 mm).

For L3: OG dimension found to be 1.17 mm smaller in moderate hypodontia group (mean, 8.15 mm) and 1.73 mm smaller in severe group (mean, 7.59 mm), each compared to 9.32 mm in control group. In addition addition to a difference in groups, a consistent difference between genders was suggested of size 0.46 mm (M>F), which applies in each group.

For L4: OG dimension found to be 0.98 mm smaller in moderate hypodontia group (mean, 6.97 mm) and 0.95 mm smaller in severe group (mean, 7.00 mm), each compared to 7.95 mm in control group. In addition addition to a difference in groups, there is evidence for a consistent difference between genders (P2 = 0.532) was found of size 0.30 mm (M>F), which applies in each group.

For L6: OG dimension found to be 0.80 mm smaller in moderate hypodontia group (mean, 5.13 mm) and 0.98 mm smaller in severe group (mean, 4.95 mm), each compared to 5.93 mm in control group.

For L5: A consistent difference between genders was suggested of size 0.29 mm (M>F), which applies in each group.

See appendix 2 tables for further descriptive details

Summary of OG findings

The analysis results for the occlusogingival (OG) measurements are summarised as follows:

When the genders were combined in all tooth types; multi-group comparison tests and final adjustment of significance levels revealed:

1) *The OG mean values in severe and moderate hypodontia groups were statistically less than the values in the control group for teeth U1, U2, U3, U4, U5, U6, L1, L3, L4 and L6.*
2) *The OG mean value in mild hypodontia was significantly less than the value in control group for teeth U2 and U3.*
3) *The OG mean value in severe hypodontia was also significantly less than the value in mild group for U6.*
4) *The OG mean value in severe hypodontia was significantly less than the mean value in each of the control and mild hypodontia group for tooth L2.*

Table 57: Summary results of occlusogingival measurements (OG)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.005	0.000	0.013
	Gender		0.187	0.025	0.261	0.453	0.006	0.013	0.573	0.105	0.505	0.010	0.002	0.029	0.689	0.365
	Group & Gender		0.803	0.266	0.629	0.681	0.462	0.996	0.722	0.950	0.292	0.108	0.120	0.944	0.894	0.831
Multi-group comparisons	0	1	*	**	**	(*)	*	(*)	(*)	*		(*)	(*)	*	*	
		2	**	**	**	**	**	**	*	**	(*)	**	**	*	**	
		3	**	**	**	**	**	**	*	**	**	**	**		**	*
	1	2					*						*		*	
		3	(*)		*			**			**	*			*	
	2	3	*					(*)								

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 2 tables.

7.3.5. Perimeter Measurements From Buccal Aspect

The analysis of perimeter measurements of the buccal view for diferent tooth types was summarised in table 58. Descriptive statistics and size of differences are demonstrated in appendix 3, tables 1-42. The following are main findings.

Genders combined:

Since no interaction was revealed, differences between groups do not depend on gender. Significant differences between group means were found for all tooth types (see table 58 for p-values).

With the exception of U7, L2 and L7, each of hypodontia group showed smaller Pb measurement mean than the control group. For U7, the mean in each of mild and moderate hypodontia group was smaller, while for L2 each of moderate and severe hypodontia Pb was smaller as compared to control group. However, for all the above list but two types, the Pb dimensions of hypodontia groups did not differ among themselves. For both U1 and L2, statistically smaller Pb dimensions were detected in the severe group when compared to the mild group.

There was evidence of differences between the controls and each of the mild hypodontia (for L2) and severe hypodontia groups (for U7). There is also a difference between mild and each of moderate (for U4) and severe group (for U6).

Differences were suggested but failed to retain significance after final adjustments of significance levels (Table 58) between control and severe means (for L7), between mild and moderate means (for U5), between mild and severe means (for U3, U4, L1 and L3) and between moderate and severe means (for U1, U6, L1 and L2). For all the above the Pb measurements values becoming smaller with increase in hypodontia severity. See table 58 and appendix 1, tables for the detail.

For U1: Pb dimension found to be 2.68 mm smaller in mild hypodontia group (mean, 29.91 mm), 3.45 mm smaller in moderate group (mean, 29.14 mm) and 5.25 mm smaller in severe group (mean, 27.34 mm), each compared to 32.59 mm in control group. Severe group was also smaller than mild hypodontia group by 2.57 mm.

For U2: Pb dimension found to be 4.94 mm smaller in mild hypodontia group (mean, 20.48 mm), 4.75 mm smaller in moderate group (mean, 20.67 mm) and 5.48 mm smaller in severe group (mean, 19.94 mm), each compared to 25.42 mm in control group.

For U3: Pb dimension was found to be 3.45 mm smaller in mild hypodontia group (mean, 24.54 mm), 4.38 mm smaller in moderate group (mean, 23.61 mm) and 5.21 mm smaller in severe group (mean, 22.78 mm), each compared to 27.99 mm in control group.

For U4: Pb dimension found to be 2.03 mm smaller in mild hypodontia group (mean, 21.11 mm), 3.42 mm smaller in moderate group (mean, 19.72 mm) and 3.25 mm smaller in severe group (mean, 19.89 mm), each compared to 23.14 mm in control group.

For U5: Pb dimension found to be 2.26 mm smaller in mild hypodontia group (mean, 18.85 mm), 3.41 mm smaller in moderate hypodontia group (mean, 17.70 mm) and 2.83 mm smaller in severe group (mean, 18.28 mm), each compared to 21.11 mm in control group. A consistent difference between genders was suggested of size 0.25 mm (M>F).

For U6: Pb dimension found to be 1.71 mm smaller in mild hypodontia group (mean, 27.29 mm), 2.08 mm smaller in moderate group (mean, 26.92 mm) and 3.11 mm smaller in severe group (mean, 25.89 mm), each compared to 29.00 mm in control group. The mean of severe hypodontia was 1.40 mm smaller than than mild group. **This with an evidence of a consistent difference between genders (P2 = 0.532) of size 0.84 mm (M>F), which applies in each group.**

For U7: Pb dimension found to be 2.17 mm smaller in mild hypodontia group (mean, 25.37 mm) and 2.32 mm smaller in moderate group (mean, 25.22 mm), each compared to 27.54 mm in control group. A consistent difference between genders was suggested of size 0.86 mm (M>F).

For L1: Pb dimension found to be 2.04 mm smaller in mild hypodontia group (mean, 22.23 mm), 2.66 mm smaller in moderate group (mean, 21.61 mm) and 3.94 mm smaller in severe group (mean, 20.33 mm), each compared to 24.27 mm in control group.

For L2: Pb dimension found to be 2.44 mm smaller in moderate hypodontia group (mean, 21.65 mm) and 2.66 mm smaller in severe group (mean, 20.43 mm), each compared to 24.09 mm in control group.

For L3: Pb dimension found to be 2.51 mm smaller in mild hypodontia group (mean, 24.43 mm), 3.08 mm smaller in moderate group (mean, 23.86 mm) and 4.30 mm smaller in severe group (mean, 22.64 mm), each compared to 26.94 mm in control group. **An evidence of a consistent difference between genders was shown (P2 = 0.266) of size 1.27 mm (M>F), which applies in each group.**

For L4: Pb dimension found to be 2.15 mm smaller in mild hypodontia group (mean, 22.50 mm), 2.82 mm smaller in moderate group (mean, 21.80 mm) and 3.01 mm smaller in severe group (mean, 21.62 mm), each compared to 24.63 mm in control group. A consistent difference between genders was suggested of size 0.64 mm (M>F), which applies in each group.

For L5: Pb dimension found to be 2.13 mm smaller in mild hypodontia group (mean, 20.74 mm), 2.67 mm smaller in moderate group (mean, 20.20 mm) and 2.68 mm smaller in severe group (mean, 20.19 mm), each compared to 22.87 mm in control group.

For L6: Pb dimension found to be 2.16 mm smaller in mild hypodontia group (mean, 29.27 mm), 2.51 mm smaller in moderate group (mean, 28.92 mm) and 2.93 mm smaller in severe group (mean, 28.50 mm), each compared to 31.43 mm in control group. In addition, a consistent difference between genders was suggested of size 0.80 mm (M>F), which applies in each group.

For L7: A consistent difference between genders was suggested of size 1.25 mm (M>F).

See appendix 3 tables for further descriptive details.

Summary of Pb findings

The summary of results for the perimeter dimensions for the maxillary and mandibular teeth, obtained from the buccal view (Pb) is presented as follows:
Genders were combined in all tooth types and multi-group comparison tests and final adjustment of significance levels revealed:

1) *The Pb mean values in each hypodontia groups were significantly smaller than in the control group for teeth U1, U2, U3, U4, U5, U6, L1, L3, L4, L5 and L6.*
2) *For U7, the Pb mean value in mild and moderate hypodontia was significantly smaller than in the control group.*
3) *For L2, the Pb mean value in moderate and severe hypodontia was significantly smaller than in the control group.*
4) *The Pb in severe hypodontia was also significantly smaller than in mild hypodontia group for U1 and L2.*

Table 58: Summary results of perimeter measurements from buccal aspect (Pb)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035
	Gender		0.112	0.132	0.298	0.166	0.062	0.002	0.026	0.218	0.203	0.001	0.004	0.268	0.015	0.005
	Group & Gender		0.793	0.542	0.585	0.478	0.554	0.705	0.977	0.976	0.671	0.212	0.241	0.887	0.720	0.302
Multi-group comparisons	0	1	**	**	**	**	**	**	**	**	(*)	**	**	**	**	
		2	**	**	**	**	**	**	**	**	**	**	**	**	**	
		3	**	**	**	**	**	**	(*)	**	**	**	**	**	**	*
	1	2				(*)	*									
		3	**		*	*		(*)		*	**	*				
	2	3	*					*		*	*					

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 3 tables.

7.3.6. Area Measurements From Buccal Aspect

The analysis of area measurements for different teeth in buccal view was summarised in table 59. Differences between groups and descriptive findings are shown in appendix 4, tables 1-42. The following are main findings.

Genders combined:

Differences between groups do not depend on gender since no interaction was revealed. Significant differences between group means were found for all tooth types (see table 59 for p-values).

With the exception of U7 and L7, each of hypodontia group Ab mean value was found to be smaller than the control group. For U7, only in mild hypodontia group the mean was smaller than control group. However, for all the above list but three types, the Ab dimensions of hypodontia groups did not differ among themselves. For all U1, U6 and L2, statistically smaller Ab dimensions were detected in the severe group when compared to the mild group.

There is also evidence of differences betwen control group and each of moderate hypodontia (for U7) and severe hypodontia group (for U7 and L7).

Differences were also suggested but failed to retain significance after final adjustments of significance levels (Table 59) between control and moderate hypodontia means (for L7), between mild and moderate means (for U4), between mild and severe means (for U3, U4, L1, L3 and L6) and between moderate and severe means (for U1, U6 and L2). In control the measurements are bigger and decrease with increase of severity. Details are shown in table 59 and appendix 4 tables.

For U1: Ab measurement found to be 12 mm^2 smaller in mild hypodontia group (mean, 66.14 mm^2), 15.63 mm^2 smaller in moderate group (mean, 62.98 mm^2) and 23.10 mm^2 smaller in severe group (mean, 55.52 mm^2), each compared to 78.62 mm^2 in control group. Severe group was also samller than mild hypodontia group with a difference of 10.62 mm^2. In addition to a difference in groups a consistent difference between genders was suggested of size 2.70 mm^2 (M>F).

For U2: Ab value found to be 16.12 mm^2 smaller in mild hypodontia group (mean, 31.31 mm^2), 15.38 mm^2 smaller in moderate group (mean, 32.05 mm^2) and 17.47 mm^2 smaller in severe group (mean. 29.96 mm^2), each compared to 47.43 mm^2 in control group.

For U3: Ab found to be 13.23 mm^2 smaller in mild hypodontia group (mean, 45.72 mm^2), 16.75 mm^2 smaller in moderate group (mean, 42.20 mm^2) and 19.91 mm^2 smaller in severe group (mean, 39.04 mm^2), each compared to 58.95 mm^2 in control group.

For U4: Ab measurement found to be 6.47 mm^2 smaller in mild hypodontia group (mean, 33.03 mm^2), 10.46 mm^2 smaller in moderate group (mean, 29.04 mm^2) and 10.17 mm^2 smaller in severe group (mean, 29.33 mm^2), each compared to 39.50 mm^2 in control group.

For U5: Ab value found to be 6.31 mm^2 smaller in mild hypodontia group (mean, 26.22 mm^2), 9.35 mm^2 smaller in moderate hypodontia group (mean, 23.18 mm^2) and 8.00 mm^2 smaller in severe group (mean, 24.53 mm^2), each compared to 32.53 mm^2 in control group. A consistent difference between genders was also suggested of size 0.78 mm^2 (M>F).

For U6: Ab found to be 5.72 mm^2 smaller in mild hypodontia group (mean, 45.38 mm^2), 7.66 mm^2 smaller in moderate group (mean, 43.44 mm^2) and 12.27 mm^2 smaller in severe group (mean, 38.83 mm^2), each compared to 51.10 mm^2 in control group. The mean of severe hypodontia was 6.55 mm^2 smaller than than mild group. **In addition, an evidence for a consistent difference between genders was found (P2 = 0.266) of size 3.16 mm^2 (M>F).**

For U7: Ab found to be 7.77 mm^2 smaller in mild hypodontia group (mean, 37.08 mm^2) than control group (mean, 44.85 mm^2).

For L1: Ab measurement found to be 6.42 mm^2 smaller in mild hypodontia group (mean, 33.42 mm^2), 7.46 mm^2 smaller in moderate group (mean, 31.38 mm^2) and 10.13 mm^2 smaller in severe group (mean, 28.71 mm^2), each compared to 38.84 mm^2 in control group.

For L2: Ab value found to be 5.02 mm^2 smaller in mild hypodontia group (mean, 34.57 mm^2), 6.87 mm^2 smaller in moderate hypodontia group (mean, 32.72 mm^2) and 10.01 mm^2 smaller in severe group (mean, 29.58 mm^2), each compared to 39.59 mm^2 in control group. The mean of severe hypodontia group was 4.99 mm^2 smaller than than mild group.

For L3: Ab found to be 9.28 mm^2 smaller in mild hypodontia group (mean, 43.74 mm^2), 11.00 mm^2 smaller in moderate group (mean, 42.02 mm^2) and 14.58 mm^2 smaller in severe group (mean, 38.44 mm^2), each compared to 53.02 mm^2 in control group. **In**

addition, a consistent difference between genders was found (P2 = 0.000) of size 4.76 mm^2 (M>F), which applies in each group.

For L4: Ab found to be 7.08 mm^2 smaller in mild hypodontia group (mean, 37.60 mm^2), 9.25 mm^2 smaller in moderate group (mean, 35.43 mm^2) and 9.84 mm^2 smaller in severe group (mean, 34.84 mm^2), each compared to 44.68 mm^2 in control group. A consistent difference between genders was suggested of size 2 mm^2 (M>F), which applies in each group.

For L5: Ab found to be 5.69 mm^2 smaller in mild hypodontia group (mean, 31.63 mm^2), 7.43 mm^2 smaller in moderate group (mean, 29.89 mm^2) and 7.54 mm^2 smaller in severe group (mean, 29.78 mm^2), each compared to 37.32 mm^2 in control group.

For L6: Ab measurement found to be 7.87 mm^2 smaller in mild hypodontia group (mean, 53.34 mm^2), 10.64 mm^2 smaller in moderate group (mean, 50.57 mm^2) and 12.46 mm^2 smaller in severe group (mean, 48.75 mm^2), each compared to 61.21 mm^2 in control group. A consistent difference between genders was suggested of size 2.29 mm^2 (M>F), which applies in each group.

For L7: A consistent difference was suggested between genders of size 4.04 mm^2 (M>F).

See appendix 4 tables for further descriptive details.

Summary of Ab findings

The results summary for the area dimensions for different teeth, obtained from the buccal view (Ab) revealed the following:
Genders were combined in all tooth types and multi-group comparison tests and final adjusment of significance levels revealed:

1) The Ab mean values in each hypodontia groups were significantly smaller than in the control group for teeth U1, U2, U3, U4, U5, U6, L1, L2, L3, L4, L5 and L6.
2) The Ab mean value in mild and moderate hypodontia was statistically smaller than in the control group for tooth U7.
3) The Ab in severe hypodontia was also significantly smaller than in the mild hypodontia group for teeth U1, U6 and L2.
4) The Ab mean values were significantly larger in males than in females in each group for tooth L3.

Table 59: Summary results of area measurements from buccal aspect (Ab)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
	Gender		0.098	0.161	0.345	0.321	0.058	0.001	0.150	0.107	0.192	0.000	0.009	0.319	0.076	0.026
	Group & Gender		0.693	0.586	0.584	0.611	0.691	0.811	0.976	0.955	0.709	0.316	0.427	0.593	0.797	0.716
Multi-group comparisons	0	1	**	**	**	**	**	**	**	**	**	**	**	**	**	
		2	**	**	**	**	**	**	(*)	**	**	**	**	**	**	*
		3	**	**	**	**	**	**	(*)	**	**	**	**	**	**	(*)
	1	2				*										
		3	**		*	*		**		*	**	*			*	
	2	3	*					*			*					

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 4 tables.

7.3.7. Findings for Crown Index of Buccal Morphology 1

Table 60 demonstrates the results of the 1st crown index measurement of buccal surface morphology (CIBM1 i.e. the ratio of MDb/OG) for different teeth. The details of descriptive data of group and subgroup means and differences are shown in appendix 5, tables 1-38. The following are the main findings for CIBM1:

Genders separately analysed:

Significant interactions were found for teeth U5, L2 and L3 indicating that differences between groups were different for males and females (see table 60 for p-values and figures 48-50).

For U5, L2 and L3 in females: Only for L3, each of control and mild hypodontia group CIBM1 mean value was smaller than the severe group mean, but these groups did not (generally) differ amongst themselves.

There is evidence for differences between female moderate hypodontia and each of female control and mild group for U5 (F2>F0 and F1).

Differences were also suggested but failed to retain significance after final adjustment between female mild and severe group for L2 and between female severe CIBM1 mean and moderate hypodontia mean for L3 (F3>F1 and F2). Detail was shown in table 60 and appendix 5 tables.

For L3: Difference between female severe group mean CIBM1 (mean, 0.92) and control group (mean, 0.78) = 0.14 and with female mild group (mean, 0.76), difference = 0.16.

For U5, L2 and L3 in males: Only for L2, a difference was suggested between male control and mild hypodontia (M0>M1) but was not significant after final adjustment (table 60).

Finally, for U5 and L3, differences between genders were suggested (Table 60) in moderate groups (F2>M2) and severe groups (F3>M3) respectively but these failed to retain significance after final adjustment. See appendix 5 tables for detail.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender.

Significant differences between group means were found for U2, U3, U4, U6, L1, L6 and L7 (see table 60 for p-values).

For U6, control group CIBM1 mean value was smaller than severe hypodontia mean, while for L6, in the mild hypodontia group the mean was found to be smaller than the severe group.

This was with evidence of differences between control and severe group means (for L6) and between mild and severe means (for U6 and L1).

Suggested differences were found but all unretained after final adjustments between control and moderate CIBM1 means (for U3, U4 and L6), between control and severe group means (for U3, L1 and L7), between mild and moderate CIBM1 means (for U4 and L6) and finally between moderate and severe means (for U6). The index value is smaller in control group and increases with an increase in severity of hypodontia. See table 60 and tables of appendix 5.

For U6: Difference in CIBM1 values between control group (mean, 2.10) and severe hypodontia group (mean, 2.43) = 0.33.

For L6: CIBM1 value found to be 0.24 smaller in mild hypodontia (mean, 1.94) than severe hypodontia group (mean, 2.18).

For U2: A consistent difference between genders was suggested of size 0.04 (F>M).

For L4 and L5: A consistent difference was suggested between genders of size 0.03 and 0.06 (F>M) respectively. See appendix 5 tables for further descriptive details.

Summary of CIBM1 findings

The results for the crown index of buccal morphology 1 for different teeth are summarised:

1) *When the genders were analysed separately for teeth U5, L2 and L3; multi-subgroup comparison tests and final adjustment of significance levels revealed:*
   Only L3 in females, the CIBM1 mean values in the severe hypodontia were significantly larger than mean values in each of control and mild hypodontia group.

2) *When genders were combined for teeth U2, U3, U4, U6, L1, L6 and L7; multi-group comparison tests and final adjustment of significance levels revealed:*
   The mean values of CIBM1 in the severe hypodontia group were significantly larger than means of control (for U6) and mild hypodontia group (for L6).

Table 60: Summary results of crown index of buccal morphology-1 (CIBM1)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.496	0.077	0.008	0.010	0.007	0.000	0.368	0.006	0.091	0.003	0.243	0.816	0.000	0.046
	Gender		0.920	0.031	0.534	0.931	0.002	0.110	0.944	0.186	0.277	0.501	0.017	0.008	0.370	0.974
	Group & Gender		0.681	0.490	0.856	0.833	0.032	0.914	0.201	0.861	0.005	0.004	0.112	0.168	0.977	0.531
Multi-group comparisons	0	1														
		2			*	*									*	
		3			*			**		*					(*)	*
	1	2				*									*	
		3						(*)		(*)					**	
	2	3						*								
Multi-subgroup comparisons	Mo	M1									*					
		M2														
		M3														
	F0	F1														
		F2					(*)									
		F3										**				
	M1	M2														
		M3														
	F1	F2					(*)									
		F3									*	**				
	M2	M3														
	F2	F3										*				
	M0	F0														
	M1	F1														
	M2	F2					*									
	M3	F3										*				

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) or subgroup ($n = 16$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 5 tables.

Figure 48: Estimated Means of CIBM1 for tooth U5

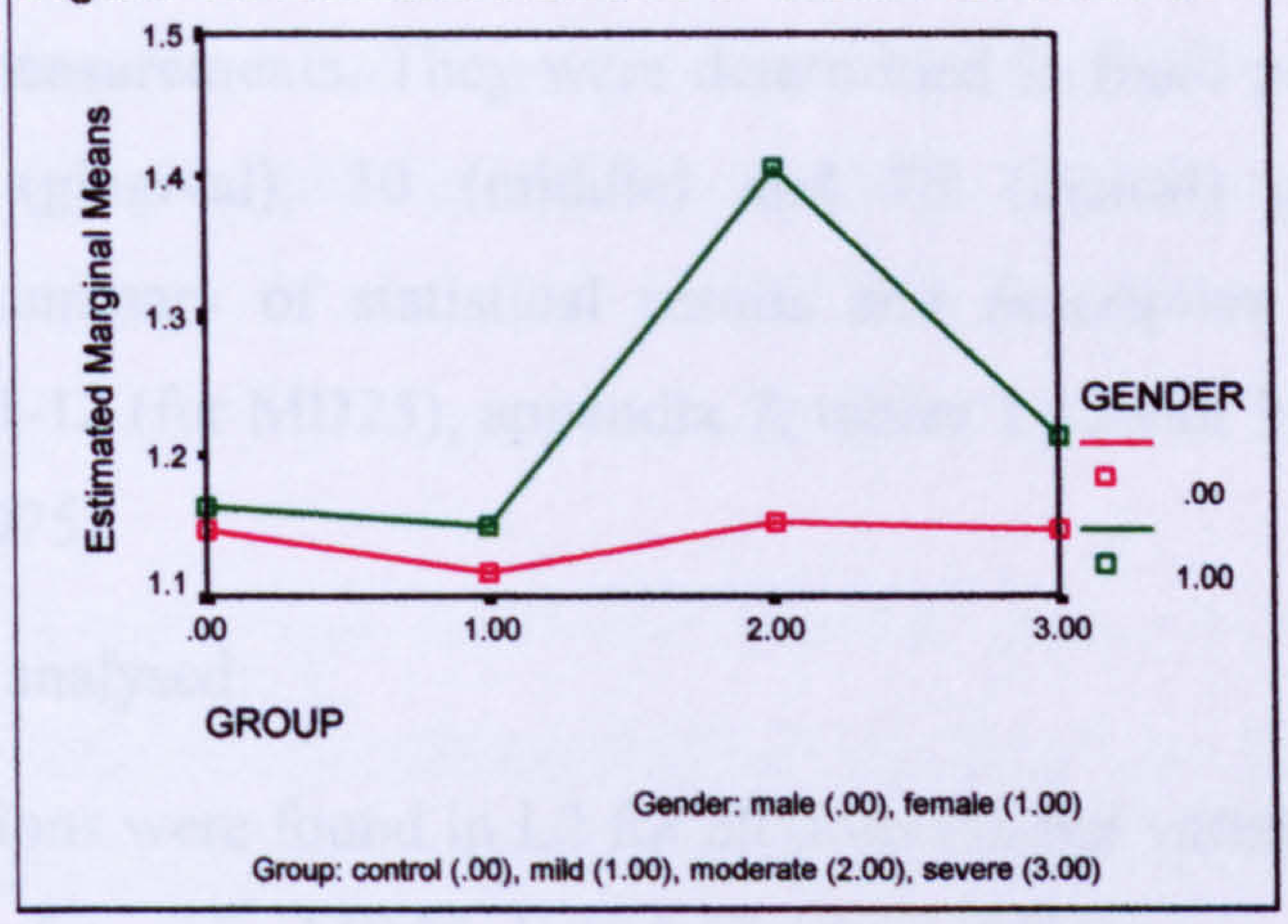


Figure 49: Estimated Means of CIBM1 for tooth L2

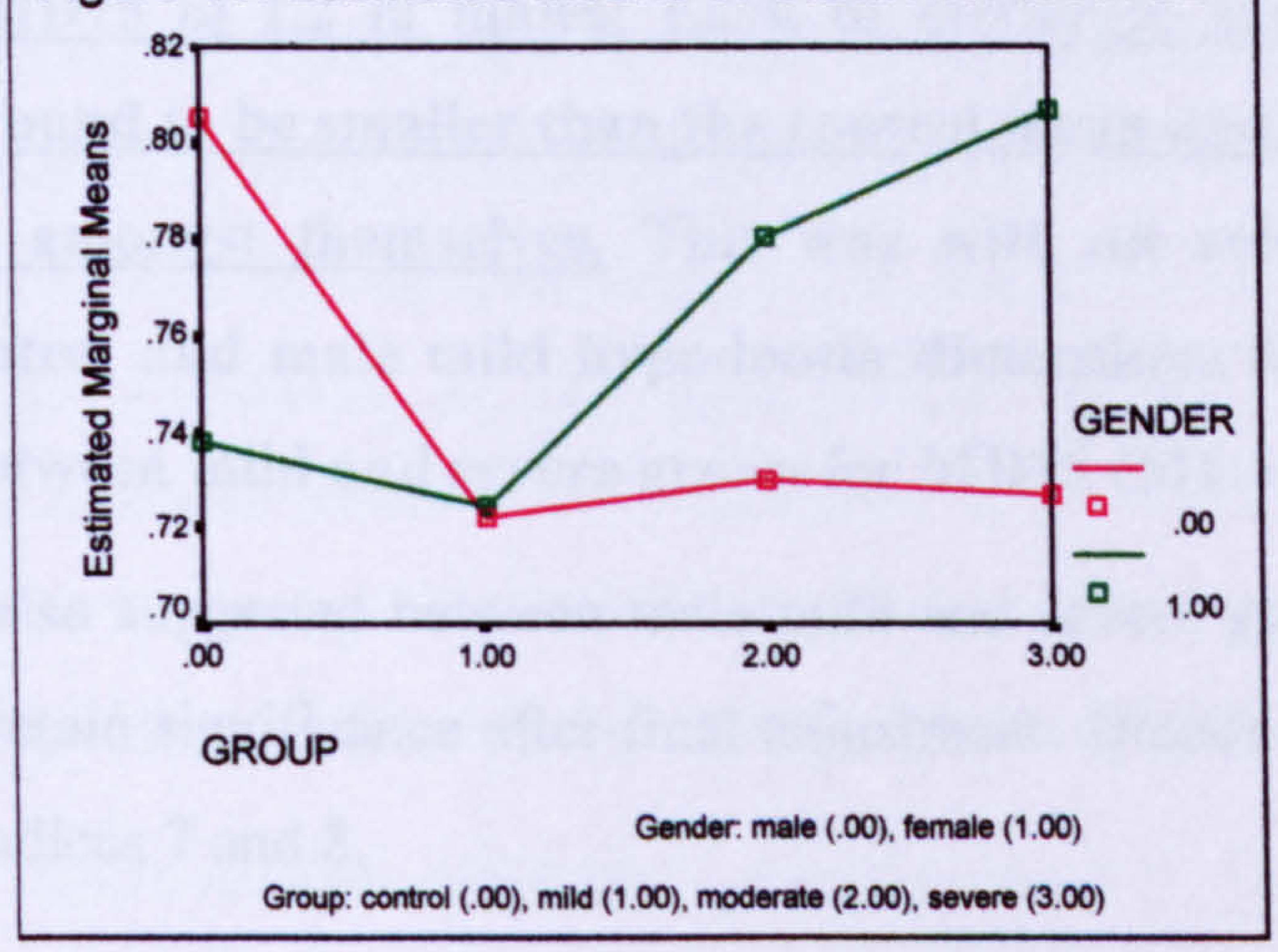
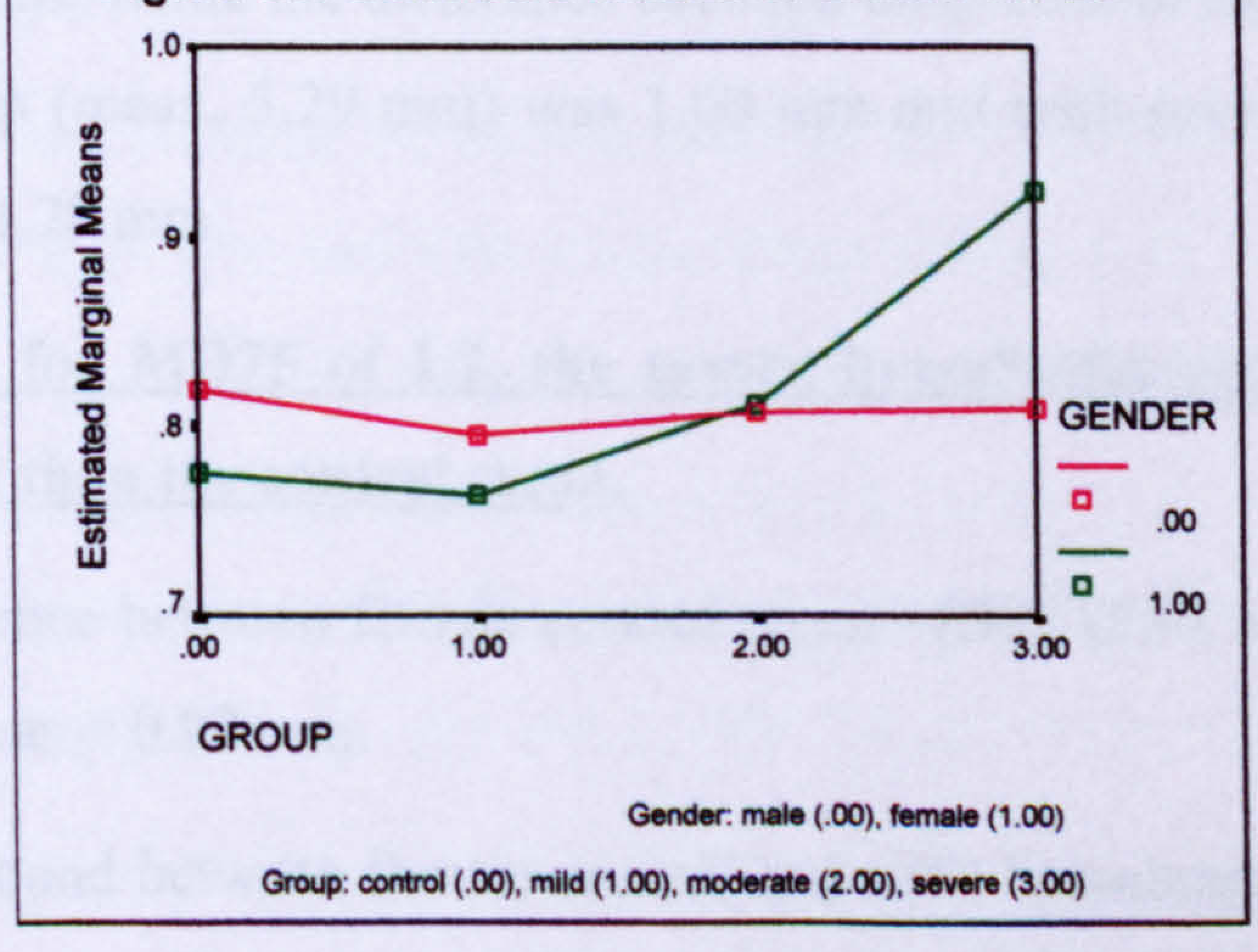


Figure 50: Estimated Means of CIBM1 for L3



7.3.8. Proportional Mesiodistal Measurements From Buccal Aspect

These three buccal variables (MD25, MD50 and MD 75) are related to incisor teeth and tooth taper index measurements. They were determined in fixed proportion crossing OG dimension at 25 (gingival), 50 (middle) and 75 (incisal) percentiles. Table 61 demonstrates the summary of statistical results and descriptive details are shown in appendix 6, tables 1-12 (for MD25), appendix 7, tables 1-12 (for MD50) and appendix 8, tables 1-12 (for MD75).

Genders separately analysed:

Significant interactions were found in L2 for all proportional variables MD25, MD50 and MD75 and in L1 for only MD25 indicating that differences between groups were different for males and females (See table 61 for p-values and figures 51-54).

For MD50 and MD75 of L2 in males: Each of moderate and severe hypodontia group mean was found to be smaller than the control mean and these groups did not (generally) differ amongst themselves. This was with an evidence of differences between male control and male mild hypodontia dimensions for MD50 and MD75 (M0 > M1) and between mild and severe group for MD75 (M1 > M3).

A difference was also suggested between male mild and severe group for MD50 (M1 > M3) but failed to retain significance after final adjustment. Details are shown in table 61 and tables of appendices 7 and 8.

For L2: Difference between male control mean MD50 (5.86 mm) and moderate hypodontia group (mean, 5.04 mm) = 0.82 mm and with severe group (mean, 4.92 mm), difference = 0.94 mm. While the difference between male control mean MD75 (6.29 mm) and moderate group (mean, 5.29 mm) was 1.00 mm and with severe group (mean, 5.01 mm), difference = 1.28 mm.

In females: Only for MD75 of L2, the severe hypodontia group mean presented smaller dimension than the control mean.

For L2: The difference between female control mean MD75 (5.98 mm) and severe group (mean, 5.06 mm) was = 0.92 mm.

Differences were found between female control and mild hypodontia mean (for MD75 of L2) and between severe mean and each of the mild (for MD25 of L1 and L2: F3 > F1 and

MD75 of L2: F1 > F3) and moderate (for MD75 of L2) means. Howevere, none of these differences retained significance after final adjustment.

A difference between genders was suggested for MD25 and MD50 in L2 between control groups (M > F) but did not retain significance after final adjustment.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. **Significant differences between group means were found for U1 and U2 (in all three variables) and L1 (in MD50 and MD75),** see table 61 for p-values.

With the exception of U1 and U2 (for MD25) in the above list, each hypodontia group was found to be smaller than the control group. U1 (for MD25), each of mild and severe group (not moderate) was smaller than controls. However, for all but one, the proportional dimensions of hypodontia groups did not differ among themselves. For U1 (MD75), statistically smaller dimensions were detected in the severe group when compared to the mild group. These with an evidence of differences in U1 between control and moderate hypodontia group (for MD25), between mild and severe group (for MD50) and between moderate and severe group (for MD75) i.e. dimension getting smaller with an increase in severity of hypodontia.

Differences were suggested but unretained significance: For MD50 of U1, between moderate and severe hypodontia group and for MD25 of U2, between control and each of hypodontia groups i.e. the severe the hypodontia, the smaller is the dimension. See table 61 and tables of appendices 6-8.

For MD25: Difference between U1 control mean (7.55 mm) and mild hypodontia group (mean, 6.85 mm) = 0.70 mm, and with severe group (mean, 6.78 mm), difference = 0.77 mm.

For MD50: U1 Dimension was found to be 0.80 mm smaller in mild hypodontia group (mean, 8.19 mm), 0.94 mm smaller in moderate group (mean, 8.05 mm) and 1.35 mm smaller in severe group (mean, 7.64 mm), each compared to 8.99 mm in the control group.

U2 Dimension was found to be 1.42 mm smaller in mild hypodontia group (mean, 5.49

mm), 1.28 mm smaller in moderate group (mean, 5.63 mm) and 1.37 mm smaller in severe group (mean, 5.54 mm), each compared to 6.91 mm in the control group.

L1 Dimension was found to be 0.50 mm smaller in mild hypodontia group (mean, 4.70 mm), 0.45 mm smaller in moderate group (mean, 4.75 mm) and 0.43 mm smaller in severe group (mean, 4.77 mm), each compared to 5.20 mm in the control group.

For MD75: U1 Dimension was found to be 0.82 mm smaller in mild hypodontia group (mean, 8.29 mm), 1.05 mm smaller in moderate group (mean, 8.06 mm) and 1.70 mm smaller in severe group (mean, 7.41 mm), each compared to 9.11 mm in the control group.

U2 Dimension was found to be 1.81 mm smaller in mild hypodontia group (mean, 5.26 mm), 1.86 mm smaller in moderate group (mean, 5.21 mm) and 1.99 mm smaller in severe group (mean, 5.08 mm), each compared to 7.07 mm in the control group.

L1 Dimension was found to be 0.58 mm smaller in mild hypodontia group (mean, 5.08 mm), 0.60 mm smaller in moderate group (mean, 5.06 mm) and 0.73 mm smaller in severe group (mean, 4.93 mm), each compared to 5.66 mm in the control group.

For further details, see appendices 6-8.

Summary of proportional MDs findings

The results of these proportional mesiodistal dimensions for the incisor teeth are summarised as follows:

1) For MD75 dimension:

a) When the genders were analysed separately for tooth L2; multi-subgroup comparison tests and final adjustment of significance levels revealed:

In males, L2 measurements in moderate and severe hypodontia were significantly less than in the control group.

In females, L2 measurements only in severe hypodontia were significantly less than in the control group.

b) When the genders were combined for teeth U1, U2 and L1; multi-group comparison tests and final adjustment of significance levels revealed:

The measurement in each hypodontia group was significantly less than in control group.

The measurement in severe hypodontia was also significantly less than in the mild hypodontia group in U1.

2) For MD50 dimension:

a) When the genders were analysed separately for tooth L2; multi-subgroup comparison tests and final adjustment of significance levels revealed:

The measurements in moderate and severe hypodontia were significantly smaller than in the control group and that was related to males only.

b) When the genders were combined for teeth U1, U2 and L1; multi-group comparison tests and final adjustment of significance levels revealed:

The measurement in each hypodontia group was significantly smaller than in the control group.

3) For MD25 dimension:

When the genders were combined for tooth U1; multi-group comparison tests and final adjustment of significance levels revealed:

The U1 measurements in mild and severe hypodontia groups were significantly smaller than in the control group.

Table 61: Summary results of proportional mesiodistal measurements from buccal aspect (MD25, MD50, MD75)

Statistical Tests			MD25				MD50				MD75			
			U1	U2	L1	L2	U1	U2	L1	L2	U1	U2	L1	L2
2-way ANOVA (P-values)	Group		0.000	0.000	0.067	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Gender		0.261	0.404	0.500	0.089	0.304	0.925	0.408	0.418	0.243	0.290	0.424	0.849
	Group & Gender		0.571	0.779	0.039	0.017	0.797	0.774	0.204	0.000	0.807	0.511	0.713	0.036
Multi-group comparisons	0	1	**	*			**	**	**		**	**	**	
		2	(*)	*			**	**	**		**	**	**	
		3	**	*			**	**	**		**	**	**	
	1	2												
		3					(*)				**			
	2	3					*				(*)			
Multi-subgroup comparisons	Mo	M1								(*)				(*)
		M2								**				**
		M3								**				**
	F0	F1												*
		F2												
		F3												**
	M1	M2												
		M3								*				(*)
	F1	F2												
		F3			*	*								*
	M2	M3												
	F2	F3												*
	M0	F0				*				*				
	M1	F1												
	M2	F2												
	M3	F3												

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendices 6-8 tables.

Figure 51: Estimated Means of MD25 for tooth L1

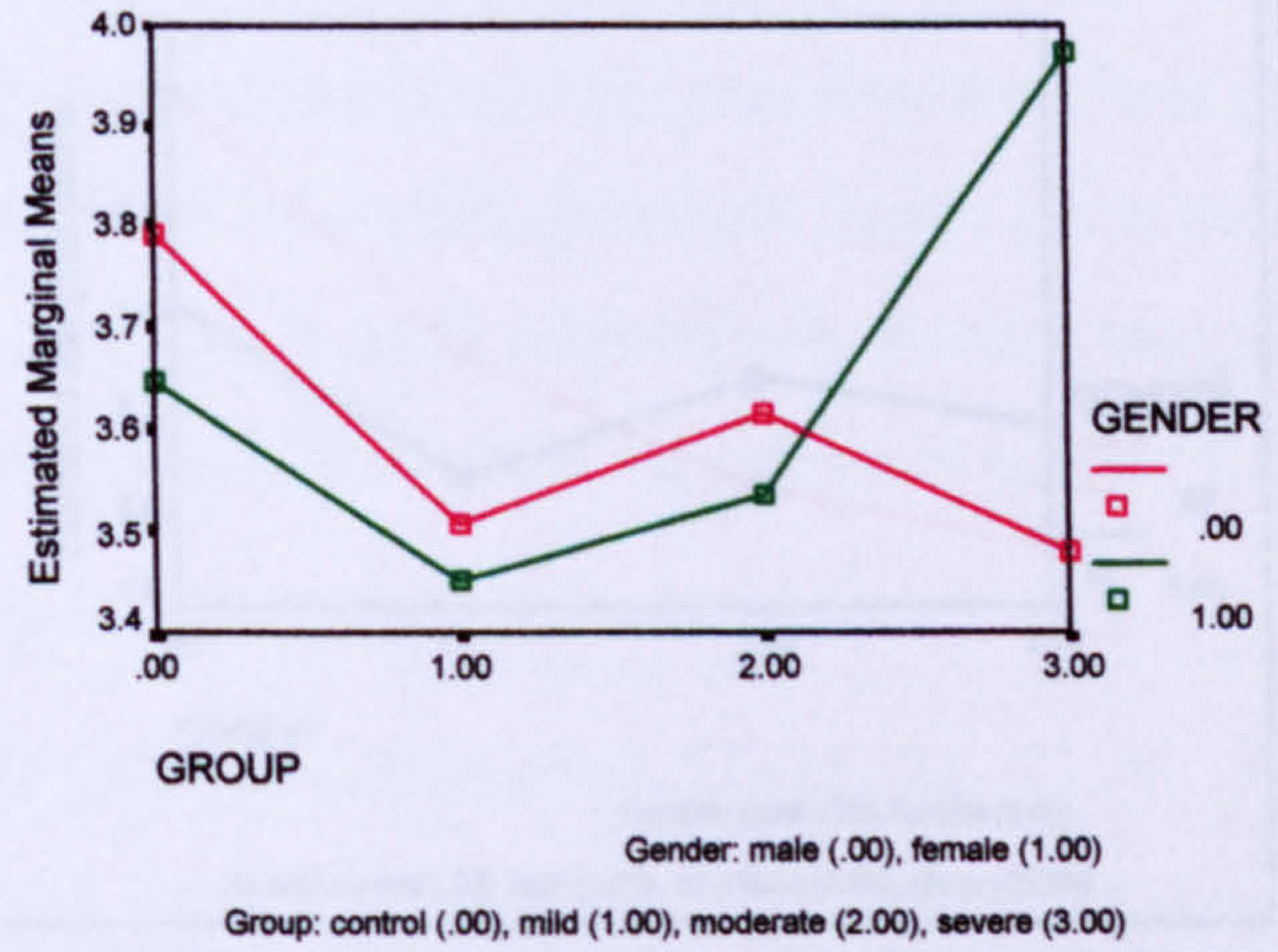


Figure 52: Estimated Means of MD25 for tooth L2

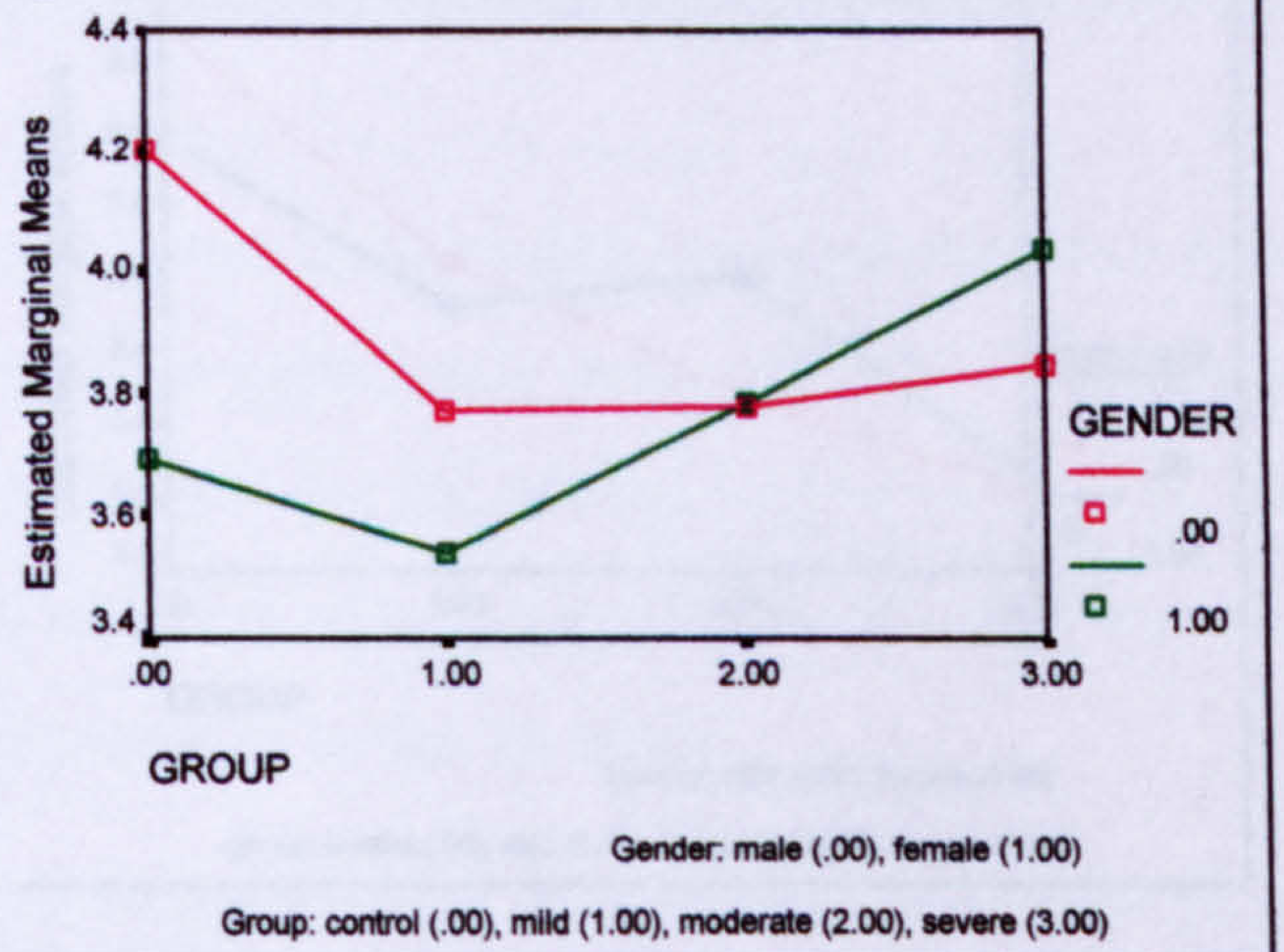


Figure 53: Estimated Means of MD50 for tooth L2

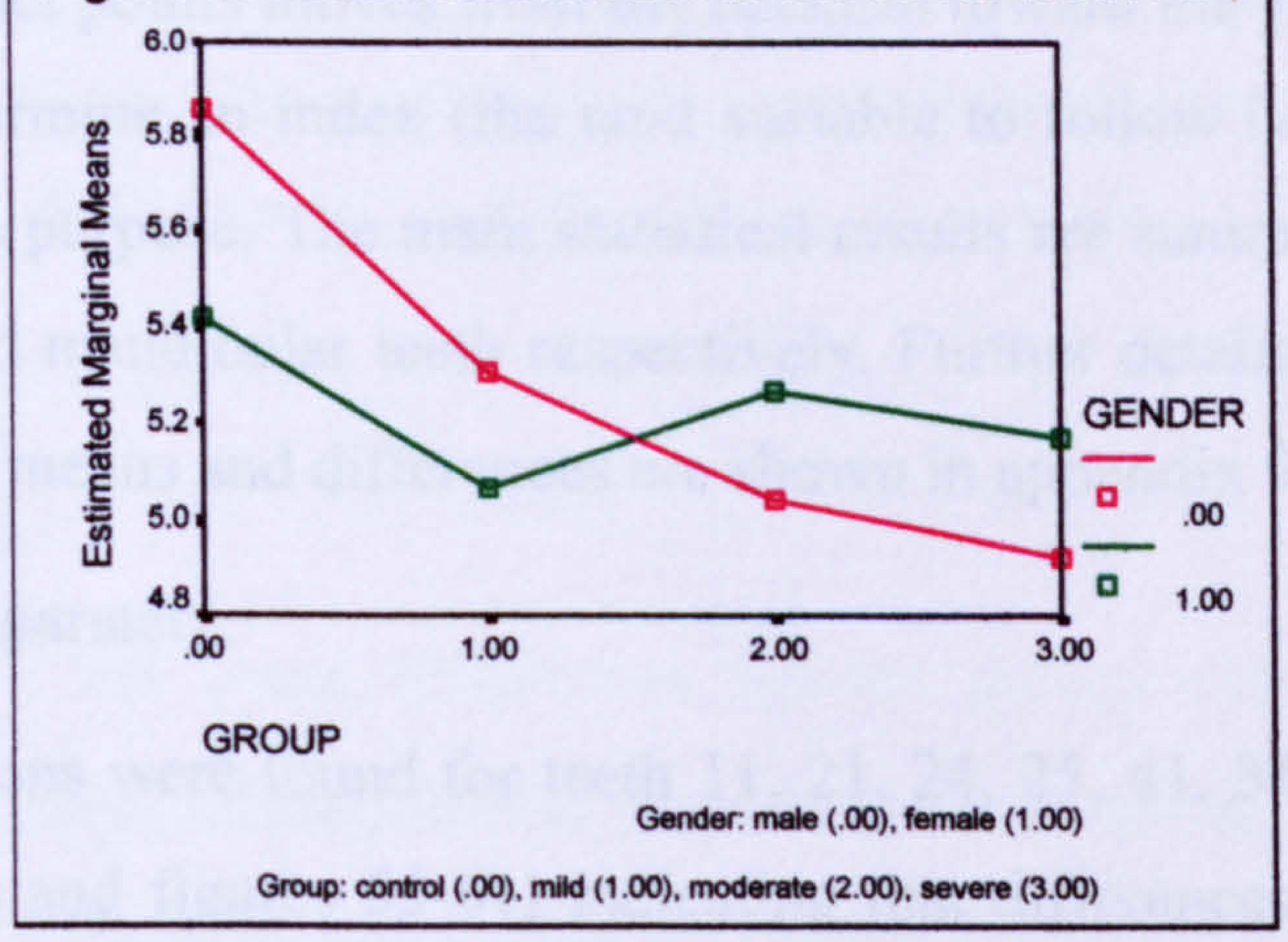
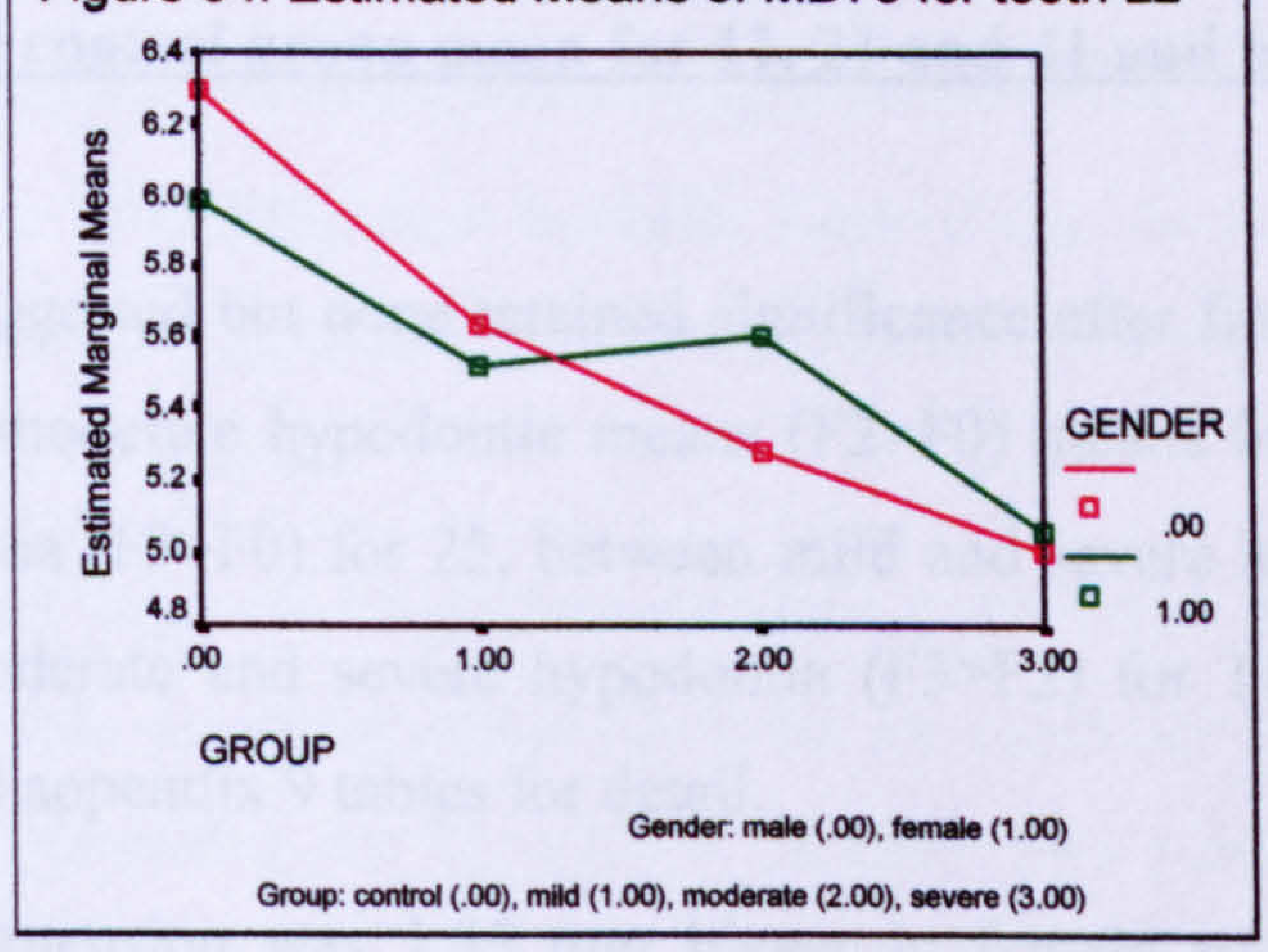


Figure 54: Estimated Means of MD75 for tooth L2



7.3.9. Db Measurements

The distance between the mesiodistal dimension and occlusal outline of perimeter for the buccal view (Db) was determined across the occlusogingival dimension. This permits evaluation the level of MDb in various groups (i.e. for how far the MDb or the line connecting the contact points moves from the occlusal toward the gingival level). Another purpose was to determine an index (the next variable to follow i.e. CIBM2) that can be used for comparison purpose. The main statistical results are summarised in tables 62 and 63 for maxillary and mandibular teeth respectively. Further details of descriptive data of group and subgroup means and differences are shown in appendix 9, tables 1-72.

Genders analysed separately:

Significant interactions were found for teeth 11, 21, 24, 25, 41, 34 and 46 (see tables 62 and 63 for p-values and figures 55-61) indicating that differences between groups were different for males and females.

In females: Severe hypodontia group Db mean value was found to be statistically bigger than each of control group mean for 11, 21 and 41 and mild group for 11 and 21.

Differences were suggested but none retained significance after final adjustment between female control and moderate hypodontia means (F2>F0) means for 21, between control and severe hypodontia (F3>F0) for 25, between mild and severe hypodontia (F3>F1) for 41 and between moderate and severe hypodontia (F3>F2) for 11, 21, 25 and 41. See tables 62 and 63 and appendix 9 tables for detail.

For 11: The Db dimension was 1.55 mm bigger in female severe hypodontia group (mean, 4.34 mm) than control group (mean, 2.79 mm) and 1.30 mm bigger than mild hypodontia group (mean, 3.04 mm).

For 21: The Db dimension was 1.84 mm bigger in female severe hypodontia group (mean, 4.37 mm) than control group (mean, 2.53 mm) and 1.50 mm bigger than mild hypodontia group (mean, 2.87 mm).

For 41: The difference between severe hypodontia (mean, 2.29 mm) and control (mean, 1.37 mm) was 0.92 mm.

In males: Suggested differences were found but did not retain significance after final adjustment between male control and moderate hypodontia (M0>M2) for 24 and between mild and severe hypodontia group (M1>M3) for 46 (Tables 67 and 68 and appendix 1, tables A289-372).

Finally, **some evidence for a gender difference between severe groups Db (F3>M3) was found (F3>M3) for 41.** Another differences between genders were also found but with unretianed significance between control groups (Mo>F0) for 25 and between severe groups (F3>M3) for 46. (Tables 62 and 63 and appendix 9 tables).

Genders combined:

Where no interaction was found, differences between groups did not depend on gender. **Significant differences between group means were found for most of other tooth types: 12, 22, 14, 16, 32, 42, 33, 45 and 36** (see tables 62 and 63 for p-values).

The control group presented smaller Db mean value than each of moderate hypodontia for 12 and severe hypodontia for 32 and 42. Mild hypodontia also showed a smaller mean value than severe hypodontia for 42.

There is an evidence of a difference between control and severe group (0<3) for 33, between mild and severe hypodontia (1<3) for 32 and between moderate and severe hypodontia (2<3) for 32 and 42.

Differences were also suggested but none retained significance between control group and each of mild hypodontia group means (0<1) for 45, moderate hypodontia (0>2) for 14 and 36 and severe hypodontia for 12, 22 and 36 (0<3 for 12 and 22 and 0>3 for 36), between mild and evere hypodontia for 16 (1>3) and 33 (1<3) and between moderate and severe hypodontia for 16 (2>3) and 33 (2<3). See tables 67 and 68 and appendix 9 tables for detail.

For 12: The Db value was found to be 0.71 mm bigger in the moderate hypodontia group (mean, 3.45 mm) than in the control group (mean, 2.74 mm). **In addition to a group difference, an evidence for consistent difference between genders (P2 = 0.266) of size 0.47 mm (M>F), which applies in each group.**

For 32: The Db mean value was found to be 0.85 mm bigger in the severe hypodontia group (mean 2.61 mm) than in the control group (mean, 1.76 mm).

For 42: The value was 0.75 mm bigger in severe group (mean, 2.56 mm) when compared to 1.81 mm in control group. The diference was also bigger (0.56 mm) in the severe hypodontia than in mild hypodontia group (mean, 2.00 mm).

A consistent difference between gender was found (P2 = 0.073) of size 0.37 mm for tooth 43 that applies in each group (M > F). An evidence of consistent difference between genders was found for tooth 22 and 33 (P2 = 0.266) of size 0.40 and 0.38 mm respectively.

Finally, a consistent difference was suggested between genders for tooth 13 of size 0.24 mm. For further detail, see tables 62 and 63 and appendix 9 tables.

Summary of Db findings

The results for the distance between the mesiodistal dimension of the buccal view and the occlusal level for all teeth are summarised as follows:
1) When the genders were analysed separately for teeth 11, 21, 24, 25, 41, 34 and 46; multi-subgroup comparison tests and final adjustment of significance levels revealed:

Only in females, the Db mean values in severe hypodontia group were significantly larger than in the control group for teeth 11, 21 and 41. Moreover, the severe hypodontia group measurements were significantly larger than in the mild hypodontia group for teeth 11 and 21.

2) When genders were combined for teeth 12, 22, 14, 16, 32, 42, 33, 45 and 36; multi-group comparison tests and final adjustment of significance levels revealed:

The measurement values of Db in the severe hypodontia group were significantly larger than in the control group for teeth 32 and 42, and than in mild hypodontia group for tooth 42.

The mean values of moderate hypodontia were significantly larger than the control group for tooth 12.

A significant gender difference was also found across severity groups for tooth 43 suggesting larger figures in males than females.

Table 62: Summary results of Db measurements for maxillary teeth from buccal aspect

Statistical Tests			11	21	12	22	13	23	14	24	15	25	16	26	17	27
2-way ANOVA	Group		0.003	0.000	0.001	0.012	0.107	0.283	0.055	0.136	0.611	0.052	0.005	0.390	0.852	0.507
(P-values)	Gender		0.571	0.238	0.001	0.001	0.075	0.287	0.128	0.146	0.166	0.062	0.483	0.330	0.154	0.061
	Group & Gender		0.001	0.003	0.602	0.179	0.972	0.844	0.634	0.083	0.879	0.007	0.475	0.739	0.778	0.692
Multi-group comparisons	0	1														
		2			**				*							
		3			*	*										
	1	2														
		3											*			
	2	3											*			
Multi-subgroup comparisons	Mo	M1														
		M2								*						
		M3														
	F0	F1														
		F2		*												
		F3	**	**								*				
	M1	M2														
		M3														
	F1	F2														
		F3	**	**												
	M2	M3														
	F2	F3	*	*								*				
	M0	F0										*				
	M1	F1														
	M2	F2														
	M3	F3	*													

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 9 tables.

Table 63: Summary results of Db measurements for mandibular teeth from buccal aspect

Statistical Tests			31	41	32	42	33	43	34	44	35	45	36	46	37	47
2-way ANOVA (P-values)	Group		0.366	0.020	0.000	0.000	0.002	0.607	0.505	0.639	0.157	0.036	0.033	0.274	0.172	0.768
	Gender		0.843	0.004	0.346	0.455	0.001	0.000	0.146	0.167	0.881	0.255	0.279	0.022	0.264	0.410
	Group & Gender		0.561	0.006	0.509	0.138	0.566	0.455	0.091	0.396	0.372	0.967	0.128	0.030	0.813	0.724
Multi-group comparisons	0	1										*				
		2											*			
		3			**	**	(*)						*			
	1	2														
		3			(*)	**	*									
	2	3			(*)	(*)	*									
Multi-subgroup comparisons	Mo	M1														
		M2														
		M3														
	F0	F1														
		F2														
		F3		**												
	M1	M2														
		M3												*		
	F1	F2														
		F3		*												
	M2	M3														
	F2	F3		*												
	M0	F0														
	M1	F1														
	M2	F2														
	M3	F3		(*)										*		

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels (P2 ≤0.10) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: P1 ≤0.00375 adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. 0.10 < P2 < 1.00 after final adjustment for significance levels.
** Other findings: P1 ≤0.10 but P2 ≥ 1.00 after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 9 tables.

Figure 55: Estimated Means of Db for tooth 11

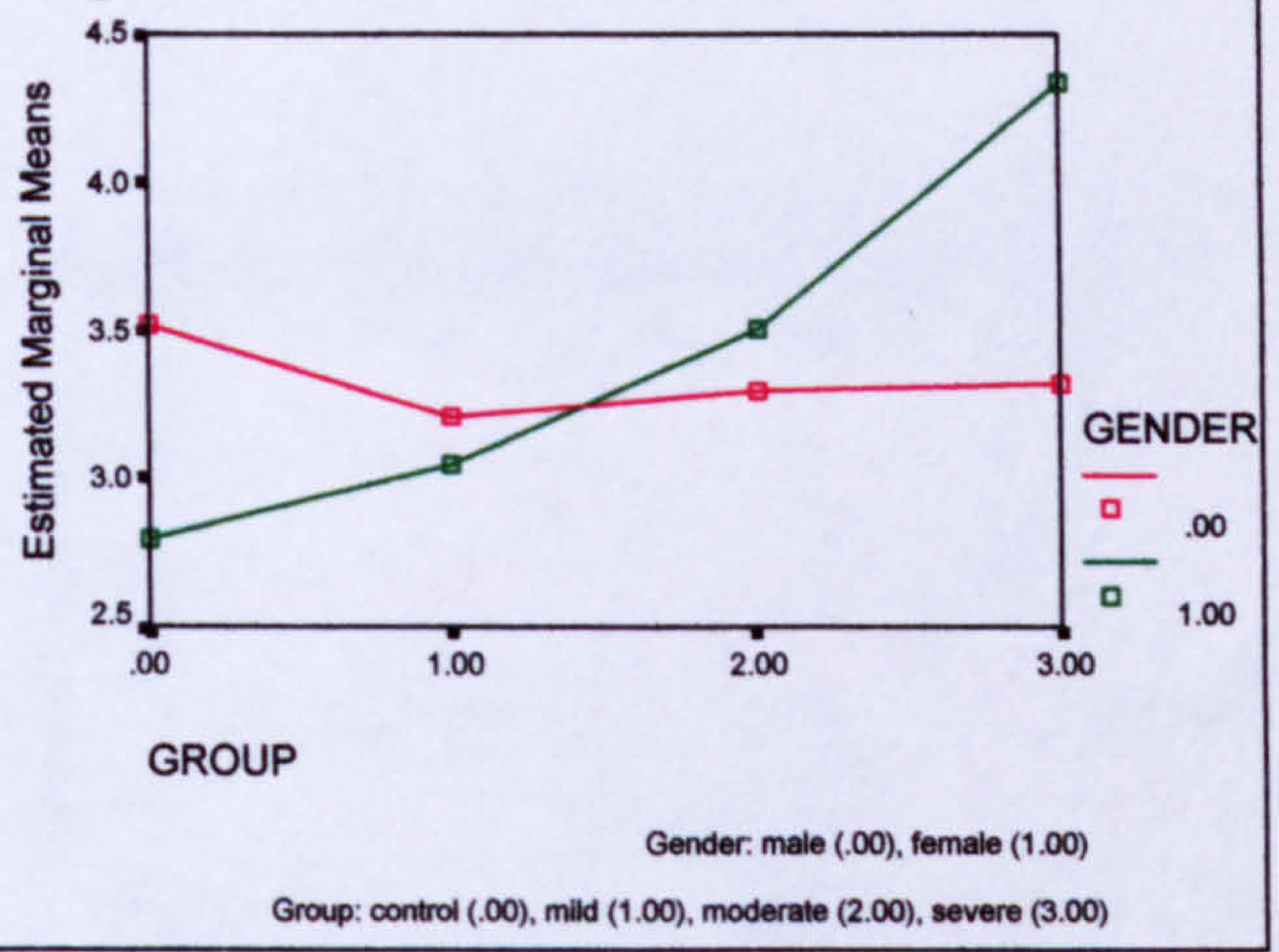


Figure 56: Estimated Means of Db for tooth 21

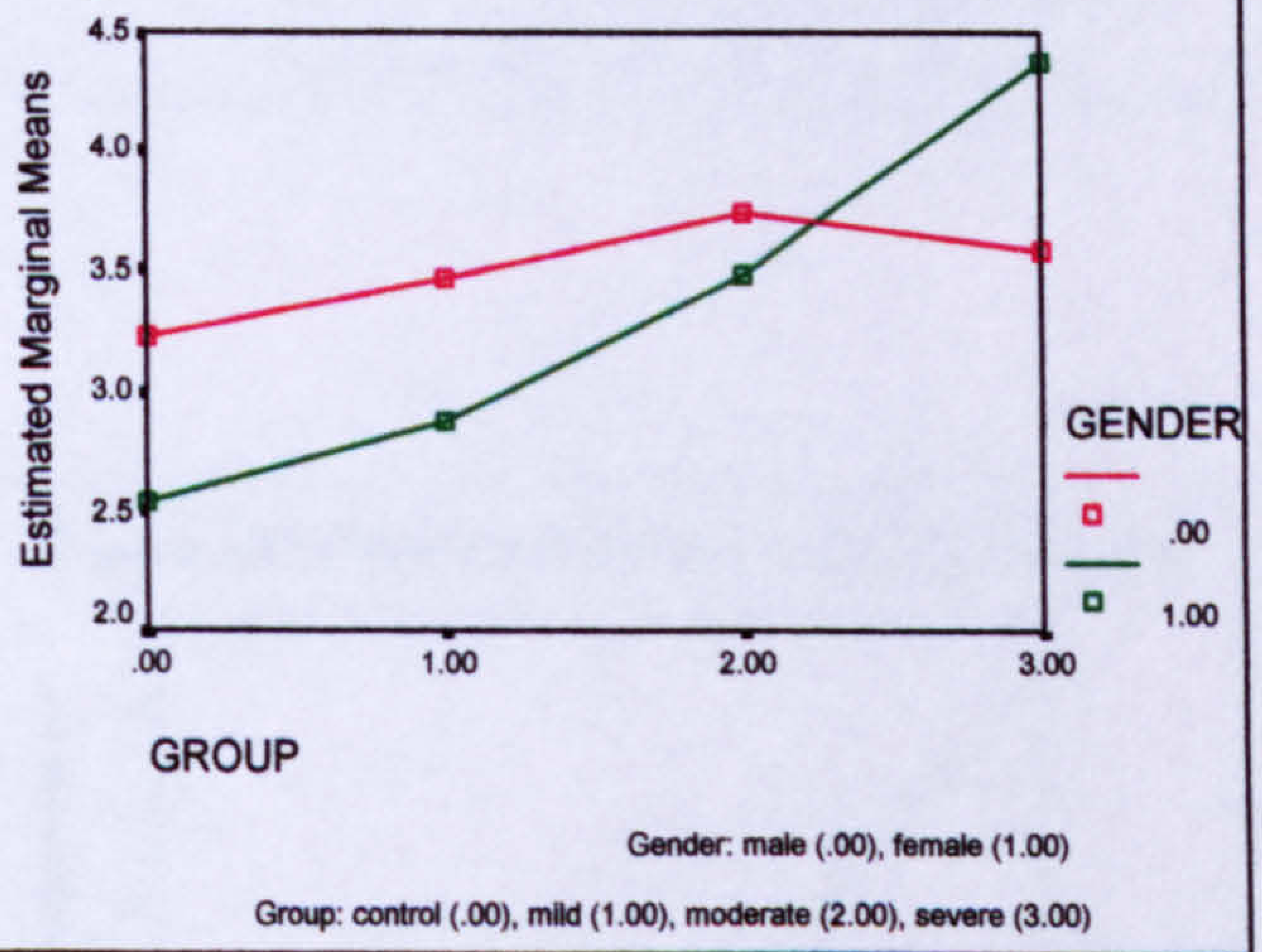
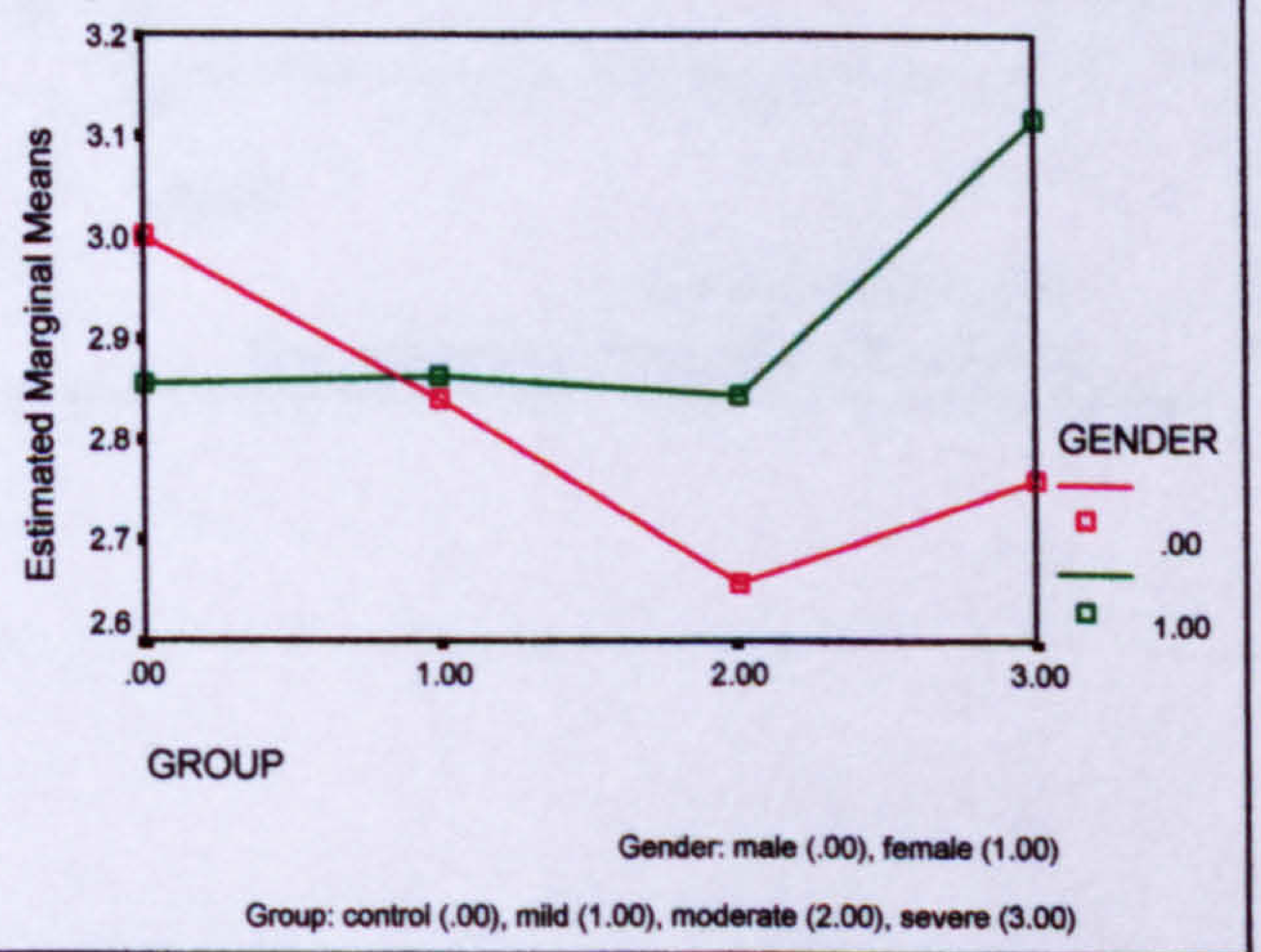


Figure 57: Estimated Means of Db for tooth 24



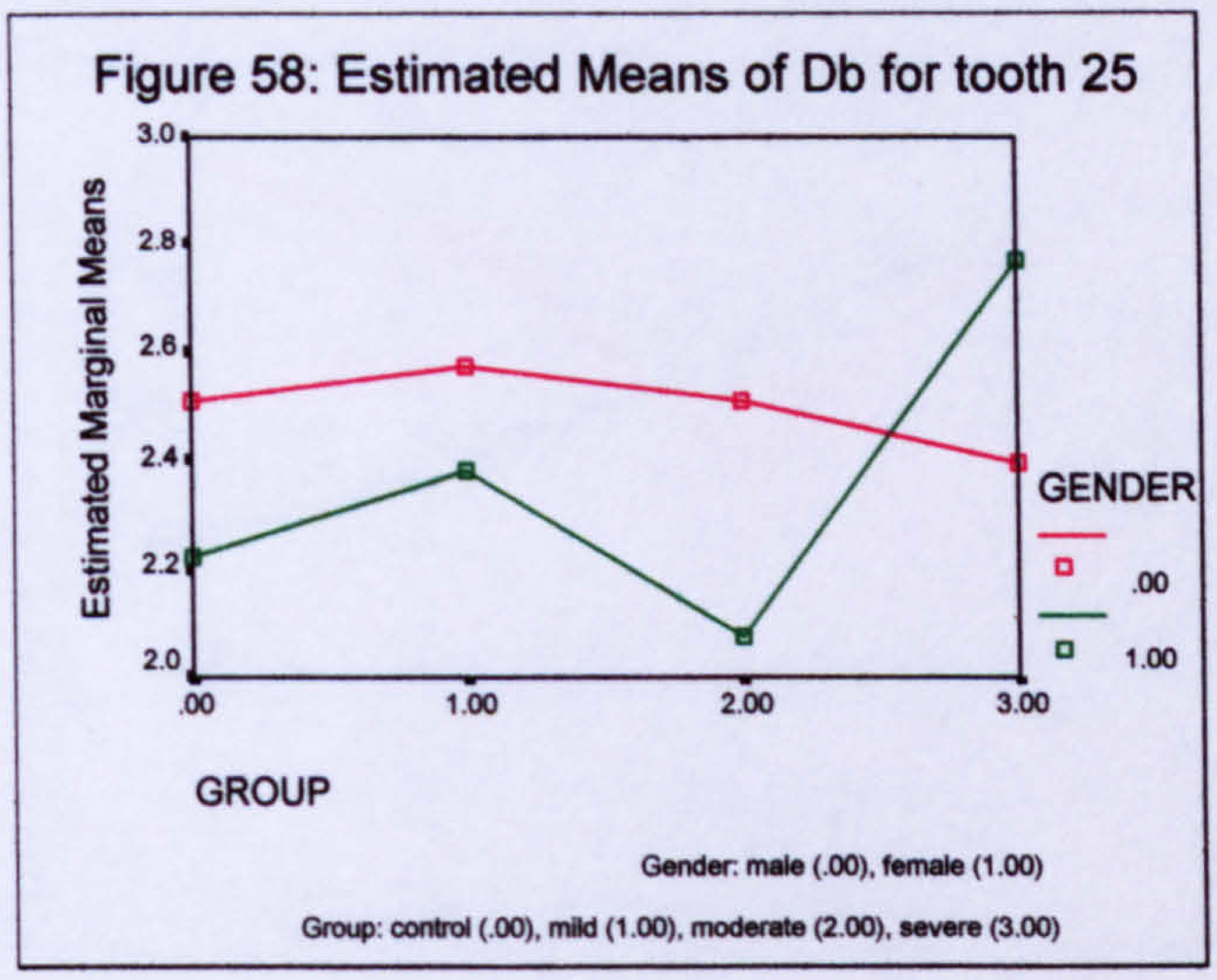


Figure 58: Estimated Means of Db for tooth 25
Estimated Marginal Means
3.0
2.8
2.6
2.4
2.2
2.0
.00
1.00
2.00
3.00
GROUP
GENDER
.00
1.00
Gender: male (.00), female (1.00)
Group: control (.00), mild (1.00), moderate (2.00), severe (3.00)

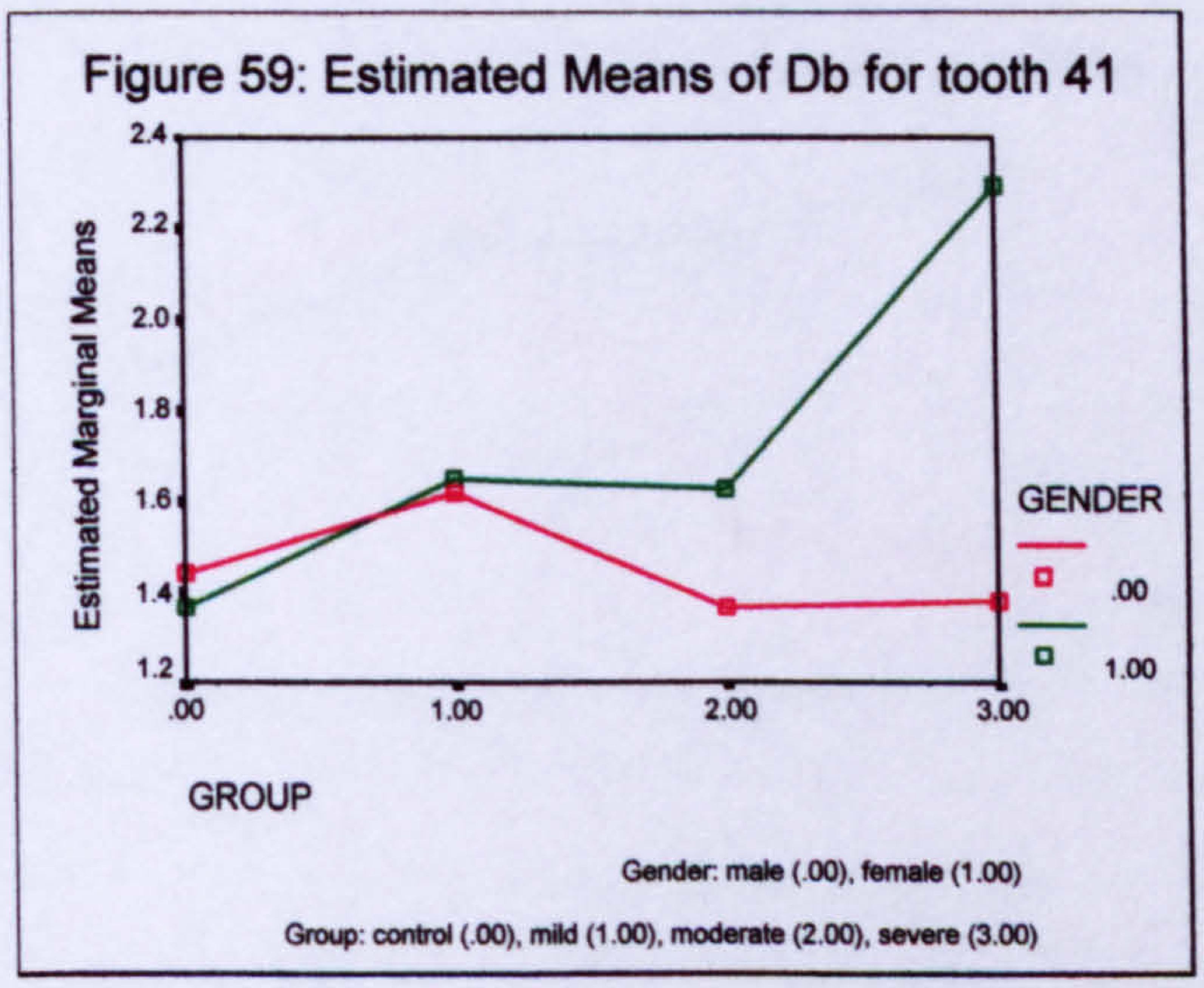


Figure 59: Estimated Means of Db for tooth 41
Estimated Marginal Means
2.4
2.2
2.0
1.8
1.6
1.4
1.2
.00
1.00
2.00
3.00
GROUP
GENDER
.00
1.00
Gender: male (.00), female (1.00)
Group: control (.00), mild (1.00), moderate (2.00), severe (3.00)

Figure 60: Estimated Means of Db for tooth 34

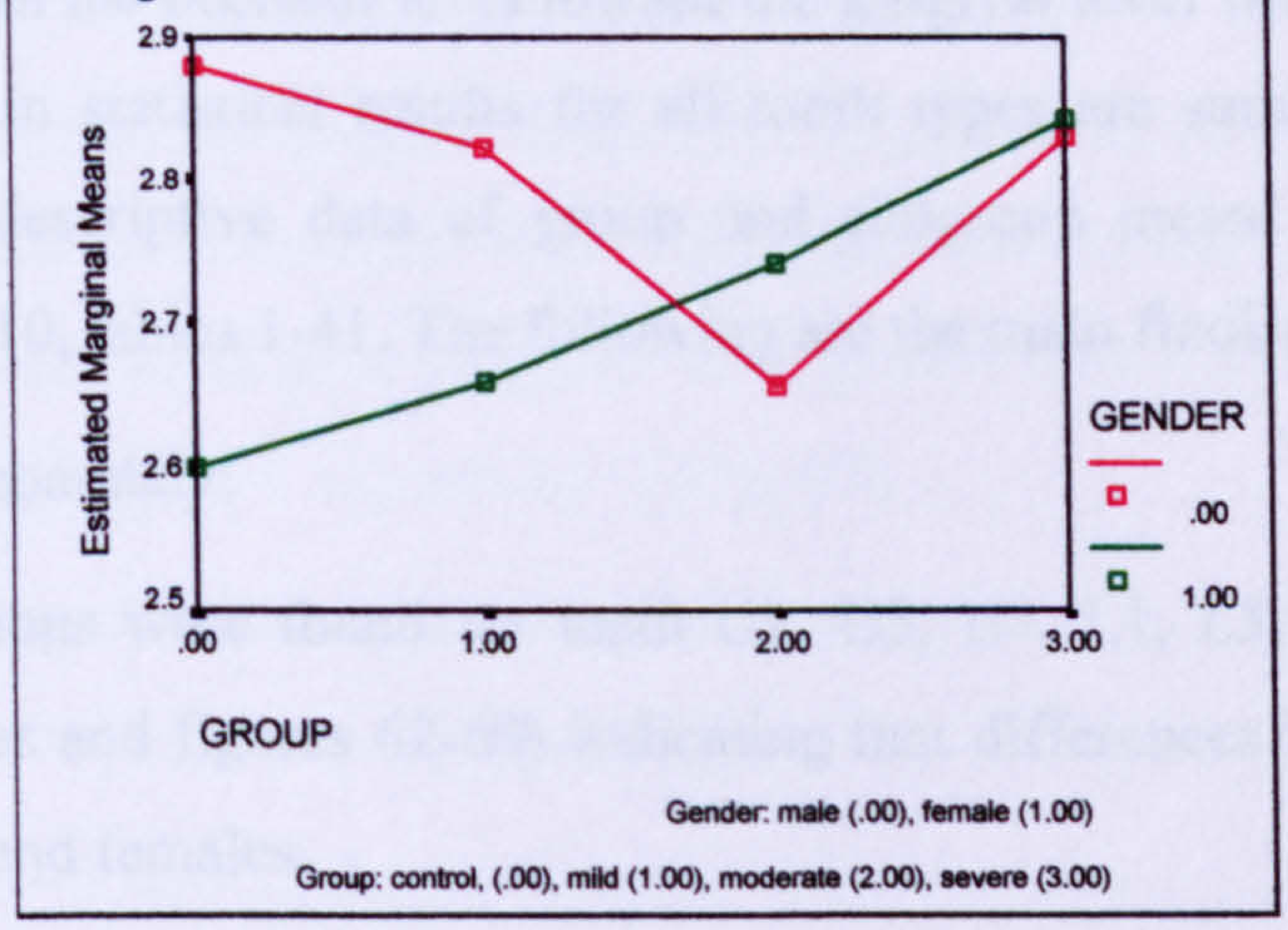
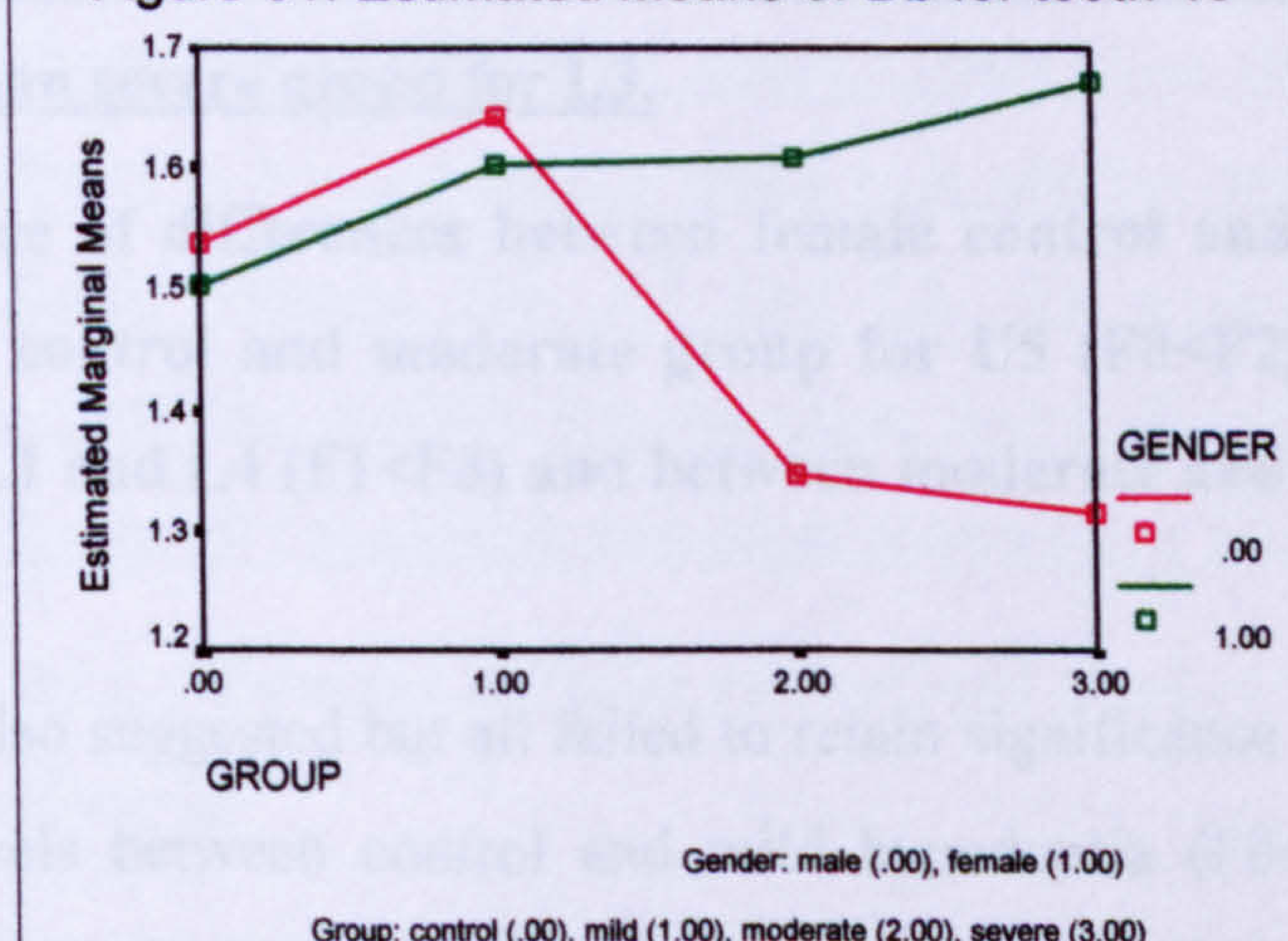


Figure 61: Estimated Means of Db for tooth 46



7.3.10. Findings for Crown Index of Buccal Morphology 2

This is the 2nd buccal crown morphology index (CIBM2) that was determined as a proportion i.e. the distance between MDb to the occlusal line of the buccal view perimeter divided by the occlusoginigival dimension (Db/OG). This permits evaluation of how far the MDb moves from the occlusal level toward the gingival level when related to the OG dimension. The main statistical results for all tooth types are summarised in table 64. Further details of descriptive data of group and subgroup means and differences are shown in appendix 10, tables 1-41. The following are the main findings.

Genders analysed separately:

Significant interactions were found for teeth U1, U5, U7, L1, L3, L4, L6 and L7 (see table 64 for p-values and figures 62-69) indicating that differences between groups were different for males and females.

In females: The control group CIBM2 mean value was found to be smaller than severe hypodontia group mean (for U1, U5, L1, L3 and L4) and moderate hypodontia group (for L4). Mild group CIBM2 means were smaller than severe hypodontia group for U1 and L3. The mean values were also smaller in the moderate group than severe group for L3.

There was evidence of differences between female control and mild group for U7 (F0<F1), between control and moderate group for U5 (F0<F2), between mild and severe group for L1 and L4 (F1<F3) and between moderate and severe group for U1 (F2<F3).

Differences were also suggested but all failed to retain significance after final adjustment of significance levels between control and mild hypodontia (F0<F1) for U5 and L4, between control and moderate group (F0<F2) for U1, L3, L6 and L7, between control and severe hypodontia (F0<F3) for U7 and L6, between mild and severe hypodontia (F1<F3) for U5 and between moderate and severe group (F2<F3) for L1. Refer to table 69 and appendix 17 tables for detail.

For U1: CIBM2 dimension found to be 0.26 smaller in female control group (mean, 0.27) and 0.20 smaller in mild group (mean, 0.33), each compared to 0.53 in female severe group.

For L1: The index was 0.16 smaller in female control group (mean, 0.17) than in severe group (mean, 0.33).

In males: Some evidence for the difference between male control and moderate hypodontia (M0<M2) was found for U5. Other differences were also found but all did not retain significance between control and mild hypodontia (M0<M1) for U5 and between control and severe hypodontia (M0<M3) for L3.

Finally, **some evidence for gender difference was found between severe groups (M3<F3) for L4.** Other differences were also suggested between that failed to retain significance after final adjustment between mild groups (M1<F1) for U7 and between severe groups (M3<F3) for U1, U5 and L1 (Table 69).

See appendix 10 tables if details are required.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. **Significant differences between group means were found for all other tooth types: U2, U3, U4, L2 and L5, except U6** (see table 64 for p-values).

Each hypodontia group presented larger mean values than the control group for teeth U2 and U3. For U4, control group mean was smaller than each of moderate and severe hypodontia groups. For L2 and L5, the severe group mean was significantly bigger than the control. On the other hand, the severe group was also bigger than each of mild and moderate hypodontia group for L2.

There is evidence for a difference between control and moderate hypodontia groups for L2 (group 0 < group 2).

Differences were also suggested but did not retain significance after adjustment (Table 64) between control and mild hypodontia for L5 (0<1), between control and moderate for l5 (0<2), between mild and moderate for U4 (0<2) and between mild and severe hypodontia for U3 (1<3). Refer to table 69 and index 10 tables if details are required.

For U2: CIBM2 value was found to be 0.11 bigger in mild hypodontia group (mean, 0.46), 0.14 bigger in each of moderate and severe group (mean, 0.49) when compared to 0.35 in control group. A consistent difference between genders was suggested of size 0.04 (M>F).

For U3: CIBM2 value found to be 0.05 bigger in mild hypodontia group (mean 0.49), 0.06 bigger in moderate group (mean, 0.50) and 0.11 bigger in severe group (mean, 0.55) when compared to 0.44 in control group. A consistent difference between genders was suggested of size 0.01 (M>F).

For U4: CIBM2 value found to be 0.07 bigger in each of moderate and severe group (mean, 0.47) when compared to 0.40 in control group.

For L2: CIBM2 value found to be 0.16 bigger in severe group (mean, 0.38) than control group (mean, 0.22).

For L5: CIBM2 value found to be 0.07 bigger in severe group (mean, 0.40) as compared to control group (mean, 0.33). In addition to a consistent difference between genders was suggested of size 0.01 (M<F).

Finally, **For U6, an evidence for consistent difference between genders was found (P2=0.798) of size 0.04 (M<F) that applies in each group.** See appendix 10 tables if detail is needed.

Summary of CIBM2 findings

The measurements results of crown index of buccal morphology 2 of all teeth are summarised as follows:
1) When the genders were analysed separately for teeth U1, U5, L1, L3, L4, L6 and L7; multi-subgroup comparison tests and final adjustment of significance levels revealed:

> *Only in females, the mean values in the severe hypodontia group were significantly larger than in the control group (teeth U1, U5, L1, L3 and L4). The severe hypodontia group measurements were significantly larger than mild hypodontia measurements (teeth U1 and L3) and also significantly larger than the moderate hypodontia group measurements (tooth L3). In addition, the measurements in the moderate hypodontia group were significantly larger than in the control group for tooth L4.*

2) When genders were combined for teeth U2, U3, U4, L2, L5; multi-group comparison tests and final adjustment of significance levels revealed:

> *The measurement values of CIBM2 in each hypodontia group were significantly larger than in the control group for U2 and U3.*
> *The mean values of severe hypodontia were significantly larger than in the control group for L2 and L5.*
> *Severe group measurements were also significantly larger than in each of the mild and moderate groups for L2.*
> *The mean values of each of the severe and moderate hypodontia were significantly larger than in control group for U4.*

Table 64: Summary results of crown index of buccal morphology-2 (CIBM2)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.435	0.004	0.000	0.000	0.000	0.000	0.000	0.002	0.022
	Gender		0.891	0.004	0.098	0.765	0.165	0.018	0.002	0.251	0.910	0.062	0.099	0.044	0.003	0.039
	Group & Gender		0.005	0.586	0.572	0.248	0.007	0.864	0.058	0.048	0.882	0.007	0.001	0.186	0.048	0.083
Multi-group comparisons	0	1		**	**	*								*		
		2		**	**	**					(*)			*		
		3		**	**	**					**			**		
	1	2				*										
		3			*						**					
	2	3									**					
Multi-subgroup comparisons	Mo	M1					*									
		M2					(*)									
		M3										*				
	F0	F1					*		(*)				*			
		F2	*				(*)					*	**		*	*
		F3	**				**		*	**		**	**		*	
	M1	M2														
		M3														
	F1	F2														
		F3	**				*			(*)		**	(*)			
	M2	M3														
	F2	F3	(*)							*		**				
	M0	F0														
	M1	F1							*							
	M2	F2											(*)		*	*
	M3	F3	*				*			*			*			

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) or subgroup ($n = 16$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 10 tables.

Figure 62: Estimated Means of CIBM2 for tooth U1

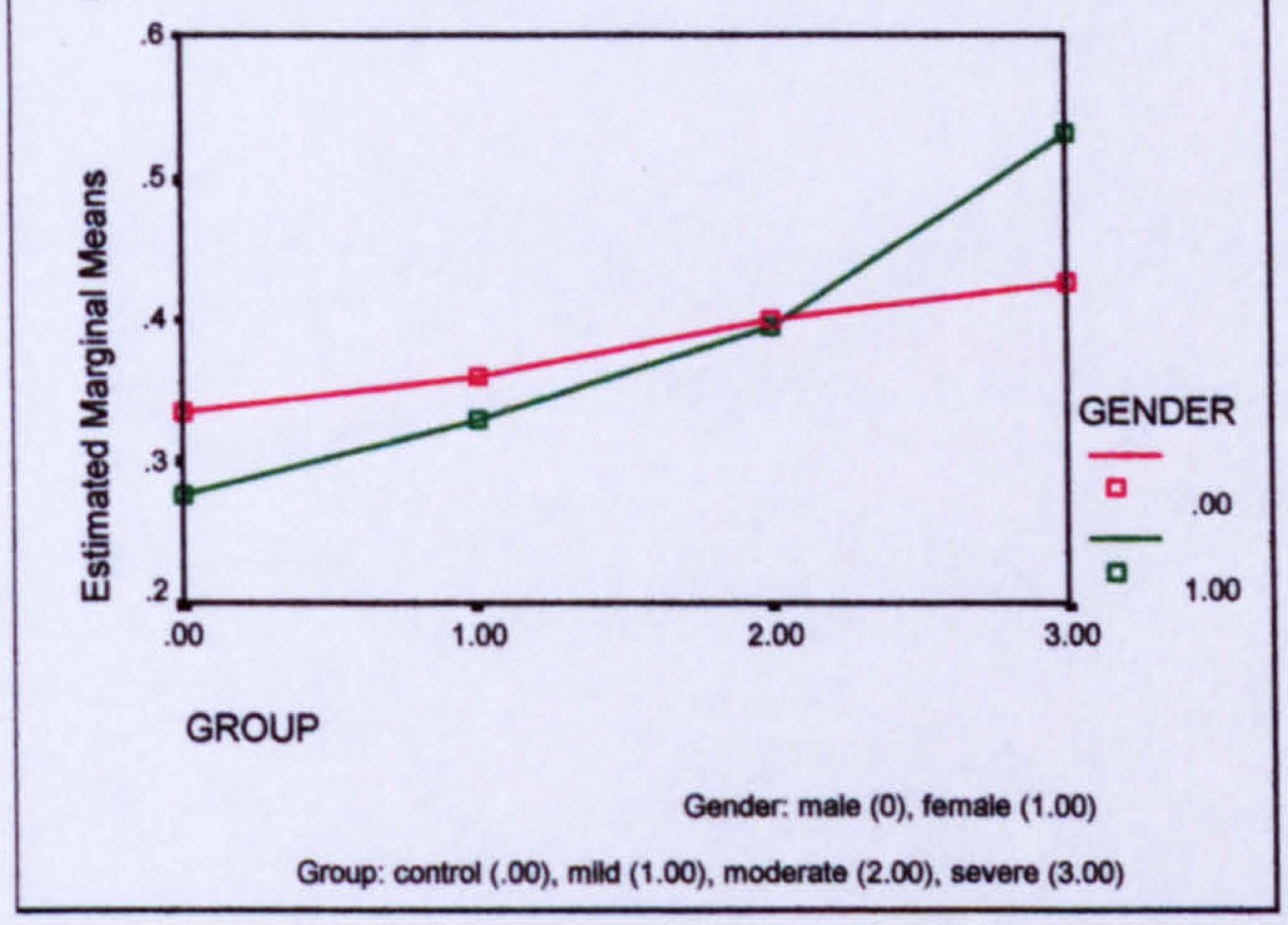


Figure 63: Estimated Means of CIBM2 for tooth U5

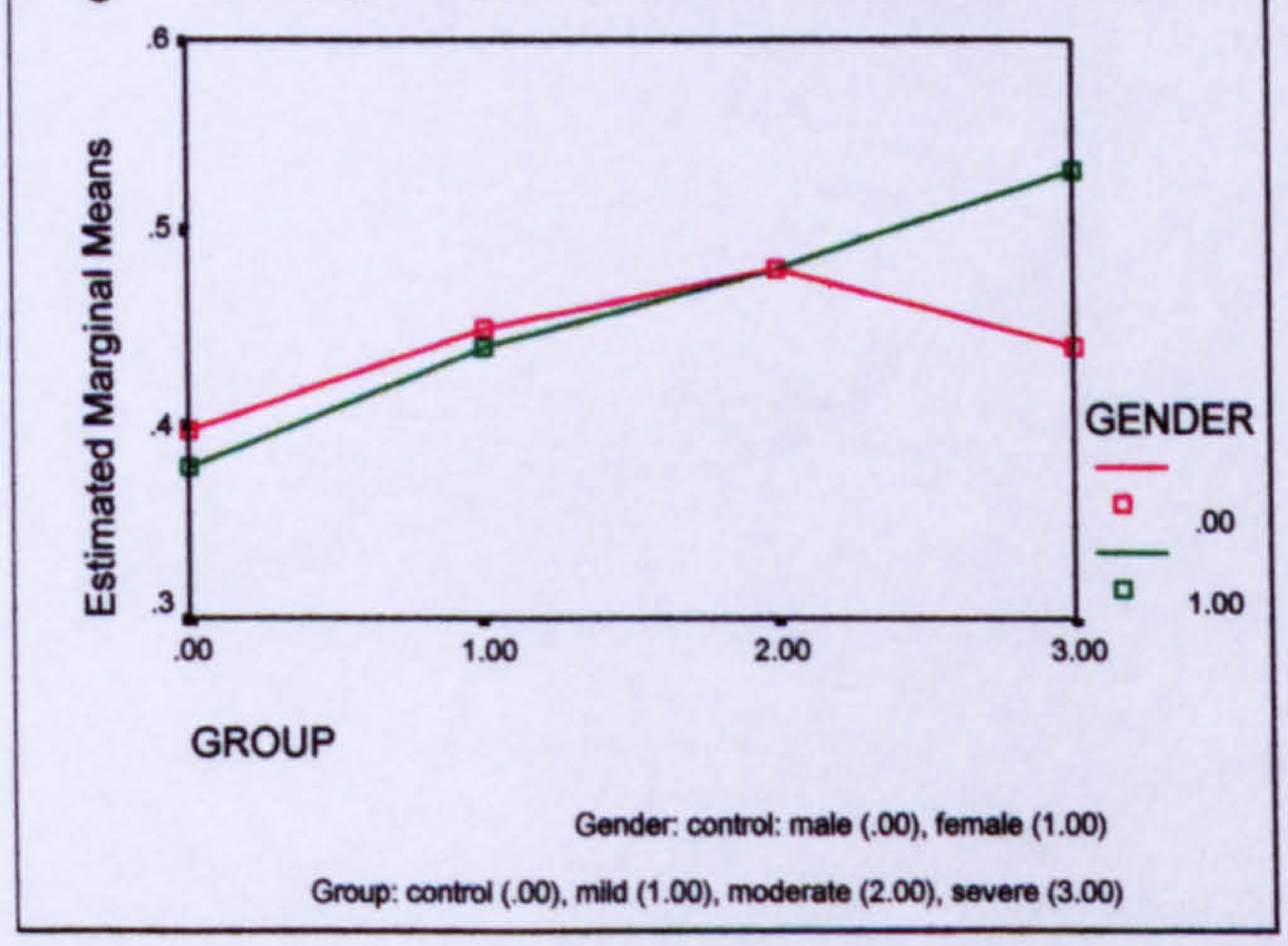


Figure 64: Estimated Means of CIBM2 for tooth U7

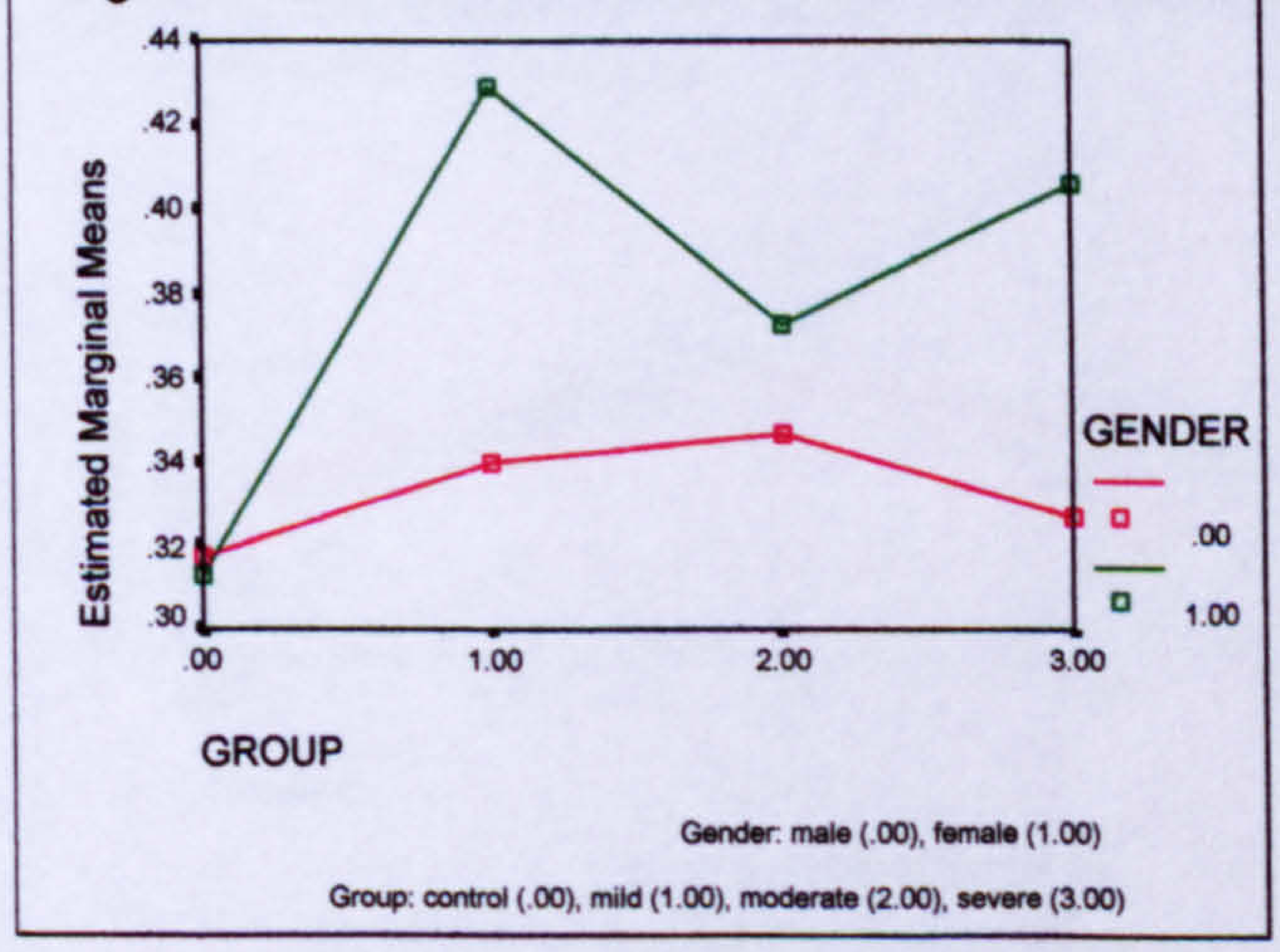


Figure 65: Estimated Means of CIBM2 for tooth L1

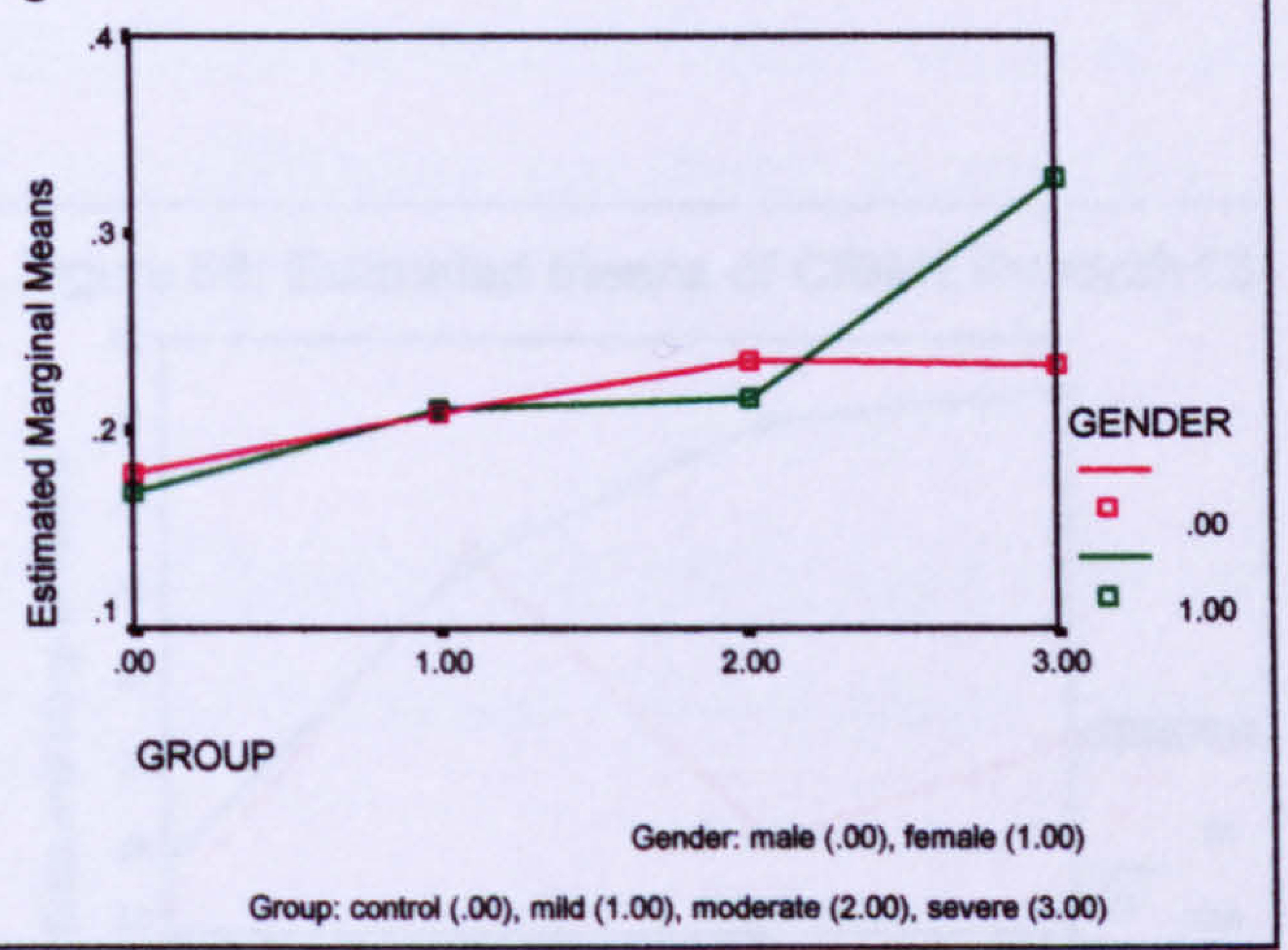


Figure 66: Estimated Means of CIBM2 for tooth L3

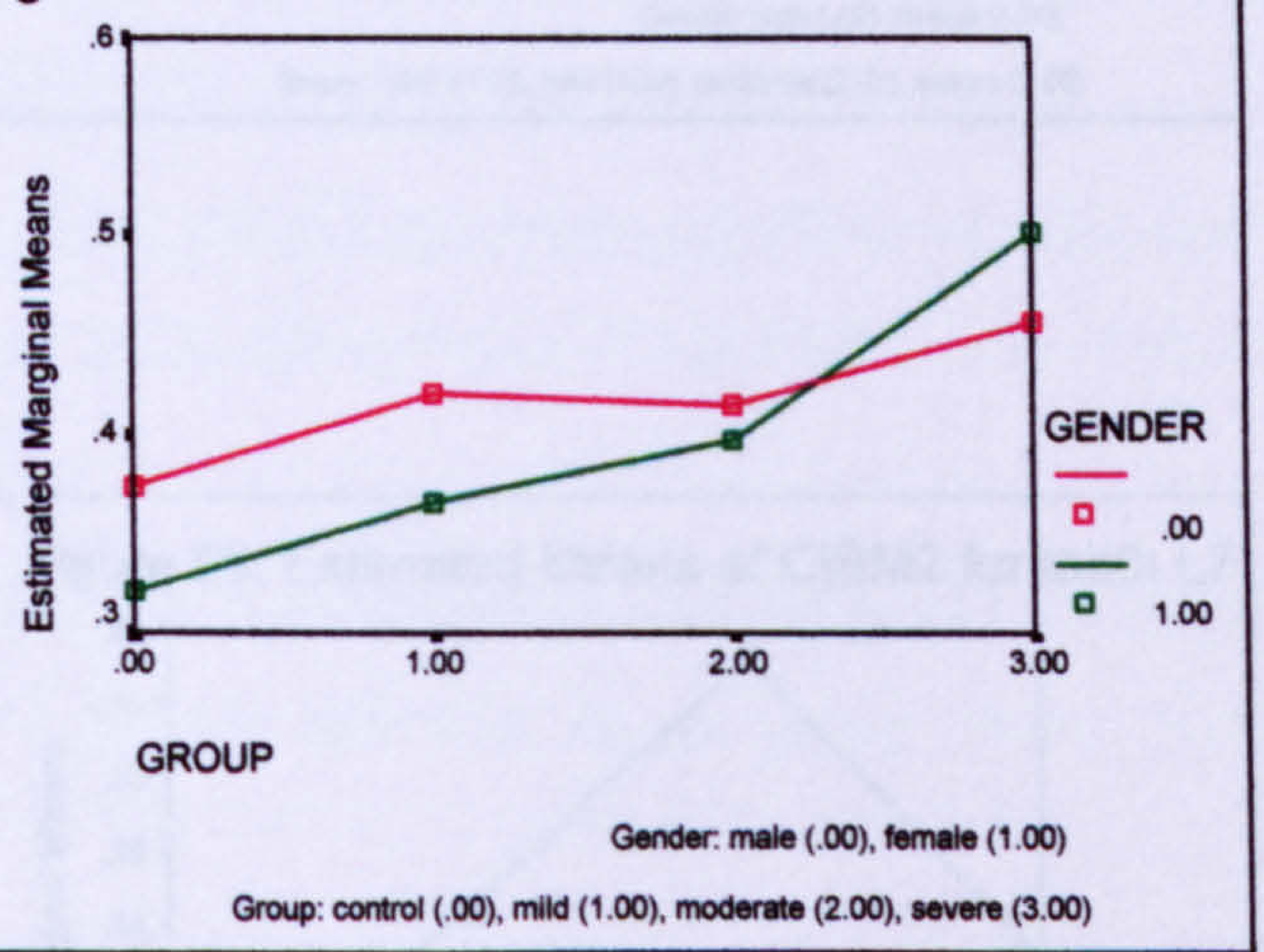


Figure 67: Estimated Means of CIBM2 for tooth L4

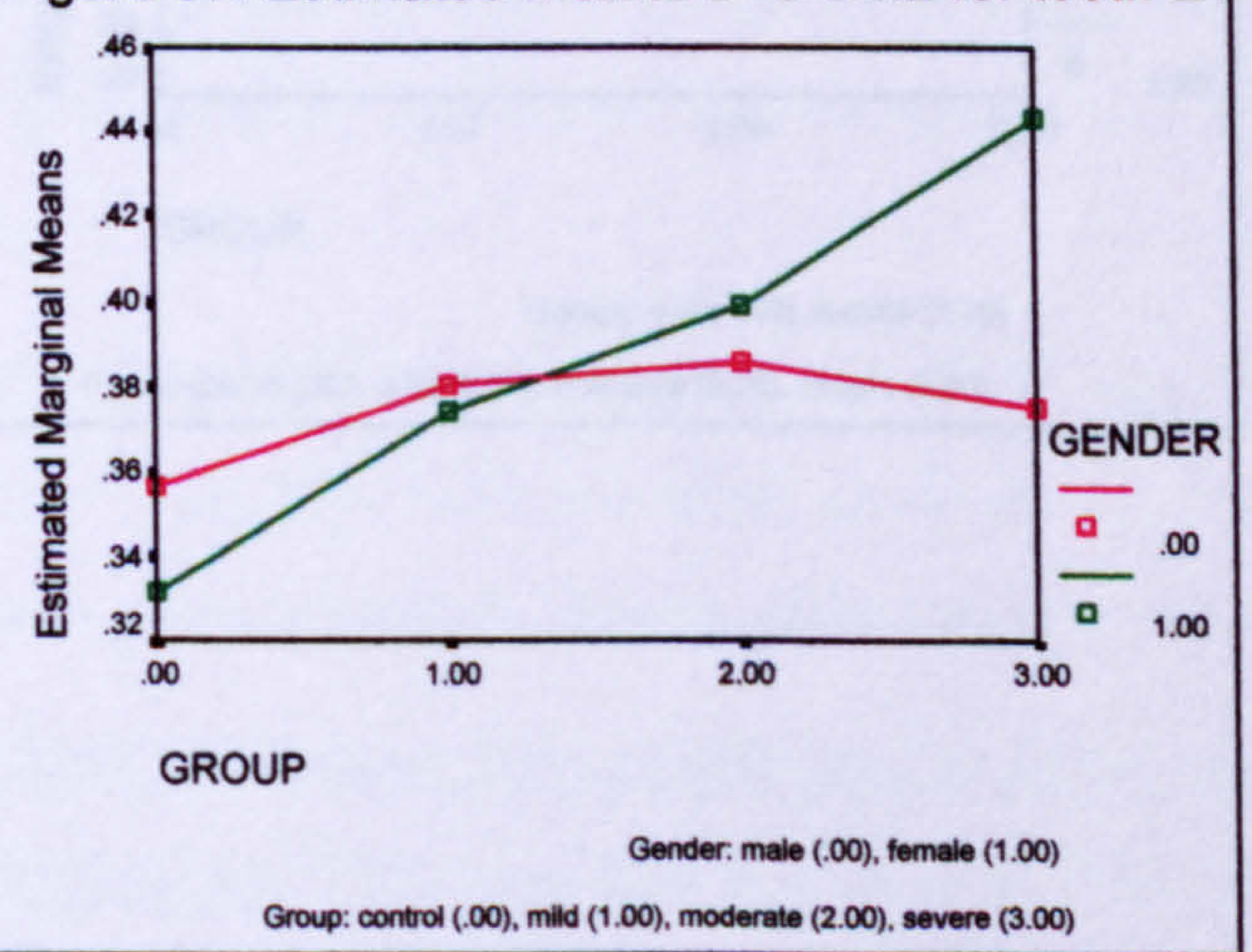


Figure 68: Estimated Means of CIBM2 for tooth L6

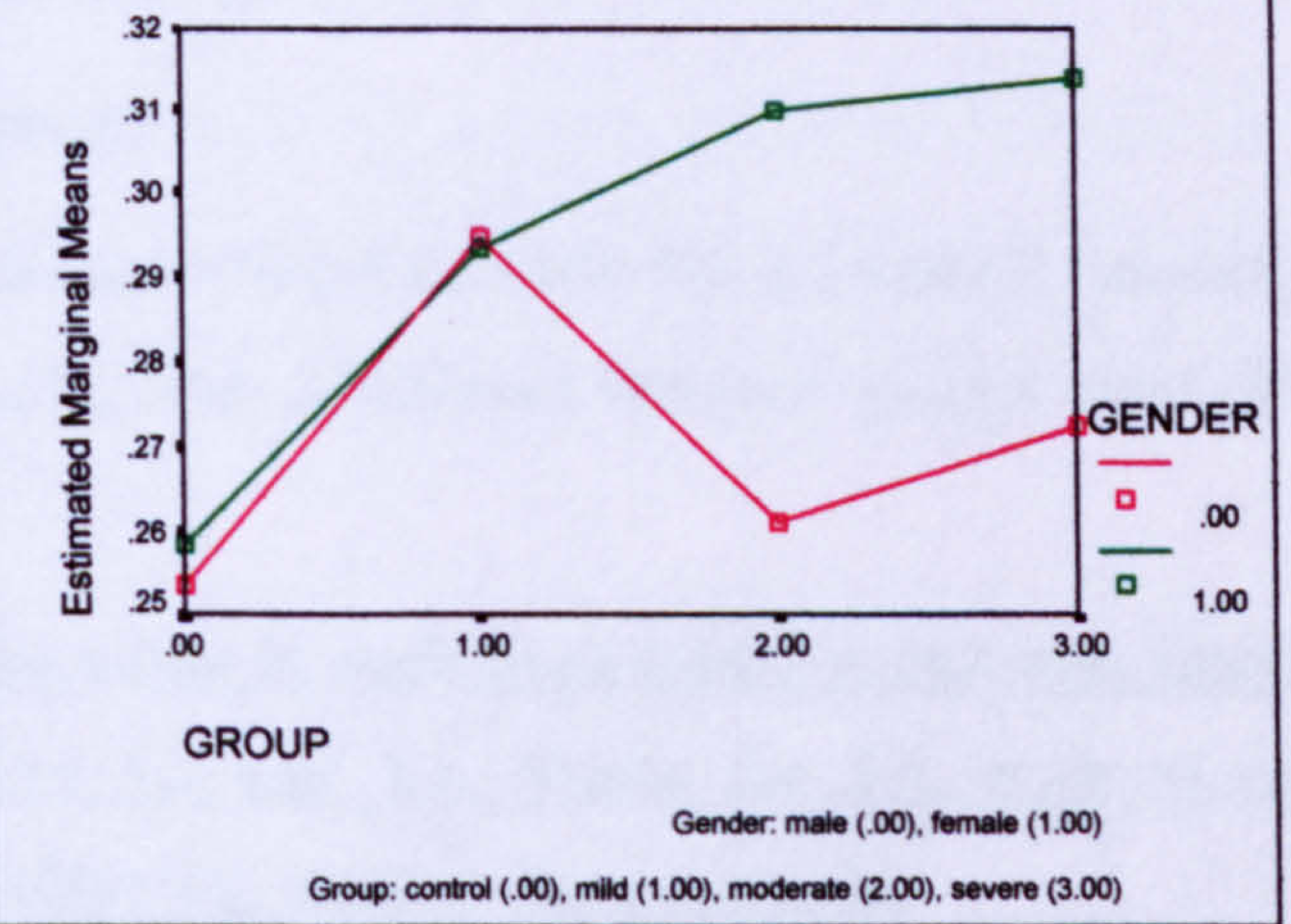
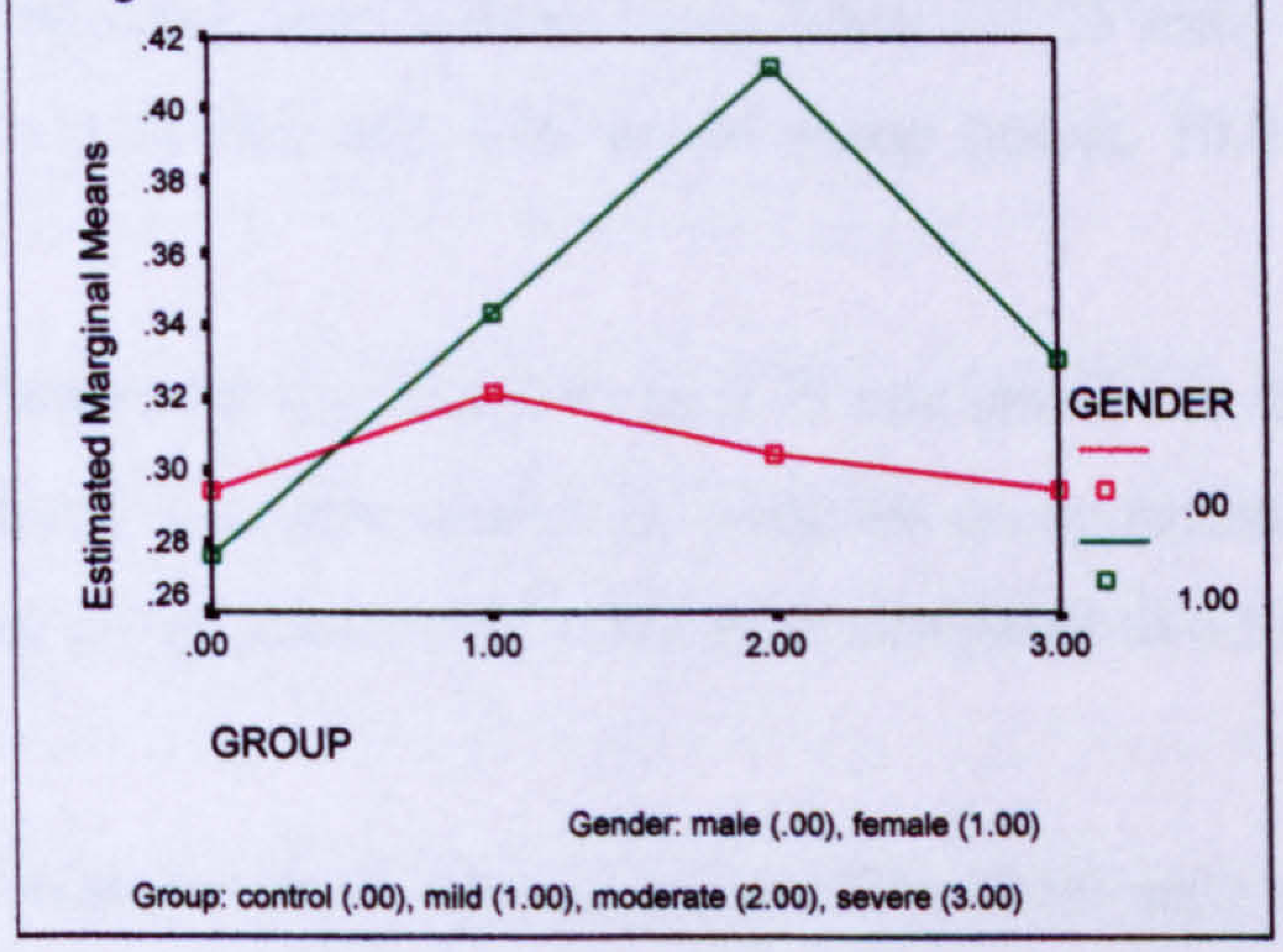


Figure 69: Estimated Means of CIBM2 for tooth L7



7.3.11. Mesiodistal Measurements From Occlusal Aspect

The main statistical results for the mesiodistal dimension of occlusal view measurement in all tooth types are summarised in table 65. Further details of descriptive data of group and subgroup means and differences are shown in appendix 11, tables 1-42. The following are the main findings.

Genders anlaysed separately:

Significant interactions were found for teeth U6, L2 and L3 (see table 65 for p-values and figures 70-72) indicating that differences between groups were different for males and females.

In males: MDo mean value in each hypodontia group was found to be smaller than the control mean for L2 and L3. While for U6, each of moderate and severe hypodontia groups MDo was smaller than controls.

A difference was suggested but did not retain significance after final adjustment between control and mild group MDo dimensions of U6 (M0> M1). Table 65 and appendix 11 tables present the detail.

For U6: Difference between male control mean MDo (11.25 mm) and moderate group (mean, 10.21 mm) = 1.04 mm and with severe group (mean, 10.04 mm), difference = 1.21 mm.

For L2: The MDo dimension was found to be 0.75 mm smaller in mild male hypodontia group (mean, 5.84 mm), 1.11 mm smaller in moderate group (mean, 5.48 mm) and 1.28 mm smaller in severe group (mean, 5.31 mm), each compared to 6.59 mm in male control group.

For L3: Difference between male control mean MDb (7.80 mm) and mild hypodontia group (mean, 6.76 mm) = 1.04 mm, with moderate group (mean, 6.66 mm), difference = 1.14 mm and with severe group (mean, 6.56 mm), difference = 1.24 mm.

In females: For L2, only the severe hypodontia group MDo mean was found to be smaller than the control mean. Thre was also evidence of differences between female control and mild hypodontia (F0 > F1) for L2 and L3.

Differences were also suggested between female control and each of the mild and severe means for U6, between control and moderate hypodontia group means for L2 and between control and each of moderate and severe hypodontia group for L3. However, none of these differences retained significance after final adjustment (F0 > each of those). See table 65 and appendix 11 tables for more detail.

For L2: MDo dimension was 0.79 mm smaller in severe group (mean, 5.51 mm) than control group (mean, 6.28 mm).

Significant difference between genders was found for L3 in the control groups indicating male MDo mean to be bigger than female. The difference was 0.79 mm between male (mean, 7.80 mm) and female (mean, 7.01 mm) control subjects. (see appendix 11 if details are required).

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. Significant differences between MDo group means were found for all other tooth types: U1, U2, U3, U4, U5, U7, L1, L4, L5, L6 and L7 (see table 65 for p-values). With the exception of L7 in the above list, each hypodontia group MDo was found to be smaller than the control group. However, for all, the MDo dimensions of hypodontia groups did not differ among themselves. **This was with evidence of a difference between mild and severe hypodontia group for U1 (1 > 3).**

Difference were also suggested but failed to retain significance after final adjustment between moderate and severe hypodontia MDo means for U1 (2 > 3) and between control and each of mild and moderate hypodontia group means For L7 (0 > 1 and 2).

For U1: MDo dimensions were found to be 0.96 mm smaller in mild hypodontia group (mean, 8.45 mm), 1.10 mm smaller in moderate group (mean, 8.31 mm) and 1.48 mm smaller in severe group (mean, 7.93 mm) when compared to 9.41 mm in control group.

For U2: The measurement was 1.66 mm smaller in mild hypodontia group (mean, 5.73 mm), 1.67 mm smaller in moderate group (mean, 5.72 mm) and 1.71 mm smaller in severe group (mean, 5.68 mm), each compared to 7.39 mm in the control group.

For U3: The MDo was found to be 0.87 mm smaller in mild hypodontia group (mean, 7.51 mm), 0.91 mm smaller in moderate group (mean, 7.47 mm) and 1.15 mm smaller in severe group (mean, 7.23 mm), each compared to 8.38 mm in control group.

For U4: MDo found to be 0.79 mm smaller in mild hypodontia group (mean, 6.72 mm), 1.00 mm smaller in moderate group (mean, 6.52 mm) and 1.01 mm smaller in severe group (mean, 6.51 mm), each compared to 7.52 mm in control group.

For U5: MDo dimension found to be 0.73 mm smaller in mild hypodontia group (mean, 6.41 mm), 0.97 mm smaller in moderate group (mean, 6.17 mm) and 0.85 mm smaller in severe group (mean, 6.29 mm), each compared to 7.14 mm in control group.

For U7: MDo dimension found to be 0.90 mm smaller in mild hypodontia group (mean, 9.56 mm), 0.96 mm smaller in moderate group (mean, 9.50 mm) and 1.17 mm smaller in severe group (mean, 9.29 mm), each compared to 10.46 mm in control group. In addition to a difference in groups, a consistent difference between genders was suggested of size 0.26 mm (M>F), which applies in each group.

For L1: The dimension found to be 0.64 mm smaller in mild hypodontia group (mean, 5.28 mm), 0.67 mm smaller in moderate group (mean, 5.25 mm) and 0.84 mm smaller in severe group (mean, 5.08 mm), each compared to 5.92 mm in control group.

For L4: MDo was 0.83 mm smaller in mild hypodontia group (mean, 6.79 mm), 0.87 mm smaller in moderate group (mean, 6.75 mm) and 0.85 mm smaller in severe group (mean, 6.77 mm), each compared to 7.62 mm in control group.

For L5: The dimension found to be 0.86 mm smaller in mild hypodontia group (mean, 6.76 mm), 0.90 mm smaller in moderate group (mean, 6.72 mm) and 0.97 mm smaller in severe group (mean, 6.65 mm), each compared to 7.62 mm in control group.

For L6: MDo dimension found to be 0.97 mm smaller in mild hypodontia group (mean, 10.62 mm), 0.78 mm smaller in moderate group (mean, 10.81 mm) and 0.89 mm smaller in severe group (mean, 10.70 mm), each compared to 11.59 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.22 mm (M > F), which applies in each group.

Finally, for L7: A consistent difference between genders was found of size 0.40 mm (M>F). See appendix 11 tables for further details.

Summary of MDo findings

The results for the mesiodistal dimensions for all the maxillary and mandibular teeth, obtained from the occlusal view are summarised:
1) When the genders were analysed separately for teeth U6, L2 and L3; multi-subgroup comparison tests and final adjustment of significance levels revealed:

For males, the MDo mean values in each hypodontia group were significantly smaller than in the control group in teeth L2 and L3, while U6 showed the same trend except in the mild group.

For females, only in L2 the MDo mean values in severe hypodontia were significantly smaller than in the control group.

Significant gender difference was found in the control group, measurements in males were significantly larger than in females.

2) When genders were combined for teeth U1, U2, U3, U4, U5, U7, L1, L4, L5, L6 and L7; multi-group comparison tests and final adjustment of significance levels revealed:

The MDo mean values in each hypodontia group were significantly smaller than in the control group for these teeth, except L7.

Table 65: Summary results of mesiodistal measurements from occlusal aspect (MDo)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
	Gender		0.280	0.604	0.218	0.349	0.419	0.009	0.071	0.459	0.818	0.000	0.161	0.789	0.068	0.028
	Group & Gender		0.759	0.770	0.364	0.101	0.192	0.095	0.203	0.875	0.010	0.014	0.552	0.107	0.112	0.466
Multi-group comparisons	0	1	**	**	**	**	**		**	**			**	**	**	*
		2	**	**	**	**	**		**	**			**	**	**	*
		3	**	**	**	**	**		**	**			**	**	**	
	1	2														
		3	(*)													
	2	3	*													
Multi-subgroup comparisons	Mo	M1						*			**	**				
		M2						**			**	**				
		M3						**			**	**				
	F0	F1						*			(*)	(*)				
		F2									*	*				
		F3						*			**	*				
	M1	M2														
		M3									*					
	F1	F2														
		F3														
	M2	M3														
	F2	F3														
	M0	F0										**				
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 11 tables.

Figure 70: Estimated Means of MDo for tooth U6

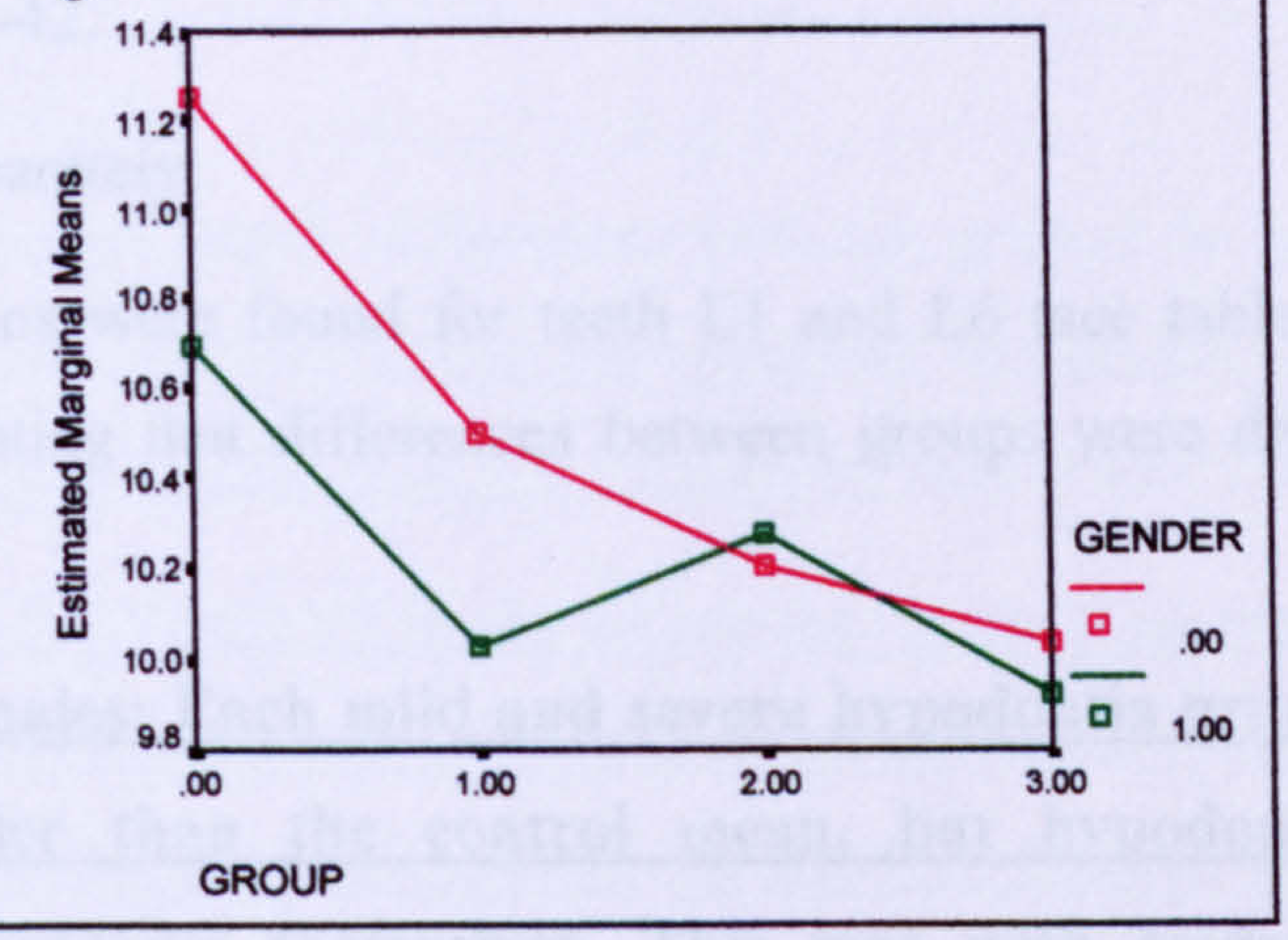


Figure 71: Estimated Means of MDo for tooth L2

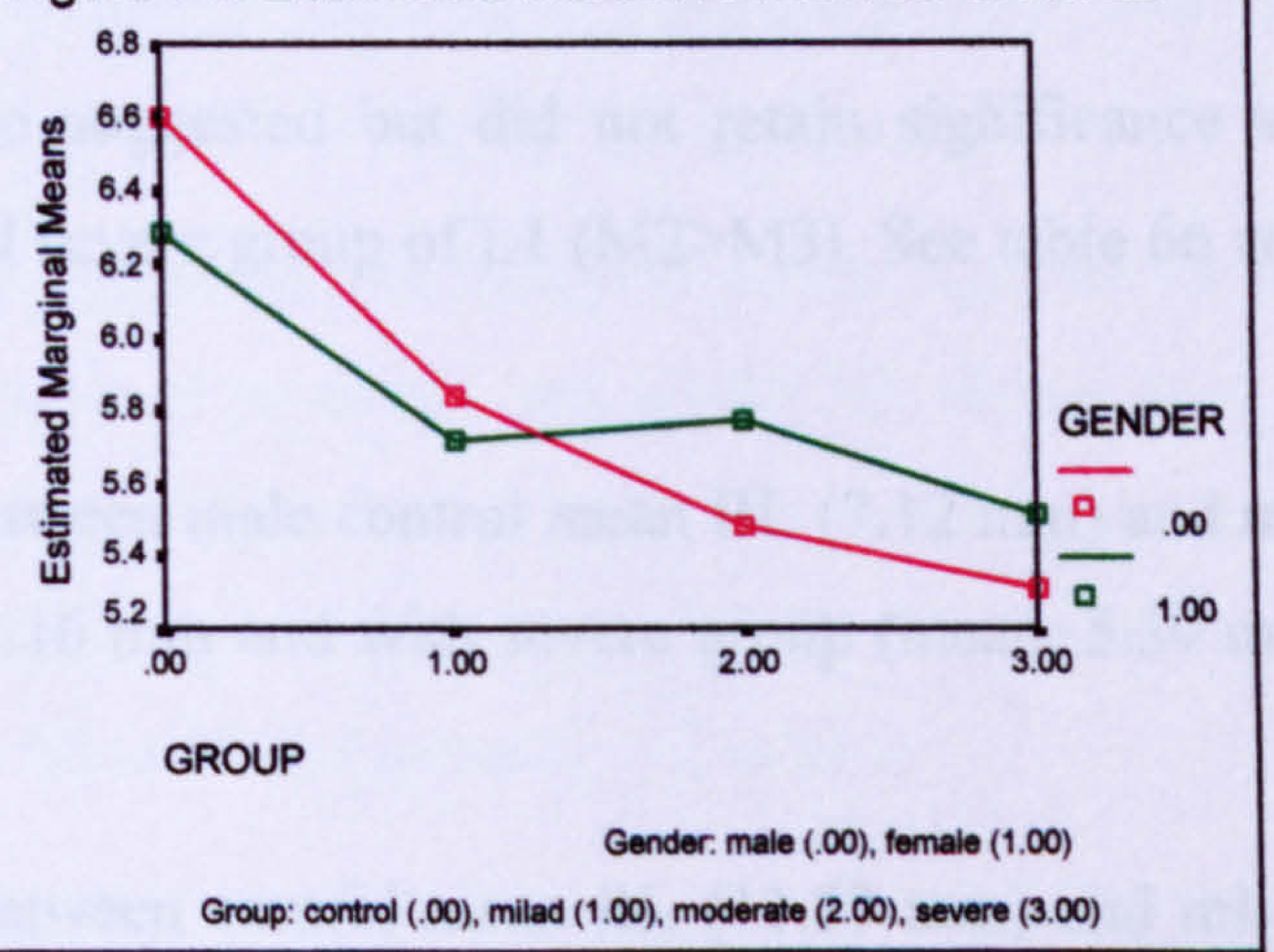
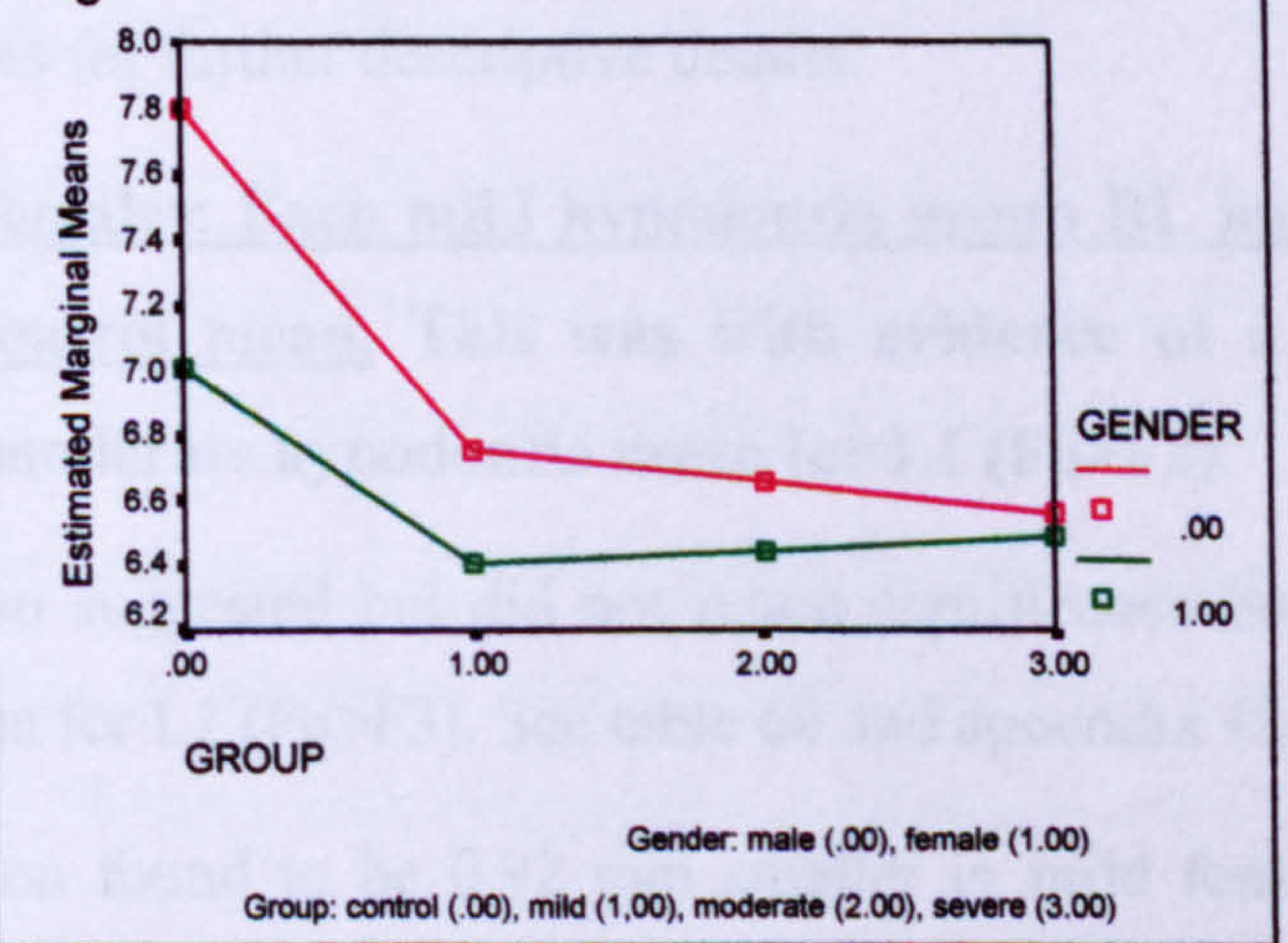


Figure 72: Estimated Means of MDo for tooth L3



7.3.12. Buccolingual Measurements

Table 66 summarises main findings of the buccolingual measurements for different teeth. Descriptive data of group and subgroup means and the differences are all shown in appendix 12, tables 1-42.

Genders analysed separately:

Significant interactions were found for teeth L1 and L6 (see table 66 for p-values and figures 73-74) indicating that differences between groups were different for males and females.

For L1 and L6 in males: Each mild and severe hypodontia group mean for BL was found to be smaller than the control mean, but hypodontia groups did not (generally) differ amongst themselves. This was with evidence of a difference between control and moderate BL dimensions of L1 and L6 (M0>M2).

A difference was also suggested but did not retain significance after final adjustment between moderate and severe group of L1 (M2>M3). See table 66 and appendix 12 tables for detail.

For L1: Difference between male control mean BL (7.12 mm) and mild hypodontia group (mean, 5.96 mm) = 1.16 mm and with severe group (mean, 5.39 mm), difference = 1.73 mm.

For L6: Difference between control mean BL (11.33 mm) and mild group (mean, 10.39 mm) = 0.94 mm and with severe group (mean, 10.16 mm), difference = 1.17 mm.

See appendix 12 tables for further descriptive details.

For L1 and L6 in females: Each mild hypodontia group BL mean was found to be smaller than the control mean. This was with evidence of a difference between female control and moderate hypodontia mean for L1 (F0>F2).

A difference was also suggested but did not retain significance between female control and severe hypodontia for L1 (Fo>F3). See table 66 and appendix 12 tables).

For L1: BL dimension found to be 0.92 mm smaller in mild female hypodontia group (mean, 5.86 mm) than female control group (mean, 6.78 mm).

For L6: BL dimension found to be 1.10 mm smaller in mild group (mean, 7.26 mm) than female control group (mean, 8.36 mm).

Refer to the tables of appendix 12 if details are required.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. **Significant differences between group means were found for all other tooth types: U1, U2, U3, U4, U5, U6, U7, L2, L3, L4, L5 and L7** (see table 66 for p-values).

With the exception of U7 and L7 in the above list, each hypodontia group was found to be smaller than the control group. However, for all, the BL dimensions of hypodontia groups did not differ among themselves. On the other hand, only mild hypodontia group was found to be smaller than control group for teeth U7 and L7. That was with an evidence of differences between control and each of moderate and severe hypodontia BL measurements for U7 (group 0>2 and 3).

Differences were also suggested but failed to retain significance after final adjustment between control and each of moderate and severe BL dimensions for L7, between mild and each of moderate hypodontia for U5 and severe hypodontia group for U4, L2 and L5 and between moderate and severe hypodontia for L2. The more severe the hypodontia the smaller is the BL. See table 66 and appendix 12 tables).

For U1: The BL dimension was found to be 1.31 mm smaller in mild hypodontia group (mean, 6.81 mm), 1.26 mm smaller in moderate group (mean, 6.86 mm) and 1.44 mm smaller in severe group (mean, 6.68 mm) when compared to 8.12 mm in control group.

For U2: The measurement was 1.98 mm smaller in mild hypodontia group (mean, 5.45 mm), 1.72 mm smaller in moderate group (mean, 5.71 mm) and 1.67 mm smaller in severe group (mean, 5.76 mm), each compared to 7.43 mm in control group.

For U3: The BL was found to be 1.37 mm smaller in mild hypodontia group (mean, 7.51 mm), 1.29 mm smaller in moderate group (mean, 7.59 mm) and 1.68 mm smaller in severe group (mean, 7.20 mm), each compared to 8.88 mm in control group.

For U4: The BL dimension was found to be 1.38 mm smaller in mild hypodontia group (mean, 8.77 mm), 1.68 mm smaller in moderate group (mean, 8.47 mm) and 1.93 mm smaller in severe group (mean, 8.22 mm), each compared to 10.15 mm in control group.

For U5: The BL dimension was found to be 1.32 mm smaller in mild hypodontia group (mean, 8.94 mm), 1.83 mm smaller in moderate group (mean, 8.43 mm) and 1.76 mm smaller in severe group (mean, 8.50 mm), each compared to 10.26 mm in control group.

For U6: The BL dimension was found to be 1.08 mm smaller in mild hypodontia group (mean, 10.91 mm), 0.89 mm smaller in moderate group (mean, 11.10 mm) and 1.16 mm smaller in severe group (mean, 10.83 mm), each compared to 11.99 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.22 mm (M>F), which applies in each group.

For U7: The BL Measurement mean value was 1.03 mm smaller in mild hypodontia group (mean, 10.66 mm) than in control group (mean, 11.69 mm). In addition to a difference in groups a consistent difference between genders was suggested of size 0.37 mm (M>F), which applies in each group

For L2: The dimension found to be 1.03 mm smaller in mild hypodontia group (mean, 6.16 mm), 1.02 mm smaller in moderate group (mean, 6.17 mm) and 1.31 mm smaller in severe group (mean, 5.88 mm), each compared to 7.19 mm in control group.

For L3: The dimension found to be 1.18 mm smaller in mild hypodontia group (mean, 6.83 mm), 0.98 mm smaller in moderate group (mean, 7.03 mm) and 1.32 mm smaller in severe group (mean, 6.69 mm), each compared to 8.01 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.23 mm (M>F), which applies in each group.

For L4: The BL dimension was 1.19 mm smaller in mild hypodontia group (mean, 7.40 mm), 1.05 mm smaller in moderate group (mean, 7.54 mm) and 1.32 mm smaller in severe group (mean, 7.27 mm), each compared to 8.59 mm in control group. In addition to a difference in groups, an evidence for a consistent difference between genders was found ($P2 = 0.532$) of size 0.26 mm (M>F), which applies in each group.

For L5: The dimension mean was 1.19 mm smaller in mild hypodontia group (mean, 8.07 mm), 1.24 mm smaller in moderate group (mean, 8.02 mm) and 1.75 mm smaller in severe group (mean, 7.51 mm), each compared to 9.26 mm in control group.

For L7: The BL dimension was found to be 1.18 mm smaller in mild hypodontia group (mean, 9.49 mm) than in control group (mean, 10.67 mm). In addition to a difference in groups, a consistent difference between genders was suggested of size 0.48 mm (M>F), which applies in each group.

See appendix 12 tables for further descriptive details.

Summary of BL findings

The findings of the buccolingual measurements for different tooth types are summarised:

1) When the genders were analysed separately in teeth L1 and L6; multi-subgroup comparison tests and final adjustment of significance levels revealed:

For males, the mean values in the severe and mild hypodontia groups were significantly smaller than in the control group.

For females, BL mean values in mild hypodontia were significantly smaller than in the control group.

2) When genders were combined for the rest of tooth types (U1, U2, U3, U4, U5, U6, U7, L2, L3, L4, L5 and L7); multi-group comparison tests and final adjustment of significance levels revealed:

The buccolingual dimension in each hypodontia group was significantly smaller than in the control group apart from U7 and L7.

For teeth U7 and L7 BL measurements, only the mild hypodontia measurements were significantly smaller than the control group measurements.

Table 66: Summary results of buccolingual measurements (BL)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Gender		0.735	0.309	0.598	0.817	0.597	0.034	0.043	0.864	0.934	0.090	0.002	0.176	0.013	0.044
	Group & Gender		0.995	0.764	0.240	0.138	0.319	0.905	0.777	0.054	0.851	0.162	0.434	0.659	0.070	0.801
Multi-group comparisons	0	1	**	**	**	**	**	**	**		**	**	**	**		**
		2	**	**	**	**	**	**	(*)		**	**	**	**		*
		3	**	**	**	**	**	**	(*)		**	**	**	**		*
	1	2					*									
		3				*					*			*		
	2	3									*					
Multi-subgroup comparisons	Mo	M1								**					**	
		M2								(*)					(*)	
		M3								**					**	
	F0	F1								**					**	
		F2								(*)						
		F3								*						
	M1	M2														
		M3														
	F1	F2														
		F3														
	M2	M3								*						
	F2	F3														
	M0	F0														
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 12 tables.

Figure 73: Estimated Means of BL for tooth L1

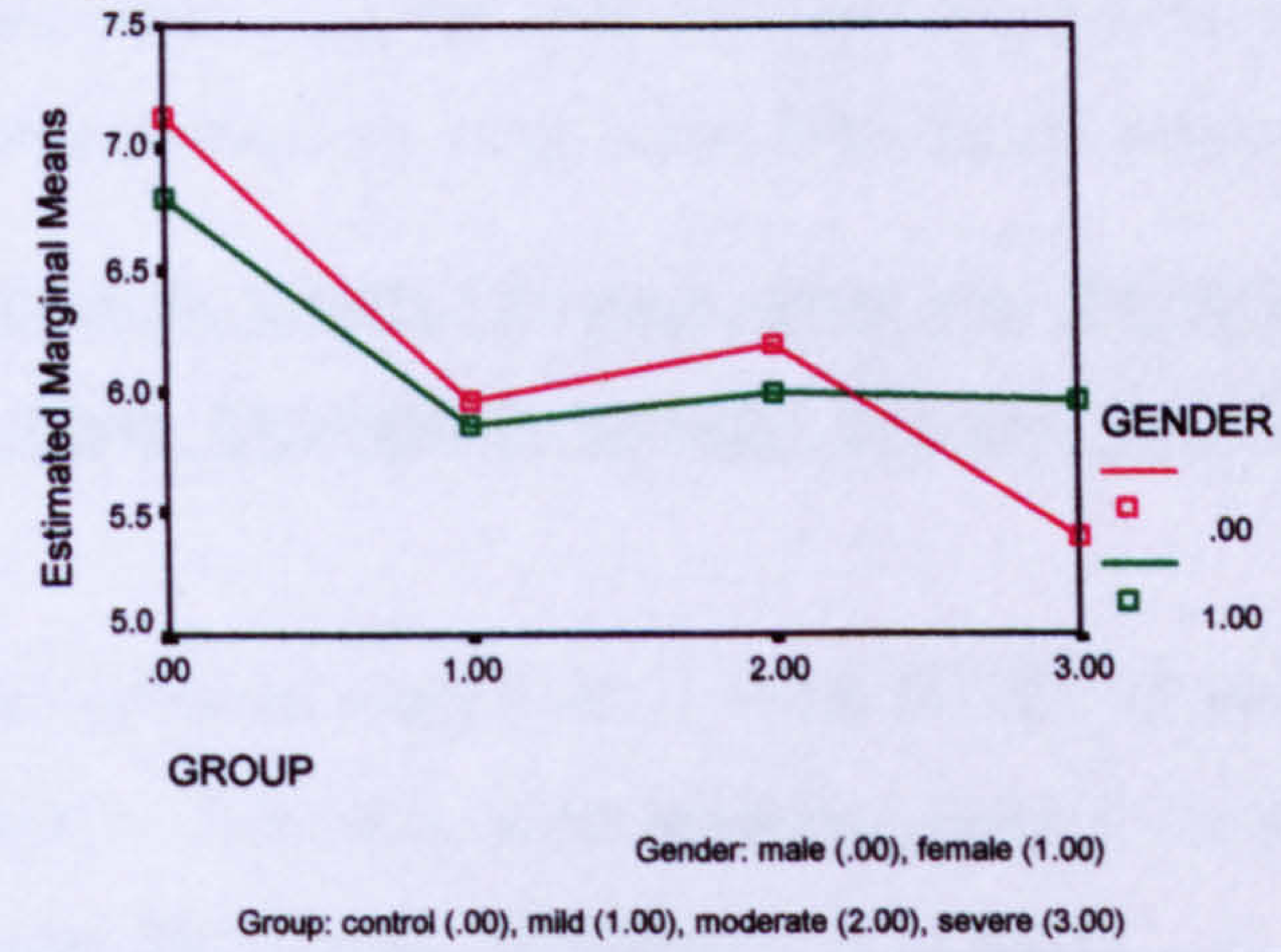
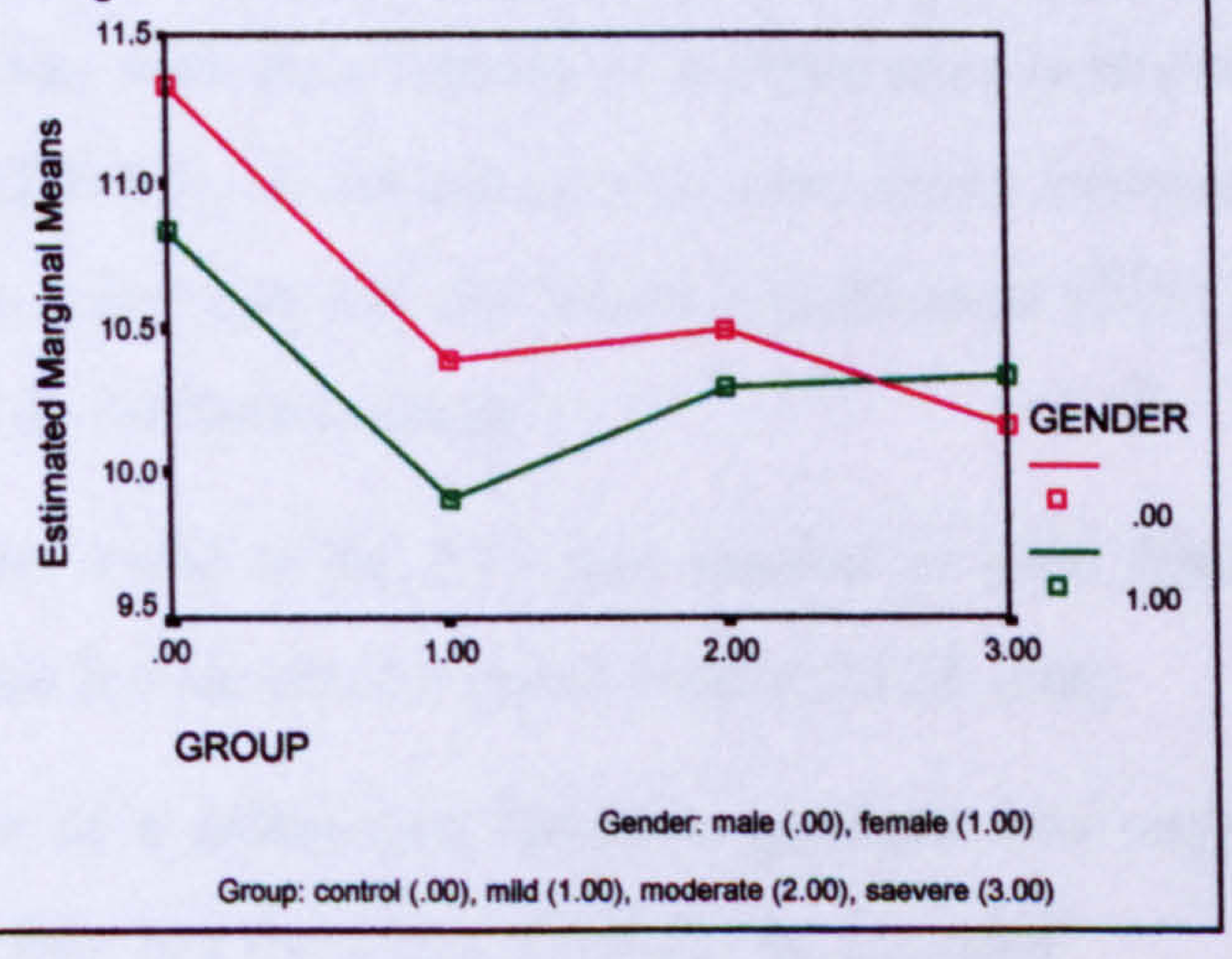


Figure 74: Estimated Means of BL for tooth L6



7.3.13. Perimeter Measurements From Occlusal Aspect

Table 67 displays main findings of crown perimeter measurements, obtained from the occlusal view, for different teeth. Descriptive data are all shown in appendix 13, tables 1-42.

Genders analysed separately:

Significant interactions were found for only L3 (see table 67 for p-values and figure 75) indicating that differences between groups were different for males and females.

In males: Each hypodontia group Po mean value was found to be smaller than the control mean, but these hypodontia groups did not (generally) differ amongst themselves.

For L7: The difference between male control mean Po (25.52 mm) and mild hypodontia group (mean, 21.9 mm) = 3.53 mm, with moderate (mean, 22.10 mm) = 3.42 mm and with severe group (mean, 21.01 mm), difference = 4.51 mm.

See appendix 13 tables for further descriptive details.

In females: Only mild hypodontia group Po mean was found to be smaller than the control mean. This was with an evidence of a difference between female control and severe hypodontia (F0>F3). A difference was also found between female control and moderate hypodontia mean but did not retain significance (F0>F2). See table 67 and index 1, tables B85-126 for further detail.

For L3: Po dimension found to be 2.51 mm smaller in mild female hypodontia group (mean, 20.87 mm) than female control group (mean, 23.38 mm).

Finally, an evidence of a difference between genders was suggested in the control groups for L3 (M0>F0). See the tables if details are required.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. **Significant differences between group means were found for all other tooth types: U1, U2, U3, U4, U5, U6, U7, L1, L2, L4, L5, L6 and L7** (see table 67 for p-values).

With the exception of L7 in the above list, each hypodontia group mean value was found to be smaller than the control group and for all, the Po dimensions of hypodontia groups did not generally differ among themselves. For L7 on the other hand, only mild hypodontia group was found to be samller than control group. Differences were suggested but failed to retain significance after final adjustment between mild and severe group Po dimensions (for U4, L2 and L5), between moderate and severe hypodontia (for L2) and between control and moderate group (for L7), see table 67.

For U1: Po dimension value was 3.66 mm smaller in the mild hypodontia group (mean, 24.33 mm), 3.64 mm smaller in the moderate group (mean, 24.35 mm) and 4.68 mm smaller in severe group (mean, 23.31 mm) when compared to 27.99 mm in the control group.

For U2: The measurement was 5.30 mm smaller in the mild hypodontia group (mean, 18.17 mm), 5.07 mm smaller in the moderate group (mean, 18.40 mm) and 5.05 mm smaller in the severe group (mean, 18.42 mm), each compared to 23.47 mm in the control group.

For U3: Po found to be 3.52 mm smaller in the mild hypodontia group (mean, 23.53 mm), 3.25 mm smaller in the moderate group (mean, 23.80 mm) and 4.38 mm smaller in the severe group (mean, 22.67 mm), each compared to 27.05 mm in the control group.

For U4: Po dimension found to be 3.31 mm smaller in the mild hypodontia group (mean, 25.25 mm), 4.23 mm smaller in the moderate group (mean, 24.33 mm) and 4.81 mm smaller in the severe group (mean, 23.75 mm), each compared to 28.56 mm in the control group.

For U5: Po dimension found to be 3.28 mm smaller in the mild hypodontia group (mean, 25.02 mm), 4.41 mm smaller in the moderate group (mean, 23.89 mm) and 4.32 mm smaller in the severe group (mean, 23.98 mm), each compared to 28.30 mm in the control group.

For U6: Po dimension found to be 3.00 mm smaller in the mild hypodontia group (mean, 35.58 mm), 2.66 mm smaller in the moderate group (mean, 35.92 mm) and 3.69 mm smaller in the severe group (mean, 34.89 mm), each compared to 38.58 mm in the control group. **In addition to a difference in groups, an evidence for consistent difference**

between genders was found (P2 = 0.266) of size 1.15 mm (M>F), which applies in each group.

For U7: Po Measurement mean value was 3.44 mm smaller in the mild hypodontia group (mean, 33.04 mm), 2.88 mm smaller in the moderate group (mean, 33.60 mm) and 3.39 mm smaller in the severe group (mean, 33.09 mm) as each compared to 36.48 mm in the control group. A consistent difference between genders was suggested of size 1.24 mm (M>F).

For L1: The dimension found to be 2.56 mm smaller in the mild hypodontia group (mean, 17.59 mm), 2.27 mm smaller in the moderate group (mean, 17.88 mm) and 2.98 mm smaller in the severe group (mean, 17.17 mm), each compared to 20.15 mm in the control group.

For L2: Po mean was 2.57 mm smaller in the mild hypodontia group (mean, 18.75 mm), 2.70 mm smaller in the moderate group (mean, 18.62 mm) and 3.47 mm smaller in the severe group (mean, 17.85 mm), each compared to 21.32 mm in the control group.

For L4: Po measurement mean was 3.14 mm smaller in the mild hypodontia group (mean, 22.75 mm), 2.92 mm smaller in the moderate group (mean, 22.97 mm) and 3.59 mm smaller in the severe group (mean, 22.30 mm), each compared to 25.89 mm in the control group. A consistent difference between genders was suggested of size 0.61 mm (M>F).

For L5: It was 3.32 mm smaller in the mild hypodontia group (mean, 24.09 mm), 3.58 mm smaller in the moderate group (mean, 23.83 mm) and 4.86 mm smaller in the severe group (mean, 22.55 mm), each compared to 27.41 mm in the control group.

For L6: Po measurements found to be 2.90 mm smaller in the mild hypodontia group (mean, 34.86 mm), 2.24 mm smaller in the moderate group (mean, 35.52mm) and 2.62 mm smaller in the severe group (mean, 35.14 mm), each compared to 37.76 mm in the control group. **This was with evidence of a consistent difference between genders (P2 = 0.798) of size 0.99 mm (M>F).**

For L7: Po dimension was found to be 3.02 mm smaller in the mild hypodontia group (mean, 33.11 mm) than in the control group (mean, 36.13 mm). A consistent difference between genders was suggested of size 1.25 mm (M>F).

See appendix 13 tables for further descriptive details.

Summary of Po findings

The findings of the perimeter measurements from the occlusal view for different teeth are summarised:

1) *When the genders were analysed separately for tooth L3; multi-subgroup comparison tests and final adjustment of significance levels revealed:*

   For males, the mean values in each hypodontia group were significantly less than in the control group.

   For females, only the measurements of mild hypodontia were significantly less than in the control group.

2) *When genders were combined for the rest of tooth types (U1, U2, U3, U4, U5, U6, U7, L1, L2, L4, L5, L6 and L7); multi-group comparison tests and final adjustment of significance levels revealed:*

   Apart from L7, the perimeter mean values in each hypodontia group were significantly less than in the control group for the above teeth.

   In L7, only the mild hypodontia measurements were significantly smaller than in the control group.

Figure 75: Estimated Means of Po for tooth L3

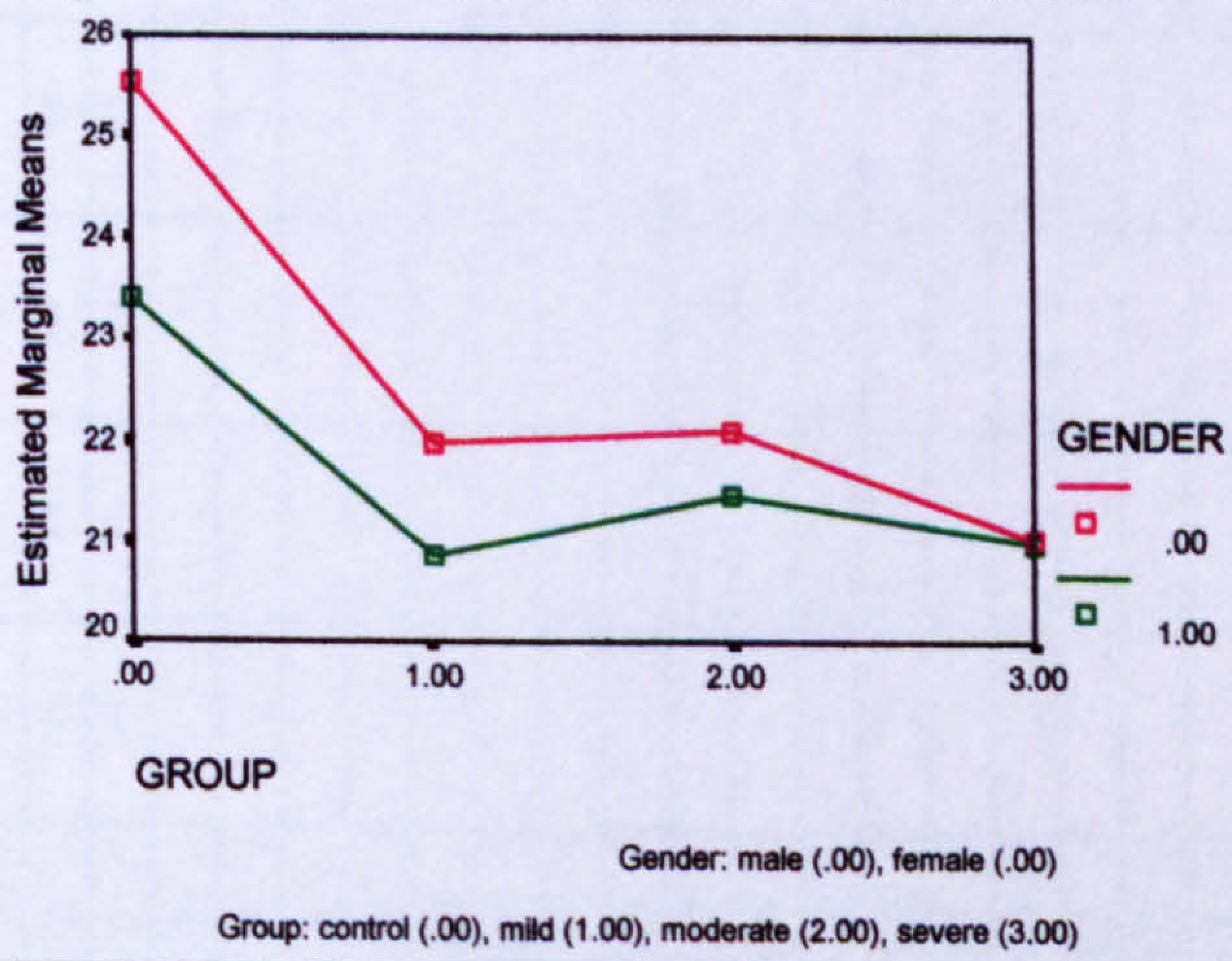


Table 67: Summary results of perimeter measurements from occlusal aspect (Po)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Gender		0.544	0.540	0.219	0.930	0.699	0.001	0.013	0.877	0.762	0.001	0.009	0.525	0.003	0.031
	Group & Gender		0.949	0.609	0.228	0.133	0.465	0.785	0.483	0.261	0.227	0.050	0.462	0.294	0.278	0.640
Multi-group comparisons	0	1	**	**	**	**	**	**	**	**	**		**	**	**	**
		2	**	**	**	**	**	**	**	**	**		**	**	**	*
		3	**	**	**	**	**	**	**	**	**		**	**	**	
	1	2														
		3				*					*			*		
	2	3									*					
Multi-subgroup comparisons	Mo	M1										**				
		M2										**				
		M3										**				
	F0	F1										**				
		F2										*				
		F3										(*)				
	M1	M2														
		M3														
	F1	F2														
		F3														
	M2	M3														
	F2	F3														
	M0	F0										(*)				
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) or subgroup ($n = 16$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 13 tables.

7.3.14. Area Measurements From Occlusal Aspect

Table 68 summarises the main findings for the area measurements of occlusal aspect, in different teeth. Appendix 14, tables 1-42 demonstrate all descriptive details.

Genders analysed separately:

Significant interactions were found for only L3 (see table 68 for p-values and figure 76) indicating that differences between groups were different for males and females.

In males: Each hypodontia group Ao mean value was found to be smaller than the control mean, but these groups did not (generally) differ amongst themselves.

The difference between male control mean Ao (49.04 mm^2) and mild hypodontia group (mean, 36.67 mm^2) = 12.36 mm^2, with moderate (mean, 37.16 mm^2) = 11.88 mm^2 and with severe group (mean, 33.95 mm^2), difference = 15.09 mm^2.

See appendix 14 tables for further descriptive details.

In females: Only in mild hypodontia group Ao mean was found to be smaller than the control mean. Two differences were suggested between female control and each of the moderate and severe means (F0>F2 and F3) but were not significance after final adjustment (Table 68).

Ao dimension found to be 7.73 mm^2 smaller in mild female hypodontia group (mean, 33.17 mm^2) than female control group (mean, 40.90 mm^2).

A gender difference was found in the control groups revealed smaller measurements in females (Table 68). For L3: Ao dimension found to be 8.14 mm^2 smaller in females than males. Refer to appendix 14 tables if details are required.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. Significant differences between group means were found for all other tooth types: U1, U2, U3, U4, U5, U6, U7, L1, L2, L4, L5, L6 and L7 (see table 68 for p-values).

With the exception of L7 in the above list, each hypodontia group demonstrated smaller Ao measurement than the control group and for all, the Ao dimensions of hypodontia groups did not differ among themselves. For L7 on the other hand, only

in mild hypodontia group, Ao was found to be samller than control group.

Differences were suggested but failed to retain significance after final adjustment (Table 68) between mild and severe group Ao dimensions (for U4, L2 and L5), between moderate and severe hypodontia (for U6 and L2) and between control and each moderate and severe group (for L7). Control measurements were larger than hypodontia and the severe the hypodontia, the smaller is the measurements.

For U1: Ao dimension value was 13.99 mm^2 smaller in mild hypodontia group (mean, 44.13 mm^2), 13.65 mm^2 smaller in moderate group (mean, 44.47 mm^2) and 17.12 mm^2 smaller in severe group (mean, 41.00 mm^2) when compared to 58.12 mm^2 in control group.

For U2: The measurement was 17.07 mm^2 smaller in mild hypodontia group (mean, 25.07 mm^2), 15.91 mm^2 smaller in moderate group (mean, 26.23 mm^2) and 16.04 mm^2 smaller in severe group (mean, 26.10 mm^2), each compared to 42.14 mm^2 in control group.

For U3: Ao found to be 12.67 mm^2 smaller in mild hypodontia group (mean, 42.66 mm^2), 11.70 mm^2 smaller in moderate group (mean, 43.63 mm^2) and 15.86 mm^2 smaller in severe group (mean, 39.47 mm^2), each compared to 55.33 mm^2 in control group.

For U4: Ao dimension found to be 12.28 mm^2 smaller in mild hypodontia group (mean, 48.00 mm^2), 15.59 mm^2 smaller in moderate group (mean, 44.69 mm^2) and 17.92 mm^2 smaller in severe group (mean, 42.36 mm^2), each compared to 60.28 mm^2 in control group.

For U5: Ao dimension found to be 12.34 mm^2 smaller in mild hypodontia group (mean, 46.78 mm^2), 16.20 mm^2 smaller in moderate group (mean, 42.92 mm^2) and 16.04 mm^2 smaller in severe group (mean, 43.08 mm^2), each compared to 59.12 mm^2 in control group.

For U6: Ao dimension found to be 16.06 mm^2 smaller in mild hypodontia group (mean, 96.51 mm^2), 14.47 mm^2 smaller in moderate group (mean, 98.10 mm^2) and 20.49 mm^2 smaller in severe group (mean, 92.08 mm^2), each compared to 112.57 mm^2 in control group. **In addition to a difference in groups, an evidence for consistent difference between genders was found (P2 = 0.532) of size 5.30 mm^2 (M>F), which applies in each group.**

For U7: Ao Measurement mean value was 17.79 mm^2 smaller in mild hypodontia group (mean, 82.67 mm^2), 14.60 mm^2 smaller in moderate group (mean, 85.86 mm^2) and 17.70 mm^2 smaller in severe group (mean, 82.76 mm^2) as each compared to 100.46 mm^2 in control group. A consistent difference between genders was suggested of size 5.86 mm^2 (M>F).

For L1: The dimension found to be 6.51 mm^2 smaller in mild hypodontia group (mean, 22.38 mm^2), 5.68 mm^2smaller in moderate group (mean, 23.21 mm^2) and 7.07 mm^2 smaller in severe group (mean, 21.82 mm^2), each compared to 28.89 mm^2 in control group.

For L2: Ao mean 7.19 mm^2 smaller in mild hypodontia group (mean, 25.80 mm^2), 7.48 mm^2 smaller in moderate group (mean, 25.51 mm^2) and 9.21 mm^2 smaller in severe group (mean 23.78 mm^2), each compared to 32.99 mm^2 in control group.

For L4: Ao measurement mean was 11.76 mm^2 smaller in mild hypodontia group (mean, 40.06 mm^2), 11.23 mm^2 smaller in moderate group (mean, 40.59 mm^2) and 13.20 mm^2 smaller in severe group (mean, 38.62 mm^2), each compared to 51.82 mm^2 in control group. In addition, a consistent difference between genders was suggested of size 2.16 mm^2 (M>F).

For L5: It was 12.71 mm^2 smaller in mild hypodontia group (mean, 44.81 mm^2), 13.75 mm^2 smaller in moderate group (mean, 43.77 mm^2) and 17.78 mm^2 smaller in severe group (mean, 39.74 mm^2), each compared to 57.52 mm^2 in control group.

For L6: Ao measurements found to be 16.20 mm^2 smaller in mild hypodontia group (mean, 93.31 mm^2), 12.60 mm^2 smaller in moderate group (mean, 96.91 mm^2) and 14.92 mm^2 smaller in severe group (mean, 94.59 mm^2), each compared to 109.51 mm^2 in control group. A consistent difference between genders was also suggested of size 4.23 mm^2 (M>F), which applies in each group.

For L7: Ao dimension was found to be 16.19 mm^2 smaller in mild hypodontia group (mean, 83.67 mm^2) than in control group (mean, 99.86 mm^2). In addition, a consistent difference between genders was suggested of size 6.32 mm^2 (M>F), which applies in each group.

See appendix 14 tables for further descriptive details.

Summary of Ao findings

The findings of the area measurements of the occlusal view for different tooth types are summarised:

1) When the genders were analysed separately for tooth L3; multi-subgroup comparison tests and final adjustment of significance levels revealed:

For males, the mean values in each hypodontia group were significantly less than in the control group.

For females, only the mean values in mild hypodontia were significantly less than in the control group.

Significant gender difference was found in the control group only, suggesting measurements of males were larger than females.

2) When genders were combined for the rest of teeth (U1, U2, U3, U4, U5, U6, U7, L1, L2, L4, L5, L6 and L7); multi-group comparison tests and final adjustment of significance levels revealed:

Apart from L7, the mean values in each hypodontia group were significantly smaller than in the control group for the above teeth.

While in L7, only the measurements of mild hypodontia were significantly smaller than in the control group.

Figure 76: Estimated Means of Ao for tooth L3

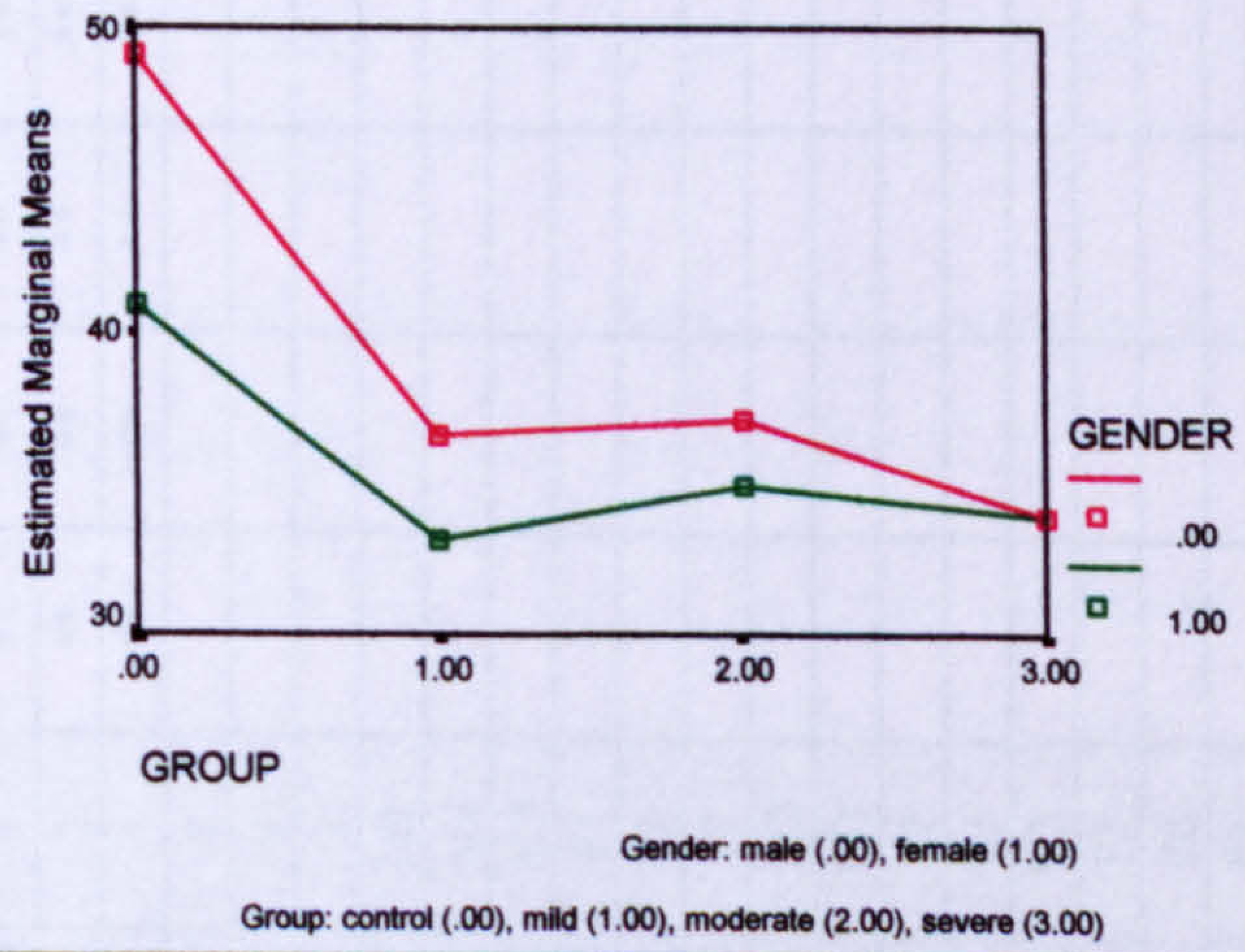


Table 68: Summary results of area measurements from occlusal aspect (Ao)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Gender		0.509	0.463	0.379	0.912	0.748	0.002	0.019	0.850	0.864	0.000	0.014	0.731	0.008	0.045
	Group & Gender		0.942	0.862	0.207	0.209	0.546	0.614	0.457	0.200	0.210	0.019	0.439	0.293	0.214	0.653
Multi-group comparisons	0	1	**	**	**	**	**	**	**	**	**		**	**	**	**
		2	**	**	**	**	**	**	**	**	**		**	**	**	*
		3	**	**	**	**	**	**	**	**	**		**	**	**	*
	1	2														
		3				*					*			*		
	2	3						*			*					
Multi-subgroup comparisons	Mo	M1										**				
		M2										**				
		M3										**				
	F0	F1										**				
		F2										*				
		F3										*				
	M1	M2														
		M3														
	F1	F2														
		F3														
	M2	M3														
	F2	F3														
	M0	F0										**				
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).

*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*

(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) or subgroup ($n = 16$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.

** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*

Details of descriptive and comparative findings are shown in appendix 14 tables.

7.3.15. Findings for Crown Index of Occlusal Morphology 1

The results of the 1st crown index measurements of occlusal surface morphology (CIOM1 i.e. MDo/BL), for different teeth, were shown in table 69. The descriptive data of group and subgroup means and differences were presented in appendix 1, tables 1-36. The following are the main findings.

Genders analysed separately:

Significant interactions were found for teeth L1 and L5 indicating that differences between groups were different for males and females (see table 69 for p-values and figures 77-78).

In females: only for L5, the control group CIOM1 mean value was found to be smaller than the severe group mean.

An evidence of a difference was found between female mild and severe hypodontia group CIOM1 mean value (F1<F3).

A suggested difference was also found between female moderate and severe CIOM1 mean value (F2<F3) but with unretained significance. See table 69 and appendix 15 tables for details.

For L5: Difference between female severe group mean CIOM1 (mean, 0.93) and female control group (mean, 0.83) = 0.10.

In males: Only for L1, some evidence of a difference between male control and severe hypodontia group CIOM 1 mean value (M0<M3).

A suggested difference was also found for L1 between moderate and severe hypodontia group (M2<M3), but did not retain significance after final adjustment. Finally, a difference between genders was suggested in severe groups (M0<F0) but this also failed to retain significance. See table 69. Descriptive details for means and differences are all present in appendix 15 tables.

Genders combined:

Where no interaction was found, differences between groups do not depend on gender. **Significant differences between group means were found for U1, U3, U4, U5, L3 and**

L4 (see table 69 for p-values). **For only U4, control group CIOM1 mean value was smaller than severe hypodontia mean.**

There is evidence of a difference between control and severe group for U5 was found. Differences were also suggested between control and mild hypodontia group CIOM1 means (for U1, U4 and U5), between control and moderate means (for U4 and U5) and between control and severe group means (for U3, L3 and L4). None of these differences retained their significance after final adjustment. These all were suggesting smaller index value in control groups and becoming bigger with increase in severity of hypodontia. See table 69 and appendix 15 tables.

For U4: The difference in CIOM1 values between control group (mean, 0.74) and severe hypodontia group (mean, 0.79) = 0.05. A consistent difference between genders was also suggested of size 0.01 (M>F).

Finally, a consistent difference between genders was suggested for U5, L3 of size 0.01, 0.03, 0.02 respectively (M>F) and for L4 of size 0.02 (M<F).

See appendix 15 tables for details.

Summary of CIOM1 findings

The results for the crown index of occlusal morphology 1 for different teeth are summarised:

1) When the genders were analysed separately for teeth L1 and L5; multi-subgroup comparison tests and final adjustment of significance levels revealed:

> *Only L5 in females, the CIOM1 measurement mean values in severe hypodontia were significantly larger than in the control group.*

2) When genders were combined for teeth U1, U3, U4, U5, L3 and L4; multi-group comparison tests and final adjustment of significance levels revealed:

> *Only in U4, the mean value in the severe hypodontia group was significantly larger than in the control group.*

Table 69: Summary results of crown index of occlusal morphology-1 (CIOM1)

Statistical Tests			U1	U2	U3	U4	U5	U6	U7	L1	L2	L3	L4	L5	L6	L7
2-way ANOVA (P-values)	Group		0.013	0.271	0.042	0.003	0.001	0.175	0.310	0.053	0.214	0.056	0.010	0.000	0.925	0.187
	Gender		0.184	0.372	0.379	0.076	0.057	0.605	0.525	0.935	0.751	0.051	0.044	0.012	0.404	0.783
	Group & Gender		0.784	0.844	0.615	0.133	0.689	0.221	0.254	0.004	0.286	0.997	0.887	0.076	0.628	0.312
Multi-group comparisons	0	1	*			*	*									
		2				*	*									
		3			*	**	(*)					*	*			
	1	2														
		3														
	2	3														
Multi-subgroup comparisons	Mo	M1														
		M2														
		M3								(*)						
	F0	F1														
		F2														
		F3												**		
	M1	M2														
		M3														
	F1	F2														
		F3												(*)		
	M2	M3								*						
	F2	F3												*		
	M0	F0														
	M1	F1														
	M2	F2														
	M3	F3								*						

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) or subgroup ($n = 16$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 15 tables.

Figure 77: Estimated Means of CIOM1 for tooth L

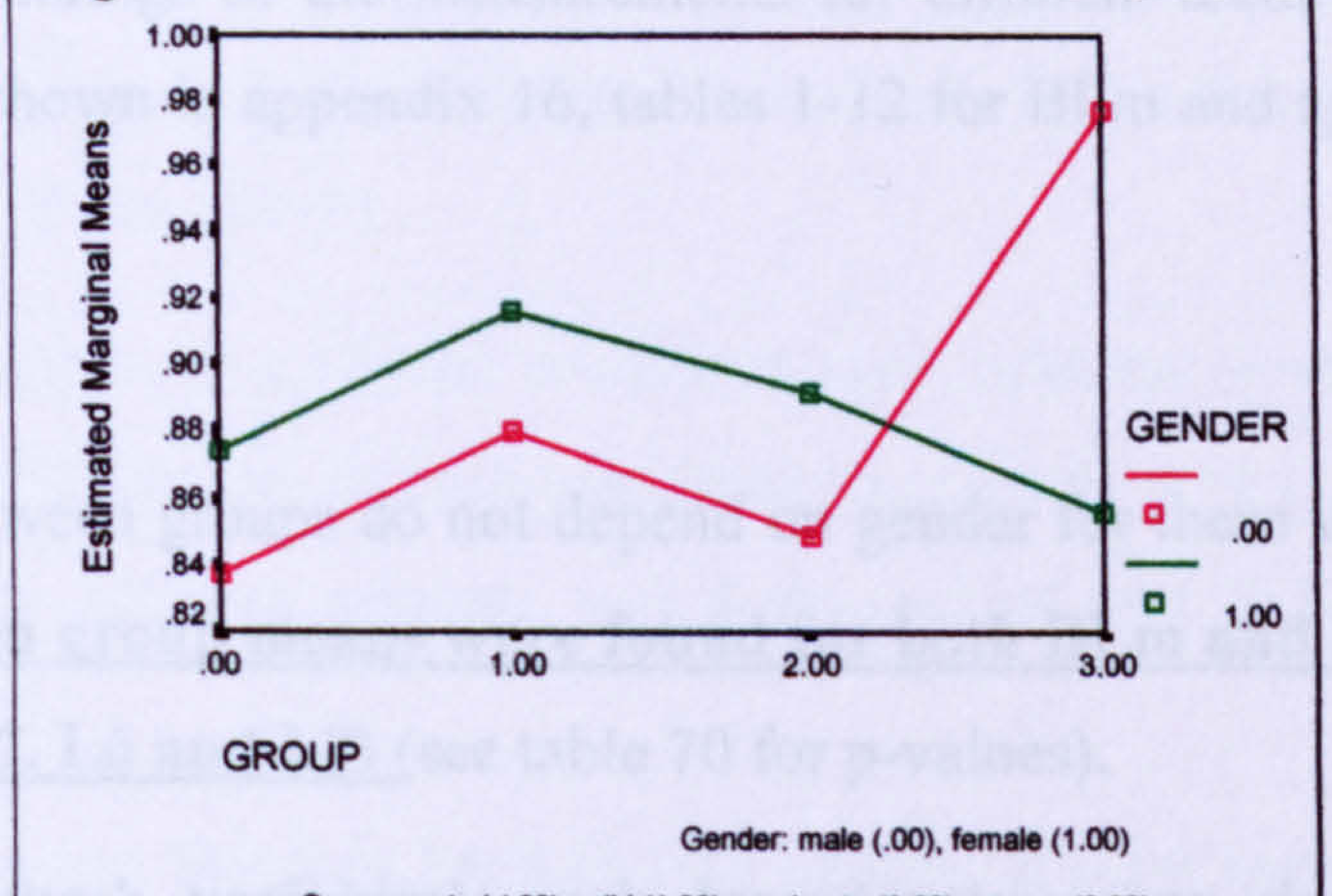
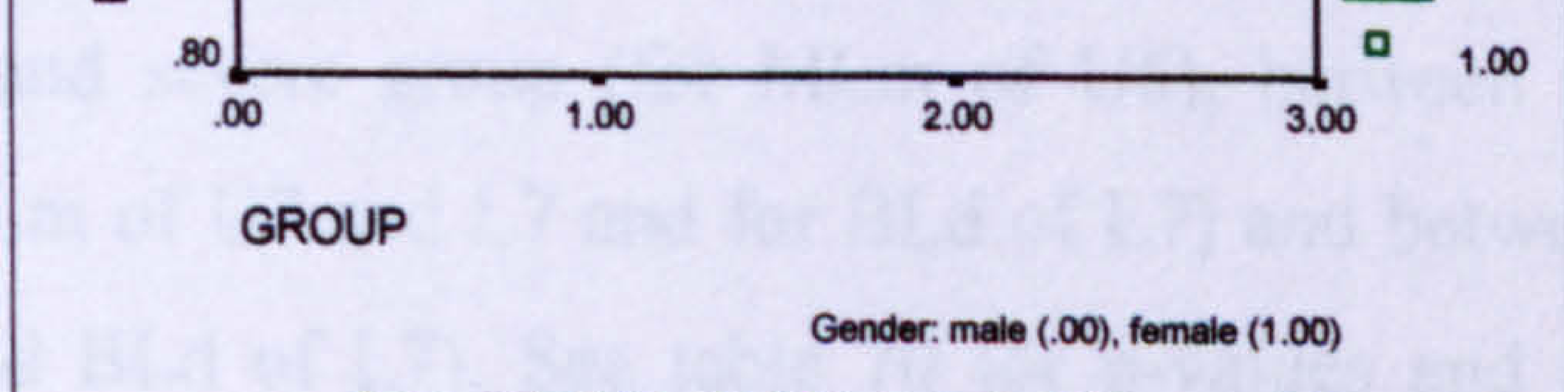


Figure 78: Estimated Means of CIOM1 for tooth L5



7.3.16. Proportional Buccolingual Measurements

These two buccolingual dimension variables (BLm and BLd) are related to molar teeth only that were determined in fixed proportions crossing the MDo dimension, one mesial and one distal, and both were parallel to principal BL dimension of molar teeth. Table 70 demostrates main findings of the measurements for different teeth. Descriptive data on the other hand are shown in appendix 16, tables 1-12 for BLm and appendix 17, tables 1-12 for BLd.

Genders combined:

The differences between groups do not depend on gender for these variables. **Significant differences between group means were found for both BLm and BLd variables in all tooth types (U6, U7, L6 and L7)** (see table 70 for p-values).

For U6 and L6 (both variables), each hypodontia group demonstrated smaller dimensions than the control group and the dimensions of hypodontia groups did not differ among themselves.

For U7, L7 (in BLm) and L7 (in BLd), only the mild hypodontia group dimensions were smaller than control group. For U7 (in BLd) on the other hand, mild as well as severe hypodontia group showed smaller dimension means than control group.

These were with an evidence of differences in U7 between control and moderate group for BLd and between control and severe hypodontia group for BLm.

Difference were also suggested but all failed to retain significance after final adjustment between moderate and severe group (for MLm of U6), between control and moderate group found (for BLm of U7 and L7 and for BLd of L7) and between control and severe group (for BLm and BLd of L7). See table 70 for p-values and appendix 1 tables for detail. All these comparisons indicate decrease in the dimensions with an increase in severity of hypodontia.

For U6: BLm dimension found to be 0.99 mm smaller in mild hypodontia group (mean, 10.15 mm), 0.75 mm smaller in moderate group (mean, 10.39 mm) and 1.24 mm smaller in severe group (mean, 9.90 mm) when compared to 11.14 mm in control group. A consistent difference between genders was suggested of size 0.35 mm (M>F).

BLd measurement was 0.95 mm smaller in mild hypodontia group (mean, 9.82 mm), 0.80

mm smaller in moderate group (mean, 9.97 mm) and 1.10 mm smaller in severe group (mean, 9.67 mm), each compared to 10.77 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.22 mm (M>F).

For U7: BLm found to be 1.11 mm smaller in mild hypodontia group (mean, 9.56 mm) than in control group (mean, 10.67 mm). A consistent difference between genders was suggested of size 0.39 mm (M>F).

BLd dimension found to be 1.13 mm smaller in each mild and severe hypodontia group (each has a mean of 9.19 mm) as each compared the control group (mean, 10.32 mm). A consistent difference between genders was suggested of size 0.29 mm (M>F), which applies in each group.

For L6: BLm dimension found to be 0.85 mm smaller in mild hypodontia group (mean, 9.62 mm), 0.59 mm smaller in moderate group (mean, 9.88 mm) and 0.73 mm smaller in severe group (mean, 9.74 mm), each compared to 10.47 mm in control group. In addition to a difference in groups a consistent difference between genders was suggested of size 0.28 mm (M>F).

BLd dimension again was 0.82 mm smaller in mild hypodontia group (mean, 9.36 mm), 0.67 mm smaller in moderate group (mean, 9.51 mm) and 0.78 mm smaller in severe group (mean, 9.40 mm), each compared to 10.18 mm in control group. A consistent difference between genders was suggested of size 0.24 mm.

For L7: BLm dimension found to be 1.15 mm smaller in mild hypodontia group (mean, 9.17 mm) than control group (mean, 10.32 mm). In addition to a difference in groups a consistent difference between genders was suggested of size 0.52 mm, which applies in each group.

BLd was also 1.03 mm smaller in mild hypodontia group (mean, 8.72 mm) than control group (mean, 9.75 mm).

See appendices 16 and 17 for further descriptive details.

Summary of proportional BLs findings

The analysis of these proportional buccolingual dimension measurements (BLm and BLd) for molar teeth suggested combining males and females and the results showed similar trend in both variables for the same tooth type. Multi-group comparison tests and final adjustment of significance levels revealed:

1) *For U6 and L6: The mean values in each hypodontia group were significantly less than in the control group.*

2) *For U7 and L7: Only the mild hypodontia group measurements were significantly less than in the control group. One exception (in U7 BLd) was found suggesting that the severe hypodontia mean value was significantly less than the control group mean value.*

Table 70: Summary results of proportional buccolingual measurements (BLm and BLd)

Statistical Tests			BLm				BLd			
			U6	U7	L6	L7	U6	U7	L6	L7
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Gender		0.005	0.042	0.005	0.009	0.034	0.058	0.024	0.378
	Group & Gender		0.735	0.701	0.252	0.820	0.771	0.384	0.272	0.972
Multi-group comparisons	0	1	**	**	**	**	**	**	**	**
		2	**	*	**	*	**	(*)	**	*
		3	**	(*)	**	*	**	**	**	*
	1	2								
		3								
	2	3	*							

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated ($n = 266$).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group ($n = 6$) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels.*
Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.
Details of descriptive and comparative findings are shown in appendices 16 and 17 tables.

7.3.17. Do Measurements

The distance between the buccal surface border and mesiodistal dimension of the occlusal view was determined across the buccolingual dimension. This was to evaluate the location of the MDo within the tooth (i.e. to determine the level of the line connecting the contact points, as being buccally or lingually located). Another purpose was to determine an index (the next variable to follow: CIOM2) that can be used for comparison purpose. The main findings are shown in tables 71 and 72. Further details are presented in appendix 18, tables 1-82.

Genders analysed separately:

Significant interactions were found for teeth 25, 41 and 36 (see tables 70 and 71 for p-values and figures 79-81) indicating that differences between groups were different for males and females.

In males: Only for 41, control group Do mean value was found to be statistically bigger than each of mild and severe hypodontia group means.

There is evidence of differences between male control Do and each of moderate hypodontia (M0>M2) for 25 and severe hypodontia (M0>M3) for 36.

A difference was also suggested but failed to retain significance after final adjustment between male moderate and severe hypodontia means (M2>M3) for 41 (tables 71 and 72 and appendix 18 tables).

For 41: Do dimension was 0.56 mm bigger in male mild hypodontia group (mean, 2.21 mm) and 0.74 mm bigger in severe hypodontia group (mean, 2,03 mm) as each was compared to the male control (mean, 2.77 mm).

In females: There is some evidence for differences between female control Do and each of severe hypodontia (F0>F3) for 25 and mild hypodontia (F0>F1) for 41.

A difference was also suggested but failed to retain significance after final adjustment between female mild and severe hypodontia means (F1>F3) for tooth 25.

Finally, a difference between between genders was suggested in control groups (M0>F0) for 36 but did not reatin the significance (See tables 71 and 72 and in appendix 18 tables).

Genders combined:

Where no interaction was found, differences between groups did not depend on gender. <u>Significant differences between group means were found for most of other tooth types: 11, 21, 12, 22, 13, 23, 14, 24, 15, 16, 26, 27, 31, 32, 42, 33, 43, 34, 44, 35, 45, 46 and 47</u> (see tables 71 and 72 for p-values).

<u>**The control group demonstrated a bigger Do mean than each of mild hypodontia (for 11, 21, 12, 22, 13, 23, 31, 32 and 42), moderate hypodontia (for 21, 12, 22, 13 and 23) and severe hypodontia (for 11, 21, 12, 13, 23, 14, 26, 32, 43, 34, 44 and 45) means.**</u>

There is an evidence of a difference between control group mean value and each of mild hypodontia group (0>1) for 43, 34 and 46, moderate hypodontia (0>2) for 45 and severe hypodontia mean values (0>3) for 31, 33, 35 and 46.

Suggested differences were also revealed between control group and each of mild hypodontia group means (0>1) for 14, 24, 16, 26, 33, 44, 35, 45 and 47, moderate hypodontia (0>2) for 11, 14, 24, 15, 26, 31, 32, 43, 34 and 44 and severe hypodontia (0>3) for 22, 24, 15, 16 and 42, between mild hypodontia and each of moderate group (1<2) for 11 and 27 and severe group (1>3) for 45 and between moderate and severe hypodontia group (2>3) for 34. Generally, the trend is control > hypodontia, see tables 71 and 72 and appendix 18 tables.

For 11: Do value found to be 0.61 mm smaller in mild hypodontia group (mean, 2.59 mm) and 0.49 mm smaller in severe group (mean, 2.71 mm), each compared to 3.20 mm in control group.

For 21: Do dimension was 0.57 mm smaller in mild hypodontia (mean, 2.76 mm), 0.47 mm smaller in moderate hypodontia (mean, 2.86 mm) and 0.59 mm smaller in severe hypodontia group (mean 2.74 mm), each compared to 3.33 mm in control group.

For 12: Do value found to be 0.67 mm smaller in mild hypodontia group (mean, 2.35 mm) and 0.55 mm smaller in moderate group (mean, 2.47 mm) and 0.53 mm smaller in severe group (mean, 2.49 mm), each compared to 3.02 mm in control group.

For 22: Do dimension was 0.59 mm smaller in mild hypodontia (mean, 2.44 mm) and 0.49 mm smaller in moderate hypodontia (mean, 2.54 mm), each compared to 3.33 mm in control group.

For 13: Do value found to be 0.74 mm smaller in mild hypodontia group (mean, 3.31 mm), 0.60 mm smaller in moderate hypodontia (mean, 3.45 mm) and 0.73 mm smaller in severe group (mean, 3.32 mm), each compared to 4.05 mm in control group.

For 23: Do dimension was 0.77 mm smaller in mild hypodontia (mean, 3.33 mm), 0.61 mm smaller in moderate hypodontia (mean, 3.49 mm) and 0.85 mm smaller in severe hypodontia group (mean 3.25 mm), each compared to 4.10 mm in control group.

For 14: Do value found to be 0.37 mm smaller in moderate hypodontia group (mean, 3.68 mm) and 0.59 mm smaller in severe group (mean, 3.46 mm), each compared to 4.05 mm in control group.

For 26: Do was 0.51 mm smaller in severe hypodontia group (mean 4.48 mm) as compared to control group (mean, 4.99 mm).

For 31: Do mean value was found to be 0.45 mm smaller in mild hypodontia group (mean 2.20 mm) as compared to control group (mean, 2.65 mm).

For 32: Do dimension was 0.56 mm smaller in mild hypodontia (mean, 2.23 mm) and 0.43 mm smaller in severe hypodontia group (mean 2.36 mm), each compared to 2.79 mm in control group.

For 42: Do mean value was found to be 0.43 mm smaller in mild hypodontia group (mean 2.30 mm) as compared to control group (mean, 2.73 mm).

For 43: Do value was found to be 0.54 mm smaller in severe hypodontia group (mean 3.11 mm) as compared to control group (mean, 3.65 mm). In addition, a consistent difference between genders was suggested of size 0.23 mm (M>F) that applies in each group.

For 34: Do was 0.63 mm smaller in severe hypodontia group (mean 4.47 mm) as compared to control group (mean, 4.10 mm). Furthermore, a consistent difference between genders was suggested of size 0.18 mm (M>F).

For 44: Do dimension was 0.48 mm smaller in severe hypodontia group (mean 3.56 mm) as compared to control group (mean, 4.04 mm).

For 45: Do was 0.66 mm smaller in severe hypodontia group (mean 3.55 mm) as compared to control group (mean, 4.21 mm).

Finally, for 33 and 46, a consistent difference between genders was suggested of size 0.15

mm, and 0.13 mm (M>F).

For further detail, see appendix 18 tables.

Summary of Do findings

The measurement results for the distance between mesiodistal dimension of the occlusal view and the buccal border of tooth crown (Do) for all teeth are summarised as follows:
1) When the genders were analysed separately for teeth 25, 41, 36, multi-subgroup comparison tests and final adjustment of significance levels revealed:

> *Only in tooth 41 of males, the mean values in each of the severe and mild hypodontia groups were significantly less than in the control group.*

2) When genders were combined for rest of teeth except 17 and 37; multi-group comparison tests and final adjustment of significance levels revealed:

> *The measurement values of Do in severe hypodontia group were significantly less than in control group for teeth 11, 21, 12, 13, 23, 14, 26, 32, 43, 34, 44 and 45.*
> *The measurements in the moderate hypodontia group were significantly less than in the control group for teeth 21, 12, 22, 13 and 23.*
> *The measurements in the mild hypodontia group were significantly less than in control group for teeth 11, 21, 12, 22, 13, 23, 31, 32 and 42.*

Table 71: Summary results of Do measurements for maxillary teeth from occlusal aspect

Statistical Tests			11	21	12	22	13	23	14	24	15	25	16	26	17	27
2-way ANOVA (P-values)	Group		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.007	0.000	0.152	0.018
	Gender		0.414	0.647	0.111	0.501	0.524	0.128	0.450	0.707	0.927	0.795	0.266	0.470	0.111	0.541
	Group & Gender		0.301	0.549	0.271	0.782	0.107	0.250	0.322	0.673	0.248	0.039	0.115	0.202	0.583	0.497
Multi-group comparisons	0	1	**	**	**	**	**	**	*	*			*	*		
		2	*	**	**	**	**	**	*	*	*			*		
		3	**	**	**	*	**	**	**	*	*		*	**		
	1	2	*													*
		3														
	2	3														
Multi-subgroup comparisons	Mo	M1														
		M2										(*)				
		M3														
	F0	F1														
		F2														
		F3										(*)				
	M1	M2														
		M3														
	F1	F2														
		F3										*				
	M2	M3														
	F2	F3														
	M0	F0														
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 18 tables.

Table 72: Summary results of Do measurements for mandibular teeth from occlusal aspect

Statistical Tests			31	41	32	42	33	43	34	44	35	45	36	46	37	47
2-way ANOVA	Group		0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.019	0.001	0.123	0.027
(P-values)	Gender		0.921	0.243	0.728	0.809	0.066	0.024	0.019	0.460	0.694	0.326	0.282	0.089	0.947	0.338
	Group & Gender		0.435	0.048	0.757	0.838	0.560	0.971	0.453	0.187	0.770	0.355	0.003	0.179	0.845	0.490
Multi-group comparisons	0	1	**		**	**	*	(*)	(*)	*	*	*		(*)		*
		2	*		*			*	*	*		(*)				
		3	(*)		**	*	(*)	**	**	**	(*)	**		(*)		
	1	2														
		3										*				
	2	3							*							
Multi-subgroup comparisons	Mo	M1		**												
		M2														
		M3		**									(*)			
	F0	F1		(*)												
		F2														
		F3														
	M1	M2														
		M3														
	F1	F2														
		F3														
	M2	M3		*												
	F2	F3														
	M0	F0											*			
	M1	F1														
	M2	F2														
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).

*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*

(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.

** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*

Details of descriptive and comparative findings are shown in appendix 18 tables.

Figure 79: Estimated Means of Do for tooth 25

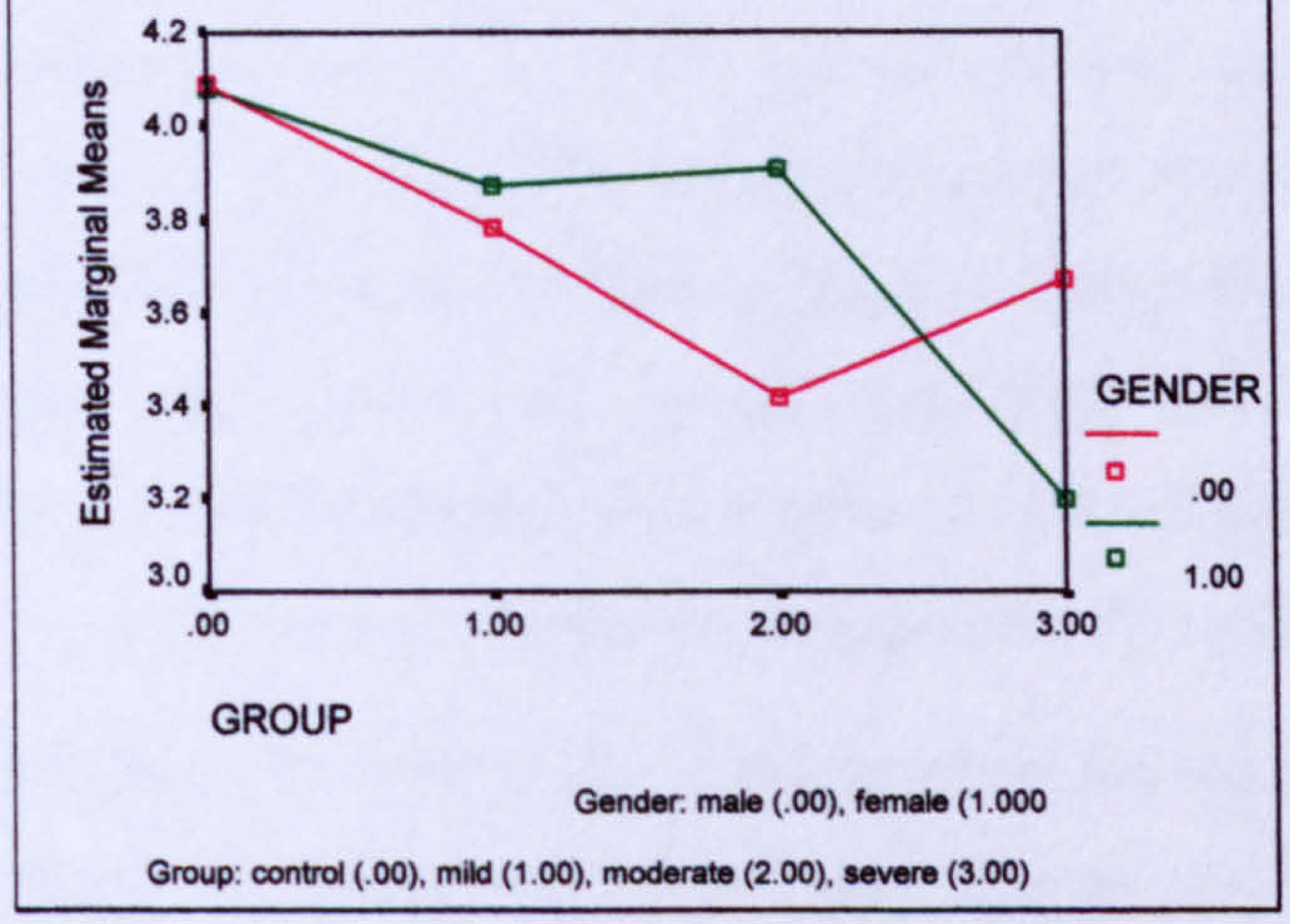


Figure 80: Estimated Means of Do for tooth 41

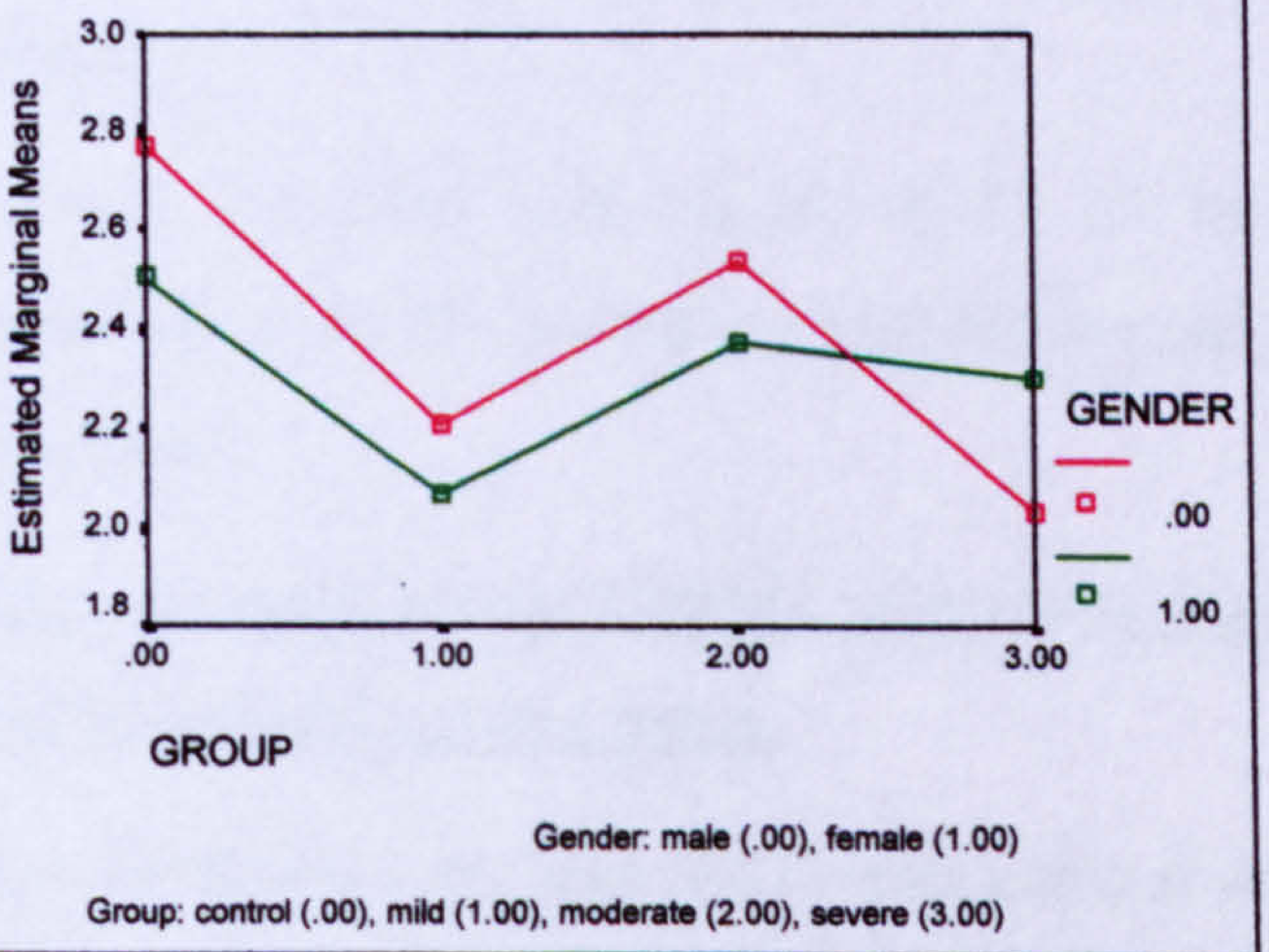
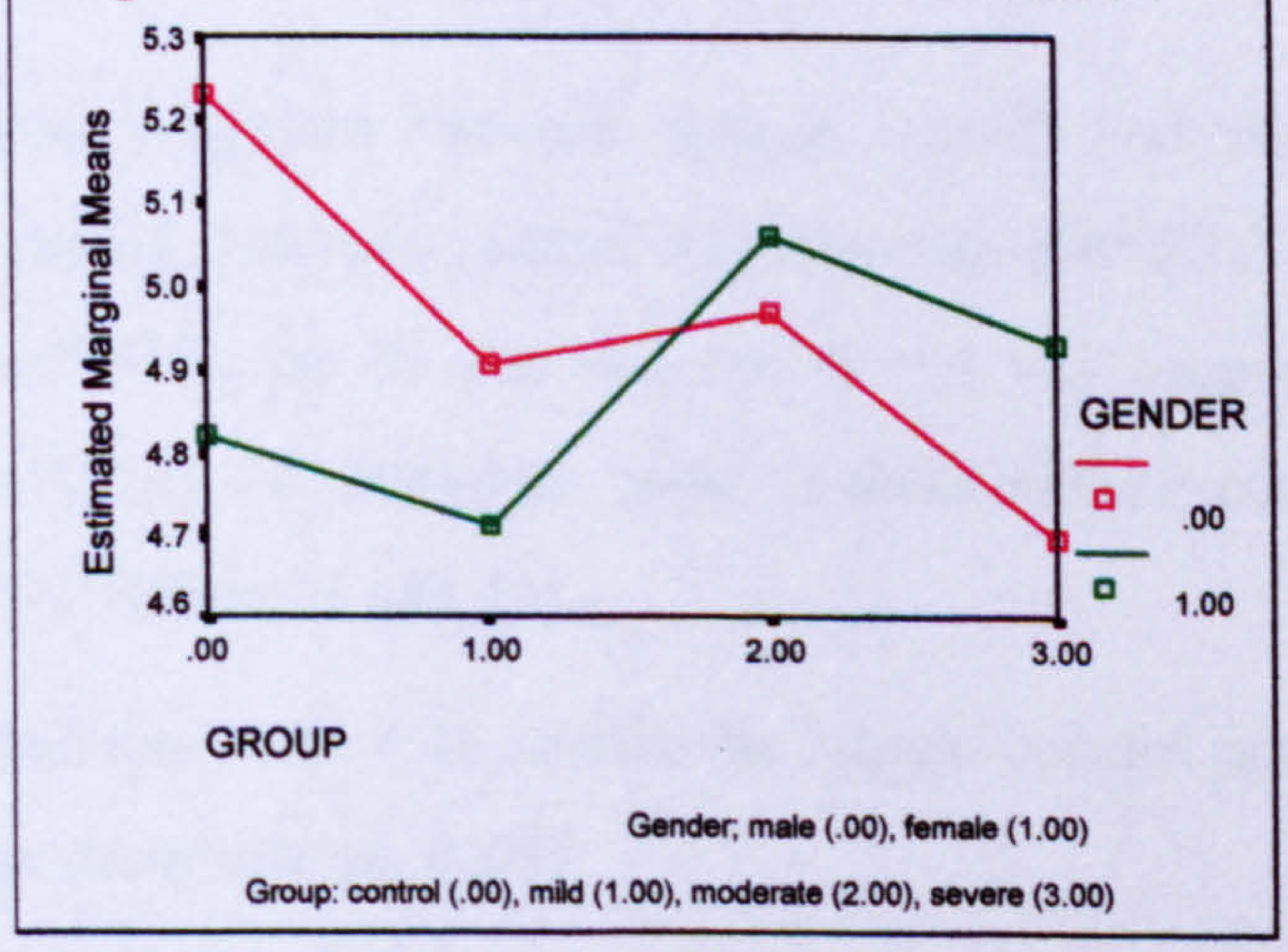


Figure 81: Estimated Means of Do for tooth 36



7.3.18. Findings for Crown Index of Occlusal Morphology 2

The 2nd index of the occlusal morphology of tooth crown (CIOM2) was also determined as a ratio i.e. the distance between MDo to the buccal outline of occlusal view divided by the buccolingual dimension (Do/BL). This allows evaluation of how far the MDo moves from the buccal surface toward the lingual (palatal) surface when related to the BL dimension. The main statistical results for all maxillary and mandibular teeth are summarised in tables 73 and 74 respectively. Further details of descriptive data of group and subgroup means and differences are shown in appendix 19, tables 1-78.

The findings indicated that MDo line tends to be located in the buccal half but close to the middle of BL dimension for both control and hypodontia groups. The following are the main findings.

Genders analysed separately:

Significant interactions were found for teeth 14, 15, 16, 17, 23, 26 and 36 (see tables 73 and 74 for p-values and figures 82-88) indicating that differences between groups were different for males and females.

Only for 36 in females: Control group CIOM2 mean was found to be statistically smaller than moderate hypodontia group mean.

There is some evidence of differences between female control and severe hypodontia (F0<F3) for 36 and between female mild and severe hypodontia group (F1>F3) for 15.

Differences were also suggested between female control and mild hypodontia means (F0<F1) for 14, 15 and 36, between control and moderate (F0<F2) for 14 and 17, between control and severe (F0<F3) for 36 and between severe and each of mild and moderate groups (F3<F1 and F2) for 14. However, none of these differences retained significance after final adjustment (Tables 73 and 74).

For 36: CIOM2 dimension was 0.04 smaller in female control group (mean, 0.45) than moderate hypodontia group (mean, 0.49).

In males: Only some evidence for a difference between male control and severe hypodontia (M0<M3) for tooth 14.

Suggested differences were also found but did not retain significance after final adjustment between male control and each of mild hypodontia (M0<M1 for 14 and 15 and M0>M1 for 23), moderate hypodontia (M0<M2) for 14 and 15 and severe hypodontia group (M0<M3) for15.

Finally, Differences between genders were found between control groups (M>F) for 23, between moderate hypodontia groups (F>M) for 26 and 36 and between severe groups (M>F) for 14 and 15, but also failed to retain significance (Tables 73 and 74 and appendix 19 tables).

Genders combined:

Where no interaction was found, differences between groups did not depend on gender. **Significant differences between CIOM2 group means were found for most of other tooth types: 11, 22, 24, 25, 27, 41, 32, 42, 34, 44, 35, 45, 46, 37 and 47** (See tables 73 and 74 for p-values).

However, only some evidence for differences was found between control and mild hypodontia group (0<1) for teeth 25 and 44) and between control and moderate hypodontia group (0<2) for tooth 24. For the rest of the above list, none had shown significant finding after final adjustment of significance level indicating no difference betwen the groups for these teeth.

Suggested differences were revealed between control group and mild hypodontia group means (0<1) for 24, 34, 35, 45 and 37, between control and moderate hypodontia (0<2) for 25, 27, 34, 44, 35, 46 and 37, between control and severe group (0<3) for 32, between mild and moderate group (1<2) for 41 and between moderate and severe hypodontia (2>3) for 46, howevere, none of these had retained significance after final adjutment. See table 73 and 74.

Finally a consistent difference between genders was suggested of size 0.02 for 43 (M>F) and for 47 (M<F).

See appendix 19 tables if detail is required.

Table 73: Summary results of crown index of occlusal morphology-2 (CIOM2) for maxillary teeth

Statistical Tests			11	21	12	22	13	23	14	24	15	25	16	26	17	27
2-way ANOVA (P-values)	Group		0.030	0.826	0.204	0.055	0.798	0.209	0.000	0.000	0.000	0.001	0.153	0.722	0.001	0.008
	Gender		0.289	0.607	0.934	0.909	0.892	0.191	0.163	0.594	0.142	0.711	0.912	0.270	0.723	0.575
	Group & Gender		0.330	0.477	0.445	0.617	0.666	0.041	0.007	0.439	0.013	0.189	0.072	0.046	0.046	0.271
Multi-group comparisons	0	1								*		(*)				
		2								(*)		*				*
		3														
	1	2														
		3														
	2	3														
Multi-subgroup comparisons	Mo	M1						*	*		*					
		M2							*		*					
		M3							(*)		*					
	F0	F1							*		*					
		F2							*						*	
		F3														
	M1	M2														
		M3														
	F1	F2														
		F3							*		(*)					
	M2	M3														
	F2	F3							*		*					
	M0	F0						*								
	M1	F1														
	M2	F2												*		
	M3	F3							*		*					

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 19 tables.

Table 74: Summary results of crown index of occlusal morphology-2 (CIOM2) for mandibular teeth

Statistical Tests			31	41	32	42	33	43	34	44	35	45	36	46	37	47
2-way ANOVA	Group		0.765	0.012	0.041	0.037	0.198	0.142	0.016	0.002	0.002	0.006	0.000	0.007	0.008	0.073
(P-values)	Gender		0.939	0.341	0.305	0.443	0.445	0.090	0.649	0.162	0.453	0.854	0.070	0.883	0.656	0.092
	Group & Gender		0.555	0.674	0.642	0.813	0.915	0.728	0.338	0.654	0.556	0.880	0.010	0.143	0.846	0.288
Multi-group comparisons	0	1							*	(*)	*	*			*	
		2							*	*	*			*	*	
		3			*											
	1	2		*												
		3														
	2	3												*		
Multi-subgroup comparisons	Mo	M1														
		M2														
		M3														
	F0	F1											*			
		F2											**			
		F3											(*)			
	M1	M2														
		M3														
	F1	F2														
		F3														
	M2	M3														
	F2	F3														
	M0	F0														
	M1	F1														
	M2	F2											*			
	M3	F3														

0 = control, 1 = mild hypodontia, 2 = moderate hypodontia, 3 = severe hypodontia, M = male, F = female, U = upper (maxillary), L = lower (mandibular).
*** Significant finding after Bonferroni final adjustment for significance levels ($P2 \leq 0.10$) accounting for multi-variables investigated (n = 266).*
(*) Suggested significant finding: $P1 \leq 0.00375$ adjusted for multi-group (n = 6) or subgroup (n = 16) comparisons i.e. $0.10 < P2 < 1.00$ after final adjustment for significance levels.
** Other findings: $P1 \leq 0.10$ but $P2 \geq 1.00$ after final adjustment for significance levels. Final adjustment of significance levels for gender in 2-way ANOVA: Multiply each figure by 266.*
Details of descriptive and comparative findings are shown in appendix 19 tables.

Summary of CIOM2 findings

The measurement results for crown index of occlusal morphology 2 (CIOM2) for all teeth are summarised as follows:

1) When the genders were analysed separately for teeth 23, 14, 15, 16, 26, 17 and 36; multi-subgroup comparison tests and final adjustment of significance levels revealed:

> *Only for tooth 36 in females, the mean values in the moderate hypodontia group were significantly greater than in the control group.*

2) When genders were combined for teeth 11, 22, 24, 25, 27, 41, 32, 42, 34, 44, 35, 45, 46, 37 and 47; multi-group comparison tests revealed:

> *No significant difference was revealed after final adjustment of the significance levels between control and hypodontia groups.*

Figure 82: Estimated Means of CIOM2 for tooth 23

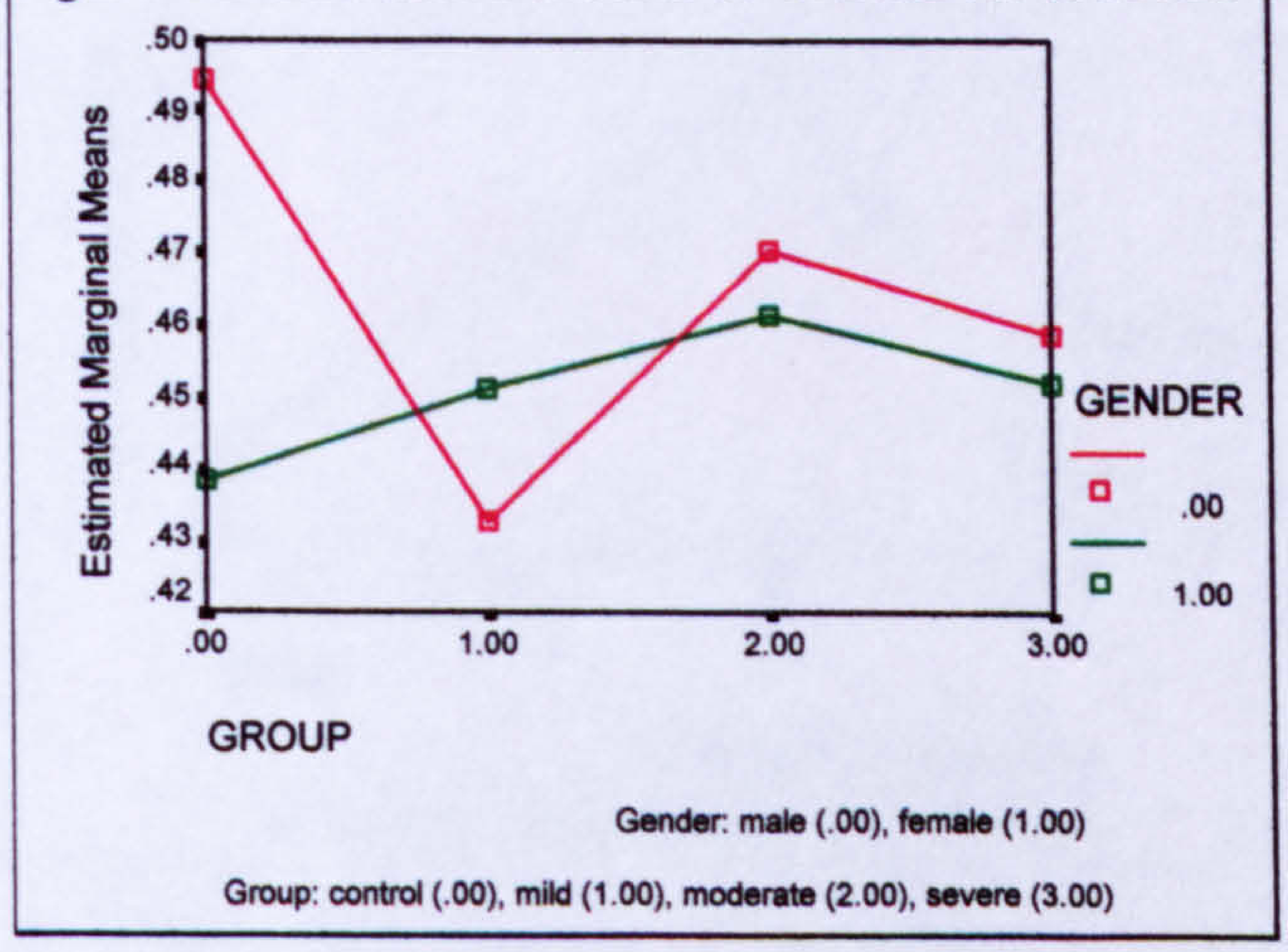


Figure 83: Estimated Means of CIOM2 for tooth 14

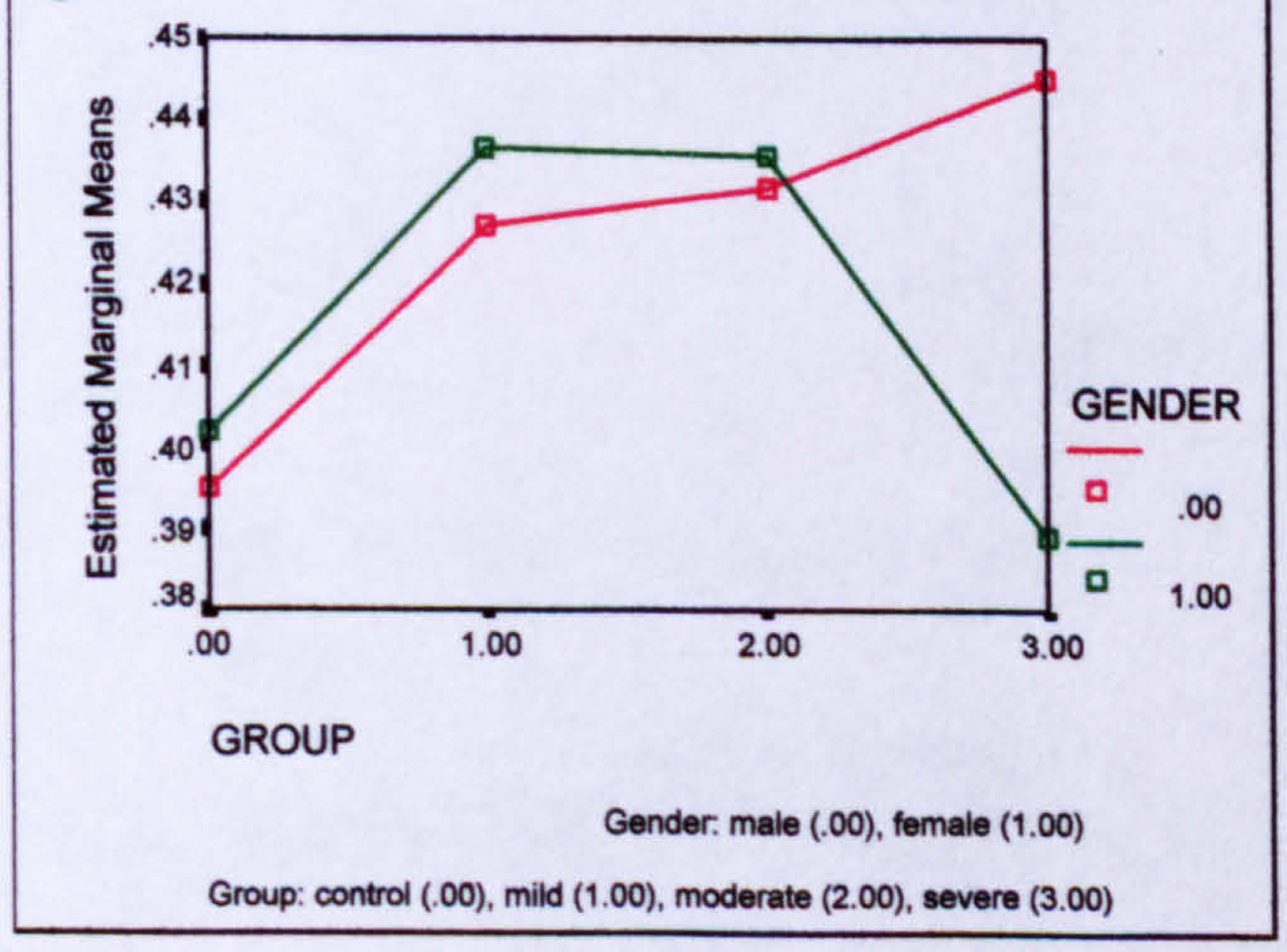


Figure 84: Estimated Means of CIOM2 for tooth 15

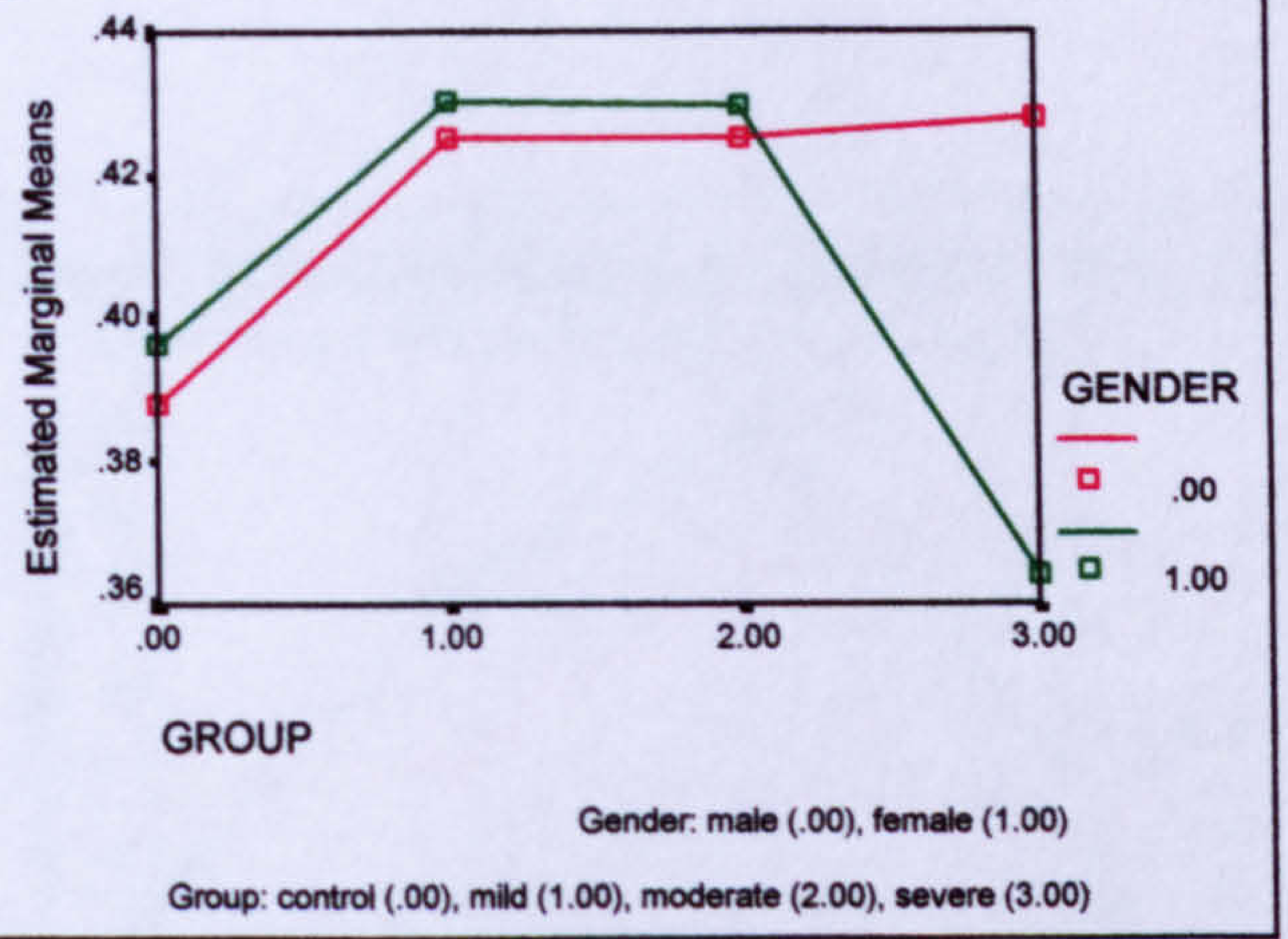


Figure 85: Estimated Means of CIOM2 for tooth 16

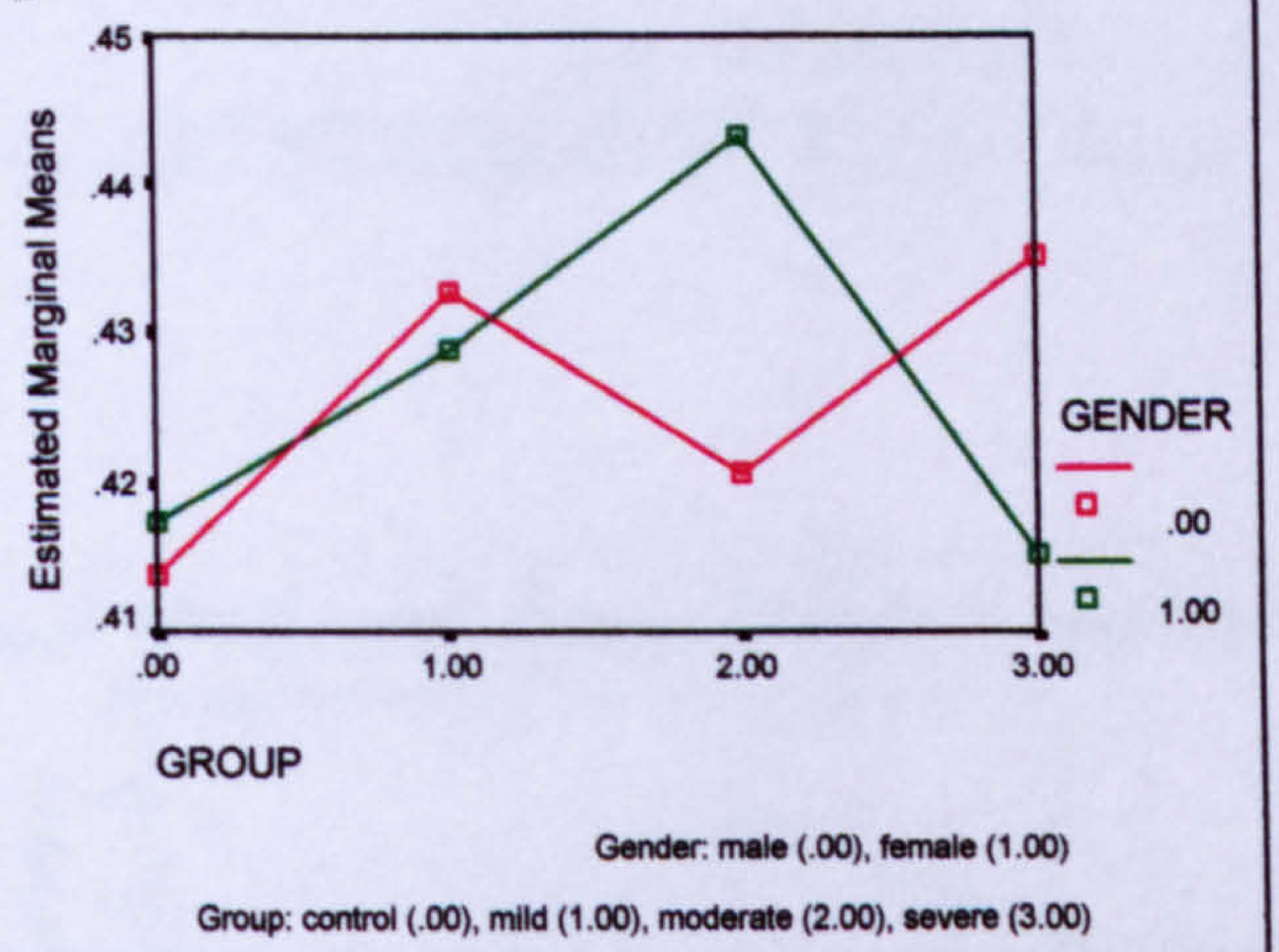


Figure 86: Estimated Means of CIOM2 for tooth 26

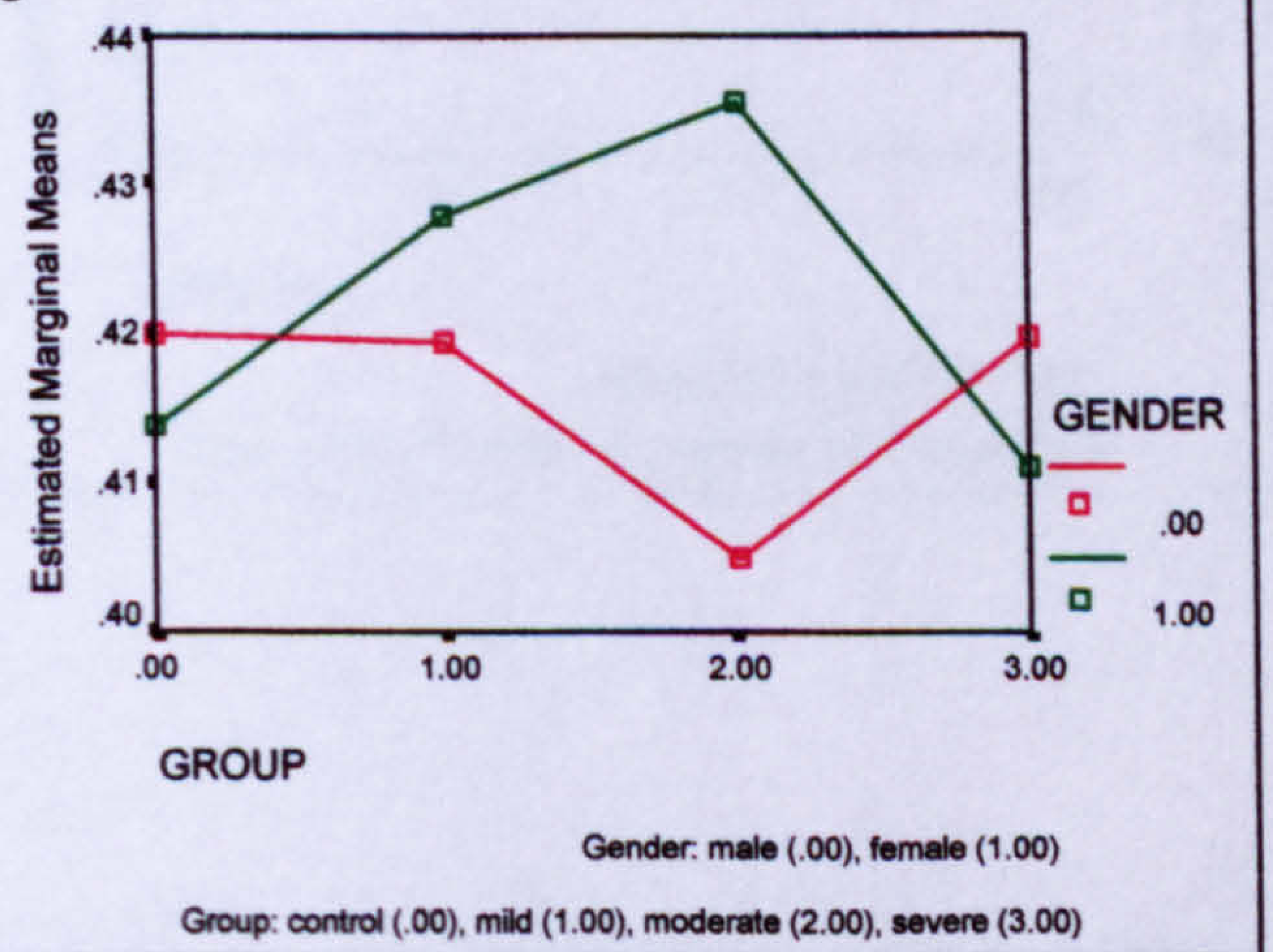


Figure 87: Estimated Means of CIOM2 for tooth 17

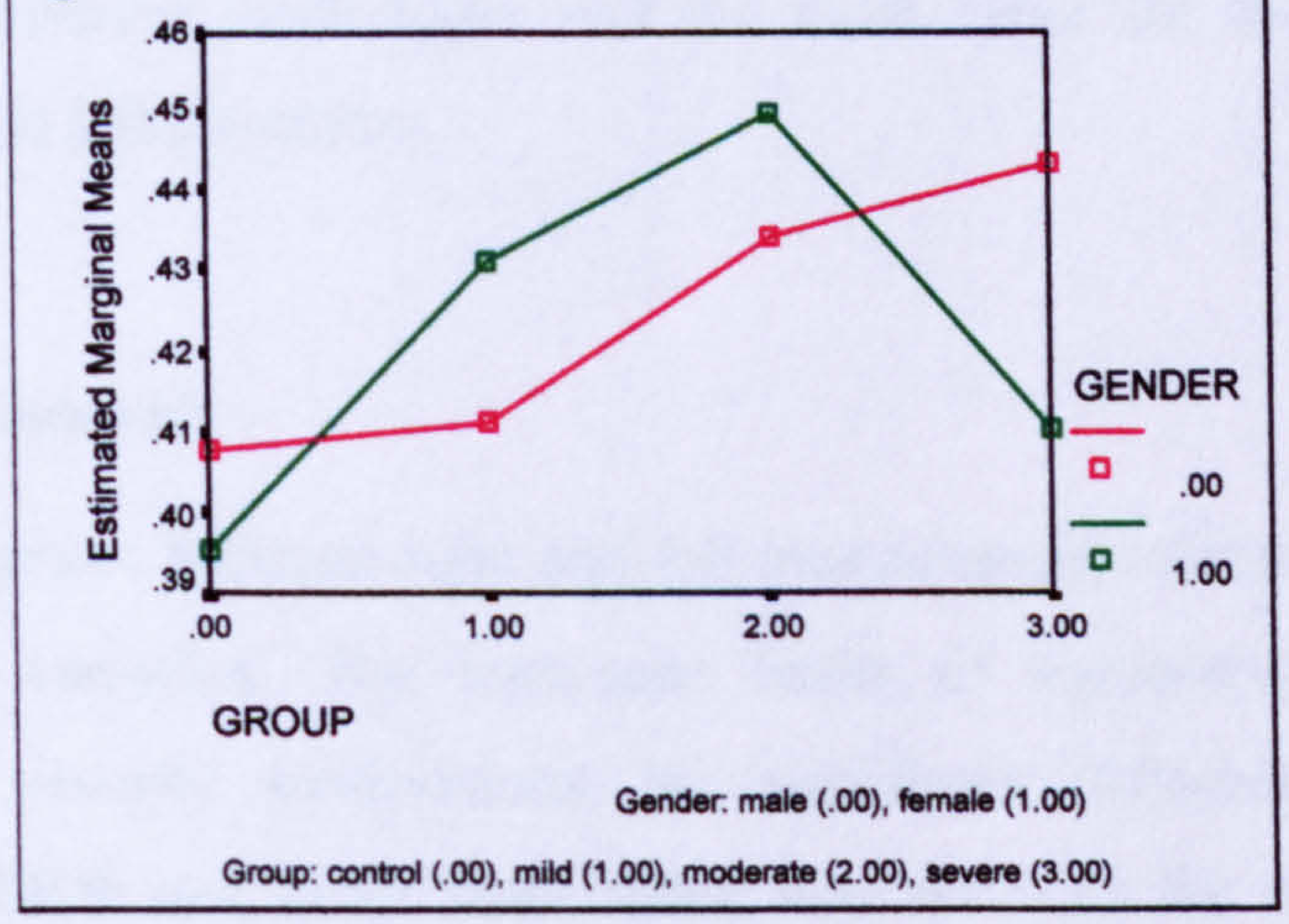
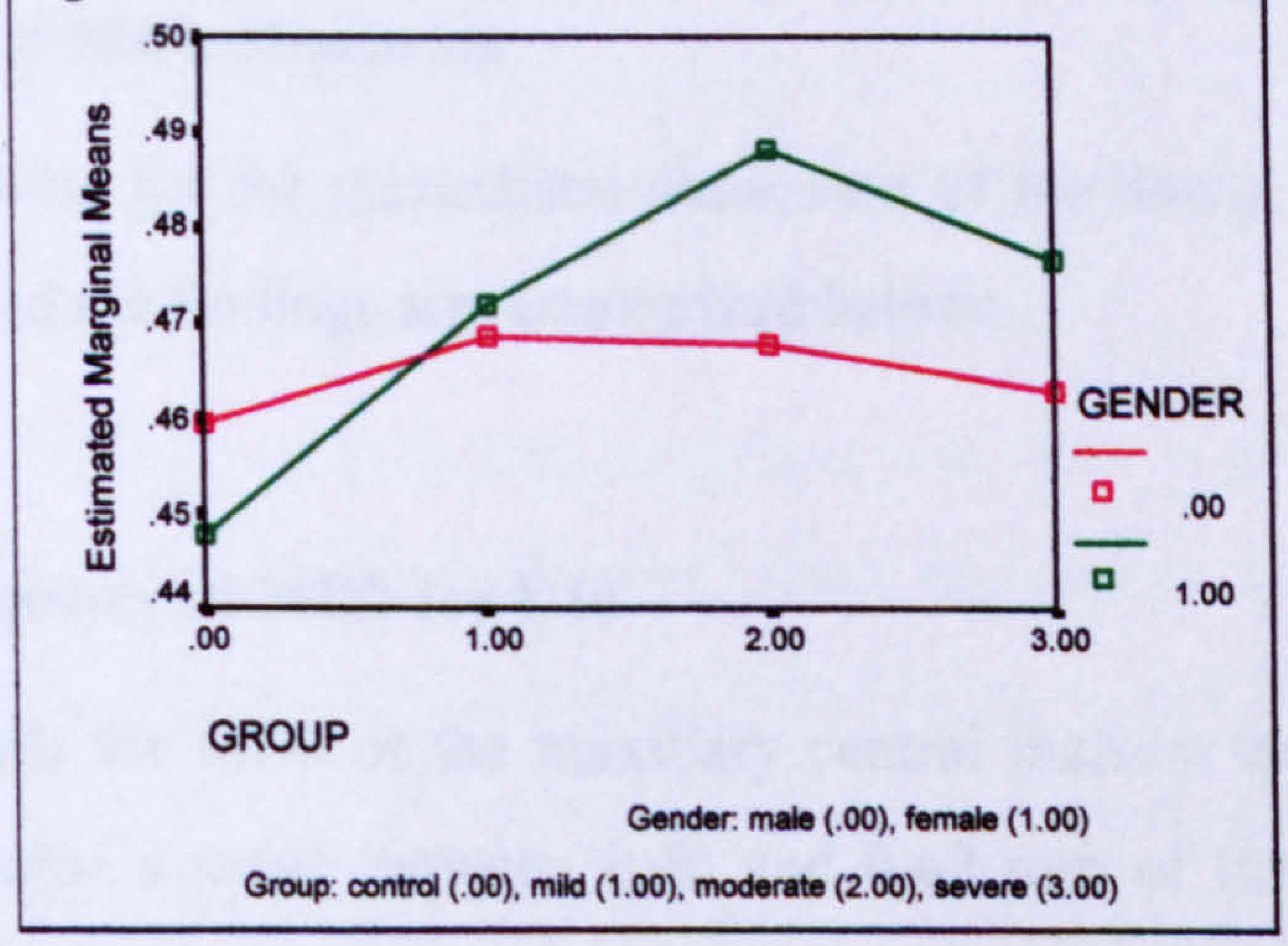


Figure 88: Estimated Means of CIOM2 for tooth 36



7.4. ADDITIONAL FINDINGS

7.4.1. Investigation of Symmetry

The effects of severity of hypodontia and gender were further evaluated by examining the symmetrical features of tooth measurements. The mesiodistal dimension of the buccal view (MDb) for different tooth types and the tooth taper for the incisor teeth were evaluted for right and left symmetry.

7.4.1.1. Statistical analysis

The absolute differences between right and left measurement values were determined for two measurement variables. The intra-case limits of agreement are presented and compared for all severity subdivisions. No significant difference between bilateral measurements of MDb and tooth taper index was revealed for any of the subgroups investigated after final adjustment of the significance levels, suggesting that one side of the mouth is never consistently larger than the other

7.4.1.2. Symmetry of MDb dimension

Symmetrical evaluation for the mesiodistal dimension of the buccal view was calculated for all tooth types and the findings are summarized below:

7.4.1.2.1. Symmetry of MDb for U1s

The symmetry results for MDb of the maxillary central incisors are shown in table 75. The data demonstrated a range between 0.40 and 0.62 mm of limits of agreement for different subgroups. The exception was related to the male control cases (agreement figure is 0.94 mm). Thus, bilateral MDb measurements appear to be less symmetrical in male controls than females for these teeth.

For hypodontia subgroups, the symmetry assessment was comparable to that for female controls, by limit values. The overall findings, therefore, suggest that there is no relationship between asymmetry of the MDb dimension and hypodontia. In mild hypodontia group, female measurements appear less symmetrical (limits, 0.60 mm) than males (limits, 0.46 mm). The opposite picture was shown for moderate and severe hypodontia groups, males showed bigger limit figures (0.50 and 0.62 mm respectively) than females (0.40 and 0.44 mm respectively).

Table 75: Summary of symmetry investigation for MDb of maxillary central incisors.

Subgroup	Tooth Pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	20	0.47	0.94
Fcontrol	18	0.29	0.58
Mmild	16	0.23	0.46
Fmild	20	0.30	0.60
Mmoderate	19	0.25	0.50
Fmoderate	20	0.20	0.40
Msevere	20	0.31	0.62
Fsevere	20	0.22	0.44

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.2. Symmetry of MDb for U2s

The findings for MDb measurement symmetry of the maxillary lateral incisors are presented in table 76. A wide range was revealed between 0.26 and 0.98 mm of limits of agreement for all subgroups. In the control group, male and female presented a similar measurement symmetry figures (0.76 and 0.72 mm respectively).

In the mild hypodontia group, male measurements were less symmetrical (limits, 0.96 mm) than those of females (limits, 0.48 mm). These also appear to be less symmetrical than controls. The right side measurement was found larger than the left side by 0.56 mm, as revealed by the estimated mean values. In moderate hypodontia group, on the other hand, female moderate MDb measurements were less symmetrical (limits, 0.98 mm) than those for males (limits, 0.46 mm) as well as the controls. Female moderate MDb measurements appeared less symmetrical than controls (and the right side measurement mean was > the left side measurement by 0.30 mm). Finally, in the severe hypodontia group, male measurements demonstrated bigger limit values (0.54 mm) than females (0.26 mm). In comparison with the controls, both severe males and females presented bilateral MDb measurements of being in a similar order of asymmetry.

Adding all this information together therefore, different patterns are suggested for maxillary lateral incisors according to severity of hypodontia and gender factors. It is important, though, to state that these findings should be counted with caution, as the number of paired teeth was small for most the subgroups. With the exception of female control and moderate hypodontia subgroups, each subgroup presented <10 tooth pairs out of 20. This in fact may be due to either, the nature of the anomaly and/or tooth absence.

Table 76: Summary of symmetry investigation for MDb of maxillary lateral incisors.

Subgroup	Tooth Pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	9	0.38	0.76
Fcontrol	16	0.36	0.72
Mmild	4	0.48	0.96
Fmild	8	0.24	0.48
Mmoderate	8	0.23	0.46
Fmoderate	11	0.49	0.98
Msevere	6	0.27	0.54
Fsevere	5	0.13	0.26

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.3. Symmetry of MDb for U3s

The results of symmetry are shown in table 77 for maxillary canine bilateral MDb measurements. The data analysis suggested limits of agreement range between 0.32 and 0.60 mm for different subgroups. In general, there is a slight tendencey for less symmetry in controls than hypodontia MDb measurements for both genders. Furthermore, males appear to demonstrate less symmetry than female in each group.

The figures for the agreement in control, mild, moderate and severe hypodontia were 0.60, 0.50, 0.52 and 0.58 mm for males, whereas 0.50, 0.32, 0.42 and 0.40 mm for females, respectively. The sample size was small in male moderate (n=7) and severe (n=5) hypodontia subgroups. However, the overall findings suggest that there is no relationship between asymmetry in MDb dimension and hypodontia for maxillay canines.

Table 77: Summary of symmetry investigation for MDb of maxillary canines.

Subgroup	Tooth Pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	14	0.30	0.60
Fcontrol	14	0.25	0.50
Mmild	14	0.25	0.50
Fmild	12	0.16	0.32
Mmoderate	7	0.26	0.52
Fmoderate	12	0.21	0.42
Msevere	5	0.29	0.58
Fsevere	10	0.20	0.40

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.4. Symmetry of MDb for U4s

The symmetry results for MDb of the maxillary 1st premolars are shown in table 78. The data demonstrated a range between 0.24 and 0.50 mm of limits of agreement for different subgroups. Two exceptions were found exceeding this range and both were of 0.72 limits for male control and female severe hypodontia subgroups. Therefore, bilateral MDb measurements appear to be less symmetrical in male controls and female severe hypodontia than the rest. The measurements of female severe hypodontia were more asymmetric than those of female control subjects (and the left side was > the right by a difference of 0.40 mm).

Considering gender separately, male measurements were less symmetrical than those of females, except in the severe group, in which the opposite was suggested. In the control, mild, moderate and severe hypodontia groups, the figures were 0.72, 0.50, 0.24 and 0.24 mm for males and 0.50, 0.46, 0.44 and 0.72 mm for females. As the number of pairs was small for male and female severe hypodontia group (n=9 and 3 respectively), it is difficult to draw a clear conclusion. However, the overall findings did not suggest a relationship between asymmetry of MDb dimension and hypodontia.

Table 78: Summary of symmetry investigation for MDb of maxillary 1st premolars.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	17	0.36	0.72
Fcontrol	14	0.25	0.50
Mmild	17	0.25	0.50
Fmild	18	0.23	0.46
Mmoderate	12	0.26	0.52
Fmoderate	14	0.22	0.44
Msevere	9	0.12	0.24
Fsevere	3	0.36	0.72

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.5. Symmetry of MDb for U5s

The results for maxillary 2nd premolar symmetry are shown in table 79. The data demonstrated a range of limits of agreement between 0.32 and 0.54 mm for hypodontia subdivisions and 0.62 to 0.72 mm for male and female controls. In the control, mild, moderate and severe hypodontia, the figures were 0.72, 0.52, 0.48 and 0.54 mm for males and 0.62, 0.32, 0.32 and 0.46 mm for females. The symmetry was consistent for gender across the groups, in which male measurements were less symmetrical than those of females. Bilateral MDb measurements appear to be less symmetrical in controls than hypodontia subjects.

The maxillary 2nd premolar is a common tooth to be affected by hypodontia. The number of pairs was, therefore, not sufficient to make final conclusion for male moderate and severe hypodontia (n=8 and 5 respectively) and female moderate and severe (n=3 and 2 respectively). The overall findings, however, did not suggest a relationship between asymmetry of MDb dimension and hypodontia.

Table 79: Summary of symmetry investigation for MDb of maxillary 2nd premolars.

Subgroup	Tooth Pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	20	0.36	0.72
Fcontrol	16	0.31	0.62
Mmild	17	0.26	0.52
Fmild	14	0.16	0.32
Mmoderate	8	0.24	0.48
Fmoderate	3	0.16	0.32
Msevere	5	0.27	0.54
Fsevere	2	0.23	0.46

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.6. Symmetry of MDb for U6s

The findings for MDb measurement symmetry of the maxillary 1st molar are presented in table 80. In control group, the limits were 1.24 and 0.56 mm for male and female respectively. These in comparison to 0.82 and 0.66 mm (in mild), 0.76 and 0.58 mm (in moderate) and 0.98 and 0.84 mm (in severe hypodontia group), respectively.

Male measurements were less symmetrical in the control group than those of hypodontia groups. Whereas, the opposite appeared for female measurements, particularly for severe group i.e. female measurements in hypodontia were less symmetrical than female controls. By comparing the control with hypodontia, no relationship between hypodontia and asymmetry may be suggested.

Table 80: Summary of symmetry investigation for MDb of maxillary 1st molars.

Subgroup	Tooth Pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	20	0.62	1.24
Fcontrol	19	0.28	0.56
Mmild	20	0.41	0.82
Fmild	18	0.33	0.66
Mmoderate	20	0.38	0.76
Fmoderate	18	0.29	0.58
Msevere	18	0.49	0.98
Fsevere	16	0.42	0.84

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.7. Symmetry of MDb for U7s

The results are shown in table 81 for MDb measurement symmetry of the maxillary 2nd molars. The range of limits was 0.65 to 0.84 mm. Three exceptional figures were found for female controls (limits, 1.16 mm), female mild hypodontia (limits, 1.00 mm) and male severe hypodontia (limits, 1.90 mm). Considering genders separately, the data indicated that the measurements appeared more symmetrical for male control and the symmetry decreases with an increase in the severity of hypodontia. The same thing but in the opposite direction for female measurements i.e. less symmetrical in control than hypodontia.

Most of the subgroups demonstrated a small tooth pairs i.e. in male control, female control, male severe (n=7), in female moderate (n=6) and in female severe hypodontia (n=4) subgroups. Comparing the figures, male severe hypodontia was the worst scenario suggesting less symmetry than male control and the rest. However, the left side measurement was > the right side by 0.16 mm difference suggesting only a weak relationship, if any, between hypodontia and asymmetry for males only.

Table 81: Summary of symmetry investigation for MDb of maxillary 2nd molars.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	7	0.28	0.56
Fcontrol	7	0.58	1.16
Mmild	11	0.35	0.70
Fmild	14	0.50	1.00
Mmoderate	11	0.36	0.72
Fmoderate	6	0.42	0.84
Msevere	7	0.95	1.90
Fsevere	4	0.32	0.64

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.8. Symmetry of MDb for L1s

For the mandibular central incisors, the results of symmetry are shown in table 82. The data revealed, in the control, mild, moderate and severe hypodontia, the figures of agreement were 0.54, 0.54, 0.40 and 0.84 mm for males and 0.38, 0.50, 0.44 and 0.44 mm for females respectively. A range between 0.38 and 0.54 mm of limits for all subgroups was demonstrated. The exception, was related to the male severe group (limits, 0.84 mm). The other subgroups demonstrated a comparable symmetry evaluation. Therefore, bilateral MDb measurements appear to be less symmetrical in male severe hypodontia than controls. The sample size was smaller in severe male and female hypodontia subgroups (n=8 and 9 respectively) than the rest.

Table 82: Summary of symmetry investigation for MDb of mandibular central incisors.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	15	0.27	0.54
Fcontrol	16	0.19	0.38
Mmild	16	0.27	0.54
Fmild	18	0.25	0.50
Mmoderate	14	0.20	0.40
Fmoderate	14	0.22	0.44
Msevere	8	0.42	0.84
Fsevere	9	0.22	0.44

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.9. Symmetry of MDb for L2s

The mandibular lateral incisors symmetry results are shown in table 83. The data demonstrated a range of limits between 0.30 and 0.58 mm. Similarly to the mandibular centrals, bilateral MDb measurements in male severe hypodontia (limits, 0.10 mm) were less symmetrical than controls and the rest. Whilst, the other subgroups presented a comparable symmetry evaluation. The overall findings only suggest some relationship between asymmetry of MDb dimension and hypodontia for male severe hypodontia subjects as compared to the other catergories.

Table 83: Summary of symmetry investigation for MDb of mandibular lateral incisors.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	13	0.29	0.58
Fcontrol	14	0.21	0.42
Mmild	17	0.19	0.38
Fmild	16	0.16	0.32
Mmoderate	15	0.15	0.30
Fmoderate	16	0.22	0.44
Msevere	12	0.51	1.02
Fsevere	10	0.27	0.54

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.10. Symmetry of MDb for L3s

The symmetry results for MDb of the mandibular canines are shown in table 84. The data demonstrated a range between 0.42 and 0.78 mm of limits of agreement for different subgroups. The worst two cases were related to the male control and female mild hypodontia (0.64 and 0.78 mm respectively), in which bilateral MDb measurements appear to be less symmetrical than the rest. For female mild hypodontia, the left side measurement mean value was > that of the right side with a difference of 0.15 mm.

The table also demonstrates that, in each group, female measurements were less symmetrical than of males except in the control groups, males were less symmetrical. Furthermore, male measurements appeared to be less symmetrical in controls than in hypodontia, whereas for female the hypodontia measurements were less symmetrical than control. The results generally provide a weak relationship between the asymmetry of MDb dimension and hypodontia.

7.4.1.2.11. Symmetry of MDb for L4s

The symmetry results for MDb of the mandibular 1st premolars are shown in table 85. The range of limits of agreements given was between 0.36 and 0.56 mm for the subgroups.

In control, mild, moderate and severe hypodontia the figures were 0.50, 0.48, 0.56 and 0.44 mm (in males) and 0.50, 0.36, 0.36 and 0.40 mm (in females) repectively.

Although, severe female hypodontia includes 8 tooth pairs, the overall findings revealed comparable symmetry evaluation for different severity subdivisions. Therefore, no relationship between hypodontia and asymmetery in MDb dimensions could be suggested

Table 84: Summary of symmetry investigation for MDb of mandibular canines.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	16	0.32	0.64
Fcontrol	16	0.21	0.42
Mmild	17	0.29	0.58
Fmild	19	0.39	0.78
Mmoderate	17	0.23	0.46
Fmoderate	20	0.25	0.50
Msevere	13	0.23	0.46
Fsevere	14	0.24	0.48

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

Table 85: Summary of symmetry investigation for MDb of mandibular 1st premolars.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	19	0.25	0.50
Fcontrol	17	0.25	0.50
Mmild	17	0.24	0.48
Fmild	19	0.18	0.36
Mmoderate	16	0.28	0.56
Fmoderate	17	0.18	0.36
Msevere	11	0.22	0.44
Fsevere	8	0.23	0.46

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.12. Symmetry of MDb for L5s

The results of symmetry evaluation for MDb dimension of mandibular 2nd premolars are shown in table 86. With exception of one, the range of limits was 0.36 to 0.78 mm for different subdivisions. For male severe hypodontia, the limits were 1.42 mm. In the control group, male and female presented similar measurement symmetry (limits, 0.66 and 0.50 mm respectively). In mild hypodontia group, both male and female measurements were less symmetrical (limits, 0.78 and 0.64 mm respectively) than controls. In moderate hypodontia group, female MDb measurements were less symmetrical than male measurements (limits, 0.46 for males and 0.62 for females). The opposite finding was shown in the severe hypodontia group (limits, 1.42 for males and 0.36 for females).

The mandibular 2nd premolar is one of the most commonly affected teeth by hypodontia. These conclusions should be carefully considered since the sample size was small in male moderate and severe (n=7 and 3) and female moderate and severe hypodontia (n=4 and 2) respectively. Based on this sample, only male severe hypodontia suggested more asymmetry in the MDb bilateral measurements than controls and the mild and moderate hypodontia groups (the right side measurement mean value was > that of the left side by 0.20 mm).

Table 86: Summary of symmetry investigation for MDb of mandibular 2nd premolars.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	14	0.33	0.66
Fcontrol	15	0.25	0.50
Mmild	11	0.39	0.78
Fmild	11	0.32	0.64
Mmoderate	7	0.23	0.46
Fmoderate	4	0.31	0.62
Msevere	3	0.71	1.42
Fsevere	2	0.18	0.36

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.13. Symmetry of MDb for L6s

The results of symmetry investigation of mandibular 1st molar MDb measurements are shown in table 87. The range of limits of agreements was between 0.60 and 0.90 mm for different subdivisions. Male measurements in the control group appear slightly less symmetrical than in each of mild and moderate hypodontia group (limits, 0.80, 0.78 and 0.70 mm respectively), but slightly more symmetrical than the severe group (limits, 0.90 mm). In female measurements, on the other hand: The control groups appear to be slightly less symmetrical than each of the mild and severe hypodontia group (limits, 0.74, 60 and 0.70 mm respectively) and slightly more symmetrical than the moderate group (limits, 0.80 mm).

As the overall findings revealed comparable symmetry evaluation between groups, no relationship between hypodontia and asymmetry of MDb for mandibualr 1st molars may be suggested.

Table 87: Summary of symmetry investigation for MDb of mandibular 1st molars.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	20	0.40	0.80
Fcontrol	17	0.37	0.74
Mmild	18	0.39	0.78
Fmild	18	0.30	0.60
Mmoderate	19	0.35	0.70
Fmoderate	19	0.40	0.80
Msevere	17	0.45	0.90
Fsevere	16	0.35	0.70

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.2.14. Symmetry of MDb for L7s

Table 88 presented the findings for MDb measurement symmetry of the mandibular 2nd molars and a wide range of limits of agreement was revealed. The control group demonstrated larger values (limits, 1.70 for male and 1.16 mm for females) than each of hypodontia groups (limits, 0.34 and 0.88 mm in mild group, 0.66 and 0.38 mm in moderate group and 0.74 and 0.52 mm in severe hypodontia group respectively). This suggests that, asymmetry in bilateral MDb measurement for maxillary 2nd molars were not related to the hypodontia.

Symmetry evaluation for hypodontia groups revealed variation in results: Male measurements becoming less symmetrical as the severity of hypodontia increases. On the other hand, the measurements of female mild hypodontia were less symmetrical than both severe and moderate groups, and severe measurements were less symmetrical than moderate group.

The sample size was also small for all subgroups and that was due to both incomplete tooth eruption and/or the missing.

Table 88: Summary of symmetry investigation for MDb of mandibular 2nd molars.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	8	0.85	1.70
Fcontrol	6	0.58	1.16
Mmild	4	0.17	0.34
Fmild	11	0.44	0.88
Mmoderate	6	0.33	0.66
Fmoderate	3	0.19	0.38
Msevere	4	0.37	0.74
Fsevere	3	0.26	0.52

The limits of agreement are +/- the figure shown and the unit is mm.
The standard deviation of differences is about zero.

7.4.1.3. Symmetry of tooth taper

Symmetrical evaluation for the tooth taper measurement was calculated for the incisor teeth and revealed the following findings:

7.4.1.3.1. Symmetry of tooth taper for U1s

The results of symmetry evaluation for tooth taper measurements of the maxillary central incisors are shown in table 89. For group assessment: The data demonstrated small figures of agreement in the control group (limits, 0.06 and 0.04 for male and female respectively) and moderate hypodontia group (limits, 0.04 and 0.08) as compared to mild (limits, 0.04 and 0.54) and severe hypodontia group (0.26 and 0.10) male and female respectively. In male severe hypodontia, the left side tooth taper mean value was > right side by 0.02. Whereas in female mild hypodontia, the left side mean value was > right side by 0.00.

For gender evaluation: Male measurements appear less symmetrical in severe group than each of control, mild and moderate group. For females, on the other hand, measurements were less symmetrical in mild group than each of control, moderate and severe hypodontia group. The overall findings, therefore, suggest some relationship between the asymmetry in tooth taper for maxillary central incisors and hypodontia, however, this only applies for female mild hypodontia. This supports the ICC findings suggesting separating the right and left measurements in the main analysis.

Table 89: Summary of symmetry investigation for tooth taper of maxillary central incisors.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	20	0.03	0.06
Fcontrol	18	0.02	0.04
Mmild	16	0.02	0.04
Fmild	20	0.27	0.54
Mmoderate	19	0.02	0.04
Fmoderate	20	0.04	0.08
Msevere	20	0.13	0.26
Fsevere	20	0.05	0.10

The limits of agreement are +/- the figure shown. The standard deviation of differences is about zero.

7.4.1.3.2. Symmetry of tooth taper for U2s

The results of symmetry assessment for maxillary lateral incisors taper measurements are shown in table 90. Within groups, male measurements showed 0.18, 0.10, 0.26 and 0.20 limits compared to those of females 0.08, 0.08, 0.18 and 0.06 (in the control, mild, moderate and severe hypodontia group respectively). Thus, male and female moderate hypodontia appear less symmetrical than the others for each gender.

Although, the sample size of tooth pairs was small for most subgroups as discussed earlier, the data generally demonstrated comparable figures with a range between 0.06 and 0.26 mm of limits. Therefore, the relationship between the asymmetry of tooth taper measurement for maxillary lateral incisor and hypodontia is weak for male moderate, if any.

Table 90: Summary of symmetry investigation for tooth taper of maxillary lateral incisors.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	9	0.09	0.18
Fcontrol	16	0.04	0.08
Mmild	4	0.05	0.10
Fmild	8	0.04	0.08
Mmoderate	8	0.13	0.26
Fmoderate	11	0.09	0.18
Msevere	6	0.1	0.20
Fsevere	5	0.03	0.06

The limits of agreement are +/- the figure shown. The standard deviation of differences is about zero.

7.4.1.3.3. Symmetry of tooth taper for L1s

The symmetry results for tooth taper measurements of the maxndibular central incisors are presented in table 91. The data demonstrated a rarrow range of limits of agreement (between 0.06 and 0.12) for different groups and subgroups, suggsting a comparable symmetry evaluation. Therefore, no relationship between hypodontia and the asymmetry of tooth taper measurements is suggested. However, this conclusion should be regarded with some caution, as the number of tooth pairs investigated was small in severe group (Table 91).

Table 91: Summary of symmetry investigation for tooth taper of mandibular central incisors.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	15	0.03	0.06
Fcontrol	16	0.04	0.08
Mmild	16	0.03	0.06
Fmild	18	0.06	0.12
Mmoderate	14	0.06	0.12
Fmoderate	14	0.04	0.08
Msevere	8	0.06	0.12
Fsevere	9	0.03	0.06

The limits of agreement are +/- the figure shown. The standard deviation of differences is about zero.

7.4.1.3.4. Symmetry of tooth taper for L2s

For the mandibular lateral incisors, the symmetry evaluation results for tooth taper are shown in table 92. The table suggests that, the figures of limits to be between 0.06 and 0.24 with, i.e. a small range as for the mandibular central incisors. The bilateral tooth taper measurements appear to be less symmetrical in female severe hypodontia (limits, 0.24) than the rest that presented a very close symmetry evaluation (Table 92). According to these findings, the relationship between the asymmetry of taper index measurement and hypodontia is weak for the mandibular lateral incisors.

Table 92: Summary of symmetry investigation for tooth taper of mandibular lateral incisors.

Subgroup	Tooth pairs	Standard Deviation of differences	Limits of agreement
Mcontrol	13	0.05	0.10
Fcontrol	14	0.05	0.10
Mmild	17	0.04	0.08
Fmild	16	0.05	0.10
Mmoderate	15	0.03	0.06
Fmoderate	16	0.04	0.08
Msevere	12	0.06	0.12
Fsevere	10	0.12	0.24

The limits of agreement are +/- the figure shown. The standard deviation of differences is about zero.

Summary of symmetry findings

The results of the symmetry investigation for the mesiodistal and tooth taper measurements from the buccal view indicated no significant difference between teeth of the right and left sides of the dentitions in both hypodontia and control subjects. However, variations in the results suggested that there is a greater tendency for bilateral tooth dimensions to be asymmetric in hypodontia groups than controls:

1) *For the mesiodistal measurements: Some subgroups suggested asymmetry in teeth U2s, U4s, U7s, L1s, L2s, L3s and L5s.*
2) *For tooth taper index measurements: Some subgroups suggested asymmetry in teeth U1s and L2s.*

Moreover, the overall variation appeared related to the severity of the anomaly.

7.4.2. Investigation of Intermaxillary Ratios

The intermaxillary dental arch relationship in each groups and subgroups of the study population was evaluated by means of counting the ratios of the total or partial tooth sizes of the lower teeth to the uppers (percentages). Using the averages of mesiodistal dimensions for different tooth types that were presented in the main study analysis, four intermaxillary tooth size ratios (anterio ratio AR, posterior ratio PR, overall ratio OR and grand ratio GR) were descriptively calculated as defined in chapter 4 (section 4.4.2.4. and Tables 4 and 5) for both buccal and occlusal views. Tables 92 and 93 demonstrate the findings of ratios for buccal and occlusal view respectively. The overall picture of findings suggests similar values from both buccal and occlusal veiws for each group (control, mild moderate and severe hypodontia) and subgroups (males and females).

Interpretation for the anterior ratio descriptive data suggests smaller mandibular anterior teeth than the maxillary teeth for all categories. In addition, the ratio tends to be larger in hypodontia groups (total range 80.34 to 81.04% buccally and 81.12 to 81.67% occlusally) than control (77.70% buccaly and 78.52% occlusally). This information suggests different effects for hypodontia on tooth size i.e. more MDb reduction in the maxillary anterior teeth than the lower.

For posterior ratios, the groups altogether presented a buccal and occlusal range of 104.49 to 106.08% and 103.29 to 105-89% respectively. The figures suggest larger mandibular posterior teeth than the maxillary in different control and hypodontia categories. In comparison with anterior ratios, the values in control group tend to be bigger than mild hypodontia but smaller than moderate and severe hypodontia groups that may also suggest general trend of more size reduction in maxillary posterior teeth associated with an increase in the severity of hypodontia.

The overall and grand ratio figures fall in between i.e. indicating smaller total mandibular teeth than the maxillary teeth but with greater figures than that of anterior ratio. The OR mean figures for control, mild, moderate and severe groups were 91.75, 92.29, 93.61 and 94.07% for buccal view and 91.70, 92.70, 93.90 and 94.32% for the occlusal view. For the GR, the ratio values were 93.64, 94.96, 96.02 and 96.61% (buccally) and 93.85, 94.88, 96.35 and 97.37% (occlusally) respectively. Descriptive group differences suggest a tendency of ratio to increase with an increase in severity of hypodontia for both overall and grand ratios. This further supports the above findings that suggesting more effect for hypodontia in the size of maxillary than the mandibular teeth.

Table 93: Summary of intermaxillary tooth size ratios for buccal view.

Group	Gender	Anterior ratio	Posterior ratio	Overall ratio	Grand ratio
Control	Male	78.94	106.02	92.55	94.03
	Female	76.49	105.22	90.92	93.23
	Total	77.70	105.69	91.75	93.64
Mild Hypodontia	Male	80.85	104.42	93.13	95.21
	Female	80.60	104.52	92.93	95.11
	Total	80.34	104.49	92.29	94.96
Moderate Hypodontia	Male	79.83	106.08	93.31	95.75
	Female	80.93	106.07	93.92	96.29
	Total	80.39	106.08	93.61	96.02
Severe Hypodontia	Male	80.13	104.68	92.95	96.65
	Female	81.72	107.98	95.38	96.85
	Total	81.04	106.01	94.07	96.61

Table 94: Summary of intermaxillary tooth size ratios for occlusal view.

Group	Subgroup	Anterior ratio	Posterior ratio	Overall ratio	Grand Ratio
Control	Male	79.91	104.95	92.58	94.30
	Female	77.14	104.24	90.78	93.39
	Total	78.52	104.64	91.70	93.85
Mild Hypodontia	Male	81.63	102.82	92.67	94.91
	Female	81.25	103.73	92.88	95.06
	Total	81.28	103.29	92.70	94.88
Moderate Hypodontia	Male	80.43	106.71	93.89	96.17
	Female	81.64	105.03	93.81	96.47
	Total	81.12	105.89	93.90	96.35
Severe Hypodontia	Male	80.55	104.12	92.88	97.28
	Female	82.39	108.66	96.00	97.65
	Total	81.67	105.88	94.32	97.37

Summary for findings of intermaxillary ratios

Using the mean values of the mesiodistal dimensions from both the buccal and occlusal views, investigation of the intermaxillary ratios suggested the following findings:

1) *There is a tendency of increase in the values of all the intermaxillay ratios in hypodontia subjects compared with controls.*
2) *Each intermaxillary ratio figure tended to increase with an increase in the severity of hypodontia.*

This may suggest a greater overall reduction in the mesiodistal dimensions in the maxillary than the mandibular teeth in individuals with hypodontia compared with controls.

7.4.3. Investigation of Cusp Number

The purpose of this part of the study was to present a general idea for the effect of hypodontia on the number of cusps after counting all cusps for each premolar and molar tooth in all groups of the study. A descriptive evaluation was made using categorical figures of the mean values of the cusps number for posterior teeth. The following summary is based on averaging the right and left sides for each tooth type:

For premolar teeth, the mean of total cusp number was larger in controls than hypodontia groups particularly for mandibular teeth, except in the female severe hypodontia subgroup (Tables 95-98). In the maxillary 1st and 2nd premolars, the mean values were the same in all groups and subgroups i.e. one buccal, one palatal and 2 total cusps. In the mandibular 1st premolars, one buccal cusp was the mean in all categories. The total cusp number in males was 2.19, 2.03, 2.06 and 2 in control, mild, moderate and severe hypodontia groups. Similarly in females, the means were 2.10, 2, 2 and 1.90 respectively. The 2nd premolars showed the following figures: for males, 2.73, 2.32, 2.19 and 2.12 cusps and for females 2.51, 2.48, 2.66 and 2 cusps in control, mild, moderate and severe hypodontia groups respectively. Thus, the reduction in the number of cusps was the result of the lingual cusp reduction.

For maxillary molar teeth, there was also the same tendency for the palatal cusp to be reduced in hypodontia subjects compared with controls (Tables 99 and 100). In maxillary 1st molars, the mean figures in males were 4.35, 4.23, 4.16 and 3.97 and in females 4.45, 4.11, 4.08 and 3.85 for control, mild, moderate and severe hypodontia respectively. For maxillary 2nd molars, the figures for males were 4, 3.29, 3.75 and 3.63 and for females 3.90, 3.62, 3.36 and 3.37 for control, mild, moderate and severe hypodontia respectively. This also suggested the same trend for tendency of palatal cusp reduction in hypodontia subjects than controls.

On the other hand, the mandibular molars demonstrated the same trend for tendency of cusp reduction in hypodontia subjects than controls but it was mainly due to deficiency in the buccal rather than the lingual cusp number (Tables 101 and 102). For mandibular 1st molars, the mean figures in males were 4.98, 4.69, 4.92 and 4.72 and in females 4.85, 4.55, 4.82 and 4.64 respectively. For mandibular 2nd molars, the figures for males were 4.20, 4, 4.20 and 4.23 and for females 4.07, 4.10, 4 and 4.48 respectively. The exception suggests more buccal cusps in the 2nd molars for severe hypodontia group.

Summary of cusp number findings

Investigation for the number of cusps in premolar and molar teeth was made using the mean values and suggested the following findings:

1) *The mean of total cusp number showed a tendency to be smaller in hypodontia groups than control group*
2) *The lingual cusps of the mandibular premolars, palatal cusps of the maxillary molars and buccal cusps of the mandibular molars were affected more in individuals with hypodontia than controls.*
3) *A relationship was also suggested between the severity of the hypodontia and cusp reduction; the more severe the hypodontia the greater the reduction in cusp number.*

Figure 95: Estimated means of cusp number for maxillary 1st premolars.

Group	Gender	Cusp	Tooth 14		Tooth 24	
			Mean	N	Mean	N
0	0	BC	1.00	18	1.00	18
		LC	1.00	18	1.00	18
		Total	2.00	18	2.00	18
	1	BC	1.00	19	1.00	20
		LC	1.00	19	1.00	20
		Total	2.00	19	2.00	20
1	0	BC	1.00	18	1.00	18
		LC	1.00	18	1.00	18
		Total	2.00	18	2.00	18
	1	BC	1.00	20	1.00	19
		LC	1.00	20	1.00	19
		Total	2.00	20	2.00	19
2	0	BC	1.00	14	1.00	15
		LC	1.00	14	1.00	15
		Total	2.00	14	2.00	15
	1	BC	1.00	18	1.00	19
		LC	1.00	18	1.00	19
		Total	2.00	18	2.00	19
3	0	BC	1.00	11	1.00	10
		LC	1.00	11	1.00	10
		Total	2.00	11	2.00	10
	1	BC	1.00	7	1.00	4
		LC	1.00	7	1.00	4
		Total	2.00	7	2.00	4

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 96: Estimated means of cusp number for maxillary 2nd premolars.

Group	Gender	Cusp	Tooth 15		Tooth 25	
			Mean	N	Mean	N
0	0	BC	1.00	20	1.00	20
		LC	1.00	20	1.00	20
		Total	2.00	20	2.00	20
	1	BC	1.00	18	1.00	19
		LC	1.00	18	1.00	19
		Total	2.00	18	2.00	19
1	0	BC	1.00	18	1.00	18
		LC	1.00	18	1.00	18
		Total	2.00	18	2.00	18
	1	BC	1.00	16	1.00	16
		LC	1.00	16	1.00	16
		Total	2.00	16	2.00	16
2	0	BC	1.00	9	1.00	9
		LC	1.00	9	1.00	9
		Total	2.00	9	2.00	9
	1	BC	1.00	4	1.00	5
		LC	1.00	4	1.00	5
		Total	2.00	4	2.00	5
3	0	BC	1.14	7	1.00	8
		LC	1.00	7	1.00	8
		Total	2.14	7	2.00	8
	1	BC	1.00	4	1.00	4
		LC	1.00	4	1.00	4
		Total	2.00	4	2.00	4

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 97: Estimated means of cusp number for mandibular 1st premolars.

Group	Gender	Cusp	Tooth 34		Tooth 44	
			Mean	N	Mean	N
0	0	BC	1.00	19	1.00	18
		LC	1.21	19	1.17	18
		Total	2.21	19	2.17	18
	1	BC	1.00	20	1.00	20
		LC	1.10	20	1.10	20
		Total	2.10	20	2.10	20
1	0	BC	1.00	18	1.00	17
		LC	1.06	18	1.00	17
		Total	2.06	18	2.00	17
	1	BC	1.00	20	1.00	20
		LC	1.00	20	1.00	20
		Total	2.00	20	2.00	20
2	0	BC	1.00	16	1.00	16
		LC	1.06	16	1.06	16
		Total	2.06	16	2.06	16
	1	BC	1.00	20	1.00	19
		LC	1.00	20	1.00	19
		Total	2.00	20	2.00	19
3	0	BC	1.00	13	1.00	14
		LC	1.00	13	1.00	14
		Total	2.00	13	2.00	14
	1	BC	1.00	10	1.00	9
		LC	0.90	10	0.89	9
		Total	1.90	10	1.89	9

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 98: Estimated means of cusp number for mandibular 2nd premolars.

Group	Gender	Cusp	Tooth 35		Tooth 45	
			Mean	N	Mean	N
0	0	BC	1.00	17	1.06	17
		LC	1.76	17	1.65	17
		Total	2.76	17	2.71	17
	1	BC	1.00	18	1.00	17
		LC	1.44	18	1.59	17
		Total	2.44	18	2.59	17
1	0	BC	1.00	14	1.00	15
		LC	1.36	14	1.27	15
		Total	2.36	14	2.27	15
	1	BC	1.00	16	1.00	12
		LC	1.56	16	1.42	12
		Total	2.56	16	2.42	12
2	0	BC	1.00	8	1.00	8
		LC	1.25	8	1.13	8
		Total	2.25	8	2.13	8
	1	BC	1.00	6	1.00	6
		LC	1.83	6	1.50	6
		Total	2.83	6	2.50	6
3	0	BC	1.00	5	1.00	8
		LC	1.00	5	1.25	8
		Total	2.00	5	2.25	8
	1	BC	1.00	4	1.00	3
		LC	1.00	4	1.00	3
		Total	2.00	4	2.00	3

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 99: Estimated means of cusp number for maxillary 1st molars.

Group	Gender	Cusp	Tooth 16		Tooth 26	
			Mean	N	Mean	N
0	0	BC	2.00	20	2.00	20
		LC	2.35	20	2.35	20
		Total	4.35	20	4.35	20
	1	BC	2.00	19	2.00	19
		LC	2.42	19	2.47	19
		Total	4.42	19	4.47	19
1	0	BC	2.00	20	2.00	20
		LC	2.25	20	2.20	20
		Total	4.25	20	4.20	20
	1	BC	2.00	19	2.00	19
		LC	2.11	19	2.11	19
		Total	4.11	19	4.11	19
2	0	BC	2.00	19	2.00	19
		LC	2.16	19	2.16	19
		Total	4.16	19	4.16	19
	1	BC	2.00	19	2.00	20
		LC	2.05	19	2.10	20
		Total	4.05	19	4.10	20
3	0	BC	2.00	18	2.00	19
		LC	1.94	18	2.00	19
		Total	3.94	18	4.00	19
	1	BC	2.00	17	2.00	17
		LC	1.76	17	1.94	17
		Total	3.76	17	3.94	17

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 100: Estimated means of cusp number for maxillary 2nd molars.

Group	Gender	Cusp	Tooth 17		Tooth 27	
			Mean	N	Mean	N
0	0	BC	2.00	9	2.00	12
		LC	2.00	9	2.00	12
		Total	4.00	9	4.00	12
	1	BC	2.00	9	2.00	10
		LC	1.89	9	1.90	10
		Total	3.89	9	3.90	10
1	0	BC	2.00	14	2.00	14
		LC	1.21	14	1.36	14
		Total	3.21	14	3.36	14
	1	BC	2.00	15	2.00	16
		LC	1.60	15	1.63	16
		Total	3.60	15	3.63	16
2	0	BC	2.00	11	2.08	13
		LC	1.73	11	1.69	13
		Total	3.73	11	3.77	13
	1	BC	2.00	9	2.00	6
		LC	1.22	9	1.50	6
		Total	3.22	9	3.50	6
3	0	BC	2.00	8	2.00	8
		LC	1.75	8	1.50	8
		Total	3.75	8	3.50	8
	1	BC	2.00	5	2.00	6
		LC	1.40	5	1.33	6
		Total	3.40	5	3.33	6

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 101: Estimated means of cusp number for mandibular 1st molars.

Group	Gender	Cusp	Tooth 36		Tooth 46	
			Mean	N	Mean	N
0	0	BC	2.90	20	2.95	20
		LC	2.05	20	2.05	20
		Total	4.95	20	5.00	20
	1	BC	2.94	18	2.76	17
		LC	2.00	18	2.00	17
		Total	4.94	18	4.76	17
1	0	BC	2.70	20	2.68	19
		LC	2.00	20	2.00	19
		Total	4.70	20	4.68	19
	1	BC	2.56	18	2.60	20
		LC	2.00	18	2.00	20
		Total	4.50	18	4.60	20
2	0	BC	2.89	18	2.79	19
		LC	2.11	18	2.05	19
		Total	5.00	18	4.84	19
	1	BC	2.84	19	2.75	20
		LC	2.00	19	2.05	20
		Total	4.84	19	4.80	20
3	0	BC	2.76	17	2.68	19
		LC	2.00	17	2.00	19
		Total	4.76	17	4.68	19
	1	BC	2.61	18	2.67	18
		LC	2.00	18	2.00	18
		Total	4.61	18	4.67	18

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Figure 102: Estimated means of cusp number for mandibular 2nd molars.

Group	Gender	Cusp	Tooth 37		Tooth 47	
			Mean	N	Mean	N
0	0	BC	2.23	13	2.17	12
		LC	2.00	13	2.00	12
		Total	4.23	13	4.17	12
	1	BC	2.00	10	2.13	8
		LC	2.00	10	2.00	8
		Total	4.00	10	4.13	8
1	0	BC	2.00	6	2.00	8
		LC	2.00	6	2.00	8
		Total	4.00	6	4.00	8
	1	BC	2.07	14	2.13	15
		LC	2.00	14	2.00	15
		Total	4.07	14	4.13	15
2	0	BC	2.11	9	2.29	7
		LC	2.00	9	2.00	7
		Total	4.11	9	4.29	7
	1	BC	2.00	6	2.00	3
		LC	2.00	6	2.00	3
		Total	4.00	6	4.00	3
3	0	BC	2.00	4	2.00	5
		LC	2.25	4	2.20	5
		Total	4.25	4	4.20	5
	1	BC	2.20	5	2.75	4
		LC	2.00	5	2.00	4
		Total	4.20	5	4.75	4

BC = buccal cusp, LC = lingual (palatal) cusp, N = number of teeth investigated.

Chapter 8

Discussion And Conclusions

8.1. RELIABILITY OF MEASUREMENTS

The digital camera of the image analysis technique produced detailed images with high resolution. The time required to image one tooth surface with this technique however is fairly rapid (four minutes on average) allowing sufficient images to be gained for comparative purposes. It is possible to image more than one tooth at a time ensuring that the relevant surfaces are not obscured. The measurements can be made simultaneously. The determination of the new technique's validity was carried out through the following stages:

1) The calibration for the measurement system was discussed earlier; this was to ensure that the investigator was adequately trained in making consistent observations with adequate calibration procedures being followed.

2) The intra-operator reproducibility of normal dentition measurements (Pilot study 1) was determined for each of the 3 operators involved. The buccal and occlusal measurements were obtained for 5 maxillary and mandibular dental casts using both manual and image analysis techniques for comparison. Only one operator acquired the images. Pilot study 1 demonstrated smaller overall limits of agreement (i.e. more accurate) than that of the gold standard of manual measurements when the measurements were obtained by multiple operators on two separate occasions (Tables 6 to 8).

3) The intra- as well as inter-operator reproducibility of normal teeth measurements (Pilot study 2) was also demonstrated for 4 operators, 10 sets of study casts and image analysis technique. Again, only one operator (the same one) acquired the images and the test was for measurements from double determinations (Tables 9 and 10).

The comparison between the imaging technique and manual method has limitations in pilot studies 1 and 2 as the former involves tooth surface orientation, imaging and then measurements of a fixed screen images. In the later technique, on the other hand, the measurements are obtained at the same time of the tooth surface orientation made by the operator. However, in pilot study 3, the techniques can be compared as it involved double determinations for the full imaging technique and manual measurement procedures. Comparing the limits of agreement results of the measurements obtained by the imaging technique for each operator in pilot study 1 (operators 1, 2 and 3) with those of pilot study 2 (operators 4, 1 and 2 respectively) indicated overall improvement in measurement repeatability. For the investigator's buccal measurements, almost the same figures for MDb, OG and Pb (0.18, 0.17 and 0.42 mm in the 1st study and 0.20, 0.19 and 0.40 mm in the 2nd study) were obtained and an improvement in Ab (5.99 mm^2 in the 1st study and 1.16 mm^2 in the 2nd study). For the occlusal measurements, on the other hand, improvement in repeatability was revealed for all MDo, BL, Po and Ao measurements (0.26, 0.27, 0.65 mm and 3.19 mm^2 in the 1st test whereas 0.23, 0.25, 0.51 mm and 2.37 mm^2 in the 2nd test) respectively.

4) The intra-operator reproducibility of measurements computed separately for different tooth types presented the reliability of the whole new technique's procedures (imaging and measurement i.e. total errors), for one operator. Linear manual measurements were also obtained for comparison (Pilot study 3 and test 5.5, see chapter 5). Maxillary central and lateral incisor, canine and 1st molar and mandibular central incisor, 2nd premolar and 1st molar were investigated from normal dentitions (Table 12-15). While the sample size was small (N = 10), for mandibular teeth and maxillary lateral incisor, the size was reasonable for the other tooth types (N = 18-20). The limits of agreement results indicated that certain teeth seem to be more difficult to investigate and measure e.g. the molar (large teeth) in comparison to the lower central incisor and upper lateral incisor (small teeth) and in particular for certain measurements e.g. the area especially for molar teeth. However, the measurement values for area were the result of perimeter tracing for each two-dimentional image investigated. No bias between the two occasions of measurements was revealed.

5) The intra-operator repeatability of the measurements was also determined for abnormal shaped teeth (teeth from the hypodontia sample), but only for maxillary (N = 20) and mandibular (N = 20) incisor teeth and from the buccal view (Pilot studies 4 and 5). (see section 8.2.).

6) The intra- and inter-operator reproducibility for the abnormal teeth measurements were further assessed (Tables 21 and 23). The field theory (Butler 1939, Dahlberg 1945) and findings of many other reports in the literature suggested more variability in the maxillary lateral incisor than the central tooth and the opposite holds for the mandibular incisor teeth. Thus, the maxillary lateral incisor (N = 15) and mandibular central incisor (N = 15) were chosen for this test to represent the upper and lower incisor teeth (section 8.2).

The new system produced higher levels of reproducibility in comparison to Brook et al.

(1986) and individual tooth imaging can cope with imbricated, rotated teeth and arch curvature by imaging individual teeth rather than a complete arch (Lowey 1993). The results do indicate that the new technique is comparable to the manual technique for linear measurement. However, a major advantage of the image analysis technique is that it provides far more information concerning tooth dimensions such as area, perimeter, tooth taper, MD25, MD50, MD75, BLm, BLd, Db, Do etc. These additional measurements have been shown in this research to discriminate between hypodontia and control samples.

Conclusion

The image analysis technique is comparable to the manual technique for linear measurements. For more comprehensive measurements, it showed repeatable observations.

8.2. DETERMINATION OF TOOTH TAPER

Previous studies utilised subjective criteria to study the severity of tooth morphological variation (Alvesalo and Portin 1969, Foster and Van Roey 1970, Woolf 1971, Schalk-van der Weide 1992). Peg-shaped, conical, pointed, narrow and elongated teeth are some of the examples reported. The maxillary lateral incisor teeth are the most commonly affected teeth by this trait (Davies 1968, Lai and Seow 1989). One study suggested that the left side was more commonly affected than the right (Sofaer et al. 1971). Thus the tapering trait has a range of severity from mild to severe and it can affect one or more teeth.

This study developed and tested a new objective method to determine tooth tapering that can be used for comparison between groups. The ratio of MD widths at 50:75 percentiles of the OG has been shown to be a useful method for this aim. The discrimination findings and the reliability of the measurements were presented in pilot studies 4 and 5 for both maxillary and mandibular teeth respectively. In these studies, only one operator (the investigator) made the measurements. Validity of the methods was also tested for inter-observer assessment (Tables 22 and 23). An acceptable overall measurement reproducibility was shown suggesting the use of this index in the main study analysis.

Continuation tests were made for evaluating imaging reliability in different tooth types with tapered morphology and assessing the reliability of the actual taper index measurement values. In the maxillary arch, the lateral incisor was chosen for investigation because it is one of the most commonly affected teeth in patients with hypodontia. For the mandibular arch, the central incisor teeth were investigated to represent the lower incisors.

With regard to the intra-observer assessment, limits of agreement were calculated (Table 21). The measurement data was compared to that for teeth with normal morphology (Table 13). The visual assessment suggest overall comparable results of the limits of agreement for intra-operator repeatability using the new image analysis technique. For maxillary incisors, normal teeth showed slightly better Db measurement determination (0.37 mm) but worse perimeter (1.32 mm) and area (4.57 mm^2) determination than those for tapered teeth (0.53 mm, 0.60mm, 1.81 mm^2 respectively). For mandibular incisor teeth, the figures of limits suggest better repeatability for these teeth (i.e. easier to be measured) than the maxillary incisors except for area measurements, the maxillary teeth showed lower limits values. Data generally indicates that the maxillary lateral incisors are more difficult than the mandibular central incisors to be measured.

Looking back for the differences of measurement pairs, it was found that all the differences were within the accepted range (0.30 mm for linear measurement e.g. MD, 1 mm for perimeter, 5 mm^2 for area and 0.30 for taper index for the mean differences) with two exceptions: One measurement was found exceeding this level for each of maxillary laterals (0.37 mm) and mandibular incisors (0.35 mm). The results of tooth taper index value demonstrated a high repeatability for both maxillary and mandibular teeth (the limits were 0.12 and 0.05 respectively).

For the inter-observer assessment (Tables 22 and 23), both the limits of agreement and the ICC were calculated to take into account the biological variation in the teeth as well as variation between two different operators and variation in errors. The mandibular teeth presented better overall reproducibility than the maxillary teeth (Table 21 and 22), whereas the Db measurements presented the most difficult dimension to be measured as compared to the rest of variables (-2.01 and 1.67 mm for lower and upper limits of agreement respectively). However, the ICC-values suggest an acceptable figure (0.78). The OG showed fairly large limit values, as in the intra-observer assessment, but generally showed good ICC-values (0.93 and 0.88 for maxillary and mandibular teeth respectively). The other linear measurements were within a reasonable range.

The actual taper index value also showed a good reproducibility (lower and upper limits of -0.11 and 0.16 and an ICC-value of 0.81 for maxillary laterals and also -0.08 and 0.05 and 0.97 respectively, for mandibular centrals). Although, the perimeter and area measurements presented overall acceptable limits and ICC-values for both maxillary and mandibular teeth, the figures suggest a better reproducibility when made by one operator than by multiple operators, as is always the case. In general, the inter-observer assessment revealed larger limits of agreement results than that of intra-observer assessment. The inter-ICC figures suggested good reproducibility, with the exception to the Db and area, in which much more variability was suggested between observers.

Conclusion

The tooth taper index measurements were reliable for the upper and lower incisor teeth. The different buccal view measurements for these teeth generally indicated similar reliability for, and comparable findings to, the same tooth types with normal morphology.

8.3. STUDY POPULATION

8.3.1. Study Models

These measurements were made on yellow stone cast duplicates rather than original study models. The first reason was to enhance the image quality as imaging white models show some difficulty when compared with yellow ones. The second was that it was not possible to keep original casts during the study period. The third reason was to avoid bias in measuring part of the teeth from the originals and part from the duplicates. The effect of duplication procedure on tooth dimensions was measured (Table 3) and the findings indicated that no differences in the measurements between the original and duplicated models.

8.3.2. Sample Size and Age

The information shown in table 23 and 24 indicates that the subjects included in groups and subgroups were balanced for size and similarly distributed for age. The general range of subjects' ages fall between 10 and 18.5 years. However, a few cases were included out of this range. Four cases in the severe hypodontia group, three males (two aged 23.33 years and one aged 9.67 years) and one female (aged 25 years). In the moderate category three male cases (aged 32.17, 20.50 and 9.58 years) and one female (aged 34 years). All the control and mild hypodontia subjects were within the 10 to 18.5 year range. Consequently, the biggest standard deviation for the age was for moderate hypodontia group (4.82 years) followed by the severe group (3 years) as compared to control and mild hypodontia group (1.36 and 1.56 years respectively). Large difference in ages could introduce some bias in measurements if the individuals demonstrate more enamel wear, gingival recession and extracted teeth. However, none of the young adults included in the study had these conditions.

8.3.3. Patterns of Tooth Absence

The patterns of tooth absence in the study sample subjects were evaluated according to two variables; the severity and location of tooth missing (Table 26 and 27). In addition to the control group, the hypodontia subjects were divided into three main groups according to the severity of hypodontia as discussed earlier. A similar tooth absence distribution for mild and moderate hypodontia subgroups was shown. More variations were shown in the severe subgroups.

The frequency according to the location of tooth absence in the mouth is shown in table 26 for all hypodontia subgroups. Each figure in the table demonstrates the number of subjects affected by that type of hypodontia and the same subject(s) may fall in any other group of tooth absence. In the mild hypodontia group, the most frequently absent teeth were maxillary lateral incisors and then mandibular 2nd premolars. In the moderate hypodontia group: For males, the most frequently absent teeth were maxillary lateral incisors and then mandibular 2nd premolars and maxillary 2nd premolars. For females, they were maxillary 2nd premolars, mandibular 2nd premolars and maxillary lateral incisors. In the severe hypodontia group on the other hand; for males, the most frequently absent teeth in order were mandibular 2nd premolars, maxillary 2nd premolars, maxillary lateral incisors, maxillary canines, mandibular central incisors and 2nd molars, maxillary 1st premolars and 2nd molars and mandibular 1st premolars. For females, it was maxillary

2nd premolars, mandibular 2nd premolars, maxillary lateral incisors, maxillary 1st premolars, mandibular central incisors and then mandibular 1st premolars. Although, this study is not a prevalence investigation, the rank order shown was, generally, in agreement with the prevalence surveys in the literature. This adds support to the value of the sample used in this study.

8.4. COMBINING BILATERAL MEASUREMENTS

Previous anthropological and orthodontic studies utilised two main approaches to compare the measurement values between samples; both take biological variation into consideration, based on their views for research problems. Measurements from one side only were obtained and analysed according to the anthropological convention. Lavelle (1968, 1971, 1975) used the left-hand side, whereas (Axelsson and Kirveskari 1983, Kieser et al. 1985) investigated the right-hand side. According to Axelsson and Kirveskari (1983), the measurements of right side were analysed because no significant difference was found. However, they did not explain their symmetry assessment. For statistical purpose, measurements from the opposite side may be taken in situations like small sample, missing teeth or caries (Lavelle 1968, 1975). In the other approach, the average of right and left measurements for the same tooth type was used for analysis in most of orthodontic and dental investigations (Moorrees et al. 1957, Moorrees and Reed 1964, Alvesalo and Tigerstedt 1974, Arya et al. 1974, Hinton et al. 1980). The measurement was taken from one tooth when the antimere was absent or not suitable for measurement (Moorrees 1957, Moorrees and Reed 1964).

In the ideal situation, right and left measurements should be independently analysed. If so, this would need a large adjustment for significance levels to investigate all variables. For the purpose of the present study, which investigated comprehensive variables, the right and left measurements were assessed to evaluate the use of averages in main analysis. The ICC-values were calculated to assess how much information was lost by averaging the measurement from the right and left sides. With the exception of four variables, the average values of bilateral measurements were used for most variables in the main analysis, after combining the right and left measurements. The relative measures of between sides and between individuals variance, of each variable, was demonstrated in tables 28 to 31. The acceptable ICC-value was decided to be 60% to support combining the measurements. For Db, Do, tooth taper and CIOM2 variables, the ICC small values suggested it was desirable to keep separate right from left measurement in analysis.

Two reasons appear to explain the low ICC-values for the above variables; these are technical and biological. The technical aspect may be due to measurement error especially the Db and Do that demonstrate somewhat large overall figures as compared to other linear measurements (Table 13 for normal dentitions and Tables 21 to 23 for tapered teeth). Biological variation appears to affect all these variables. It could be to a real difference between right and left measurements furthermore, the nature of hypodontia did not allow investigation of a statistically desirable number of teeth as many were either absent or partially erupted.

8.5. MAIN STUDY

8.5.1. Tooth Taper

In individuals with hypodontia, three main anomalies are considered in their incisor teeth: tooth absence, tooth taper and microdontia. A number of clinical appearances were seen in this study: bilateral/or unilateral absence, bilateral/or unilateral tapering, bilateral/or unilateral microdontia, bilateral/or unilateral normal tooth morphology and various combinations of these situations.

Thomsen (1952) investigated 169 inhabitants living in Tristan da Cunha and reported the rank order of hypodontia of maxillary incisors (0.7% prevalence) to be after the 3rd molars, 2nd premolars and lower incisors of the sample. Peg shaping of the upper lateral incisors was found in 5% of the investigated individuals. The differences between right and left sides and between genders were not significant. The information given by Grahnen (1956) was 2% of the sample was found with missing and peg-shaped upper lateral incisor, with similar percentages and no side and gender differences. Alvesalo and Portin (1969) investigated the problems associated with maxillary lateral incisors for 306 individuals of island of Hailuoto and found 24 individuals to be affected. They noticed that hypodontia and peg-shape of maxillary lateral incisors were commonly found in these families. There was phenotypic variation between individuals resulting differences in frequency of the gene as well as differences in its expressivity, which they felt due to modifying genes. On the other hand, the causal genes behind the reduction in tooth size of the remaining teeth were suggested to be different from those causing the absence and/or shape malformation (Alvesalo and Portin 1969). This, therefore, implies a number of genes, not only a single gene, are involved in the whole aetiological mechanism for the phenomenon of congenital tooth missing, tooth taper and microdontia.

For the present investigation, the relationship between hypodontia and tooth taper was determined (section 7.3.2., tables 32-55, figures 29-37). The analysis of data indicated variation in results between tooth types and genders. However, two main scenarios were revealed: 1) Due to significant interactions between group and genders, the genders were separated for analysis. As a result, multi-subgroup comparison tests that, in four incisor teeth (mandibular right lateral incisor and all the central incisors, except the maxillary left central incisor), only females showed a high amount of tooth taper in severe hypodontia group than the other severity groups (moderate hypodontia, mild hypodontia and control).

A similar trend was suggested for males but the results did not reach the significance level. 2) For the other incisors (maxillary left central and all the lateral incisors, except the mandibular right lateral incisor), no significant interaction was revealed, so the genders were combined for analysis. Multi-group comparison tests indicated no significant differences between genders and the degree of tapering was significantly bigger in all hypodontia group (severe, moderate and mild) teeth than control teeth. No significant difference was found among hypodontia groups.

The tapering ratio to represent tooth shape evaluation involved linear measurements along the OG dimensions, which all may be affected by a reduction in size in hypodontia groups with different effect. Adding the influence of gender, variation in results was therefore found suggesting a complex aetiology for hypodontia.

Conclusions

1) There are differences in tapering of the incisor teeth between hypodontia and control subjects (teeth 12, 21, 22 and 32). Generally, teeth of individuals with hypodontia tend to show greater tapering than teeth of the controls.

2) The differences in tapering are related to severity of hypodontia. The more severe the hypodontia the greater is the tapering (teeth 11, 31, 41 and 42).

3) There were also gender differences. Female severe hypodontia subjects showed more tapering than other groups (teeth 11, 31, 41 and 42).

4) The results showed variations between tooth types, arches and genders.

8.5.2. Mesiodistal Dimensions

The mesiodistal distal dimensions in all hypodontia and control groups were investigated from both buccal and occlusal aspects. The principal dimensions were obtained for all tooth types, buccally as well as occlusally (MDb and MDo). The results were shown earlier (Tables 56 and 65 and appendix 1 tables) and comparisons between the two views findings are discussed here. Furthermore, proportional mesiodistal dimensions (MD25, MD50 and MD75) measurements were taken for the incisor teeth buccally and the evaluation for their relationship with the MDb is also discussed here.

For MDb, two-way ANOVA revealed the two scenarios; 1) Significant interactions between severity groups and genders were found for teeth L2, L3 and L5 indicating that the differences between males and females were not consistent across the severity groups. Multi-subgroup comparison tests revealed significant differences behind these interactions. 2) Significant differences across severity groups for both genders were revealed in the rest of teeth. Multi-group comparison tests suggest MDb is generally smaller in hypodontia than controls. With the exception of L7, the effect of hypodontia on these dimensions was generally the same for the mesial and distal member of each tooth class of either the maxillary or mandibular jaw. This may indicate common aetiological elements causing this overall trend.

Some teeth showed some variations that may indicate additional or reduction in causal elements. There was a tendency of greater MDb values in males than females across the severity groups in the molar teeth. The measurement findings in tooth L7 suggest the tooth is more stable than the mesial tooth. For L7, multi-group comparison tests revealed no significant differences except between control and mild hypodontia groups and were before final adjustment. This is in disagreement with the field theory. The sample size seems to be acceptable for tooth L7, the number of teeth investigated was 25 in control, 29 in mild, 18 in moderate and 13 in severe hypodontia group. These findings reveal a complex aetiology for hypodontia that is in agreement with proponents of the multifactorial theory that consider hypodontia as a trait with various degrees of expressivity and severity, in which the anomaly is the result of many factors including a number of genetic and the environmental factors (Woolf 1971, Suarez and Spence 1974, Brook 1974b, 1984, Bailit 1975, Chosack et al. 1975).

MDo measurement results were generally in agreement with that of MDb as they should be i.e. both variables were related to hypodontia and show different patterns in different teeth by the influence of severity and gender factors. Superimposing the summary tables of mesiodistal measurements taken bucally (Table 56) and occlusally (Table 65) reveal agreements in results with few exceptions, but not affecting the general picture. While MDo had not revealed significant interaction for L5, a significant interaction was found for tooth U6 instead in comparison with MDb. Tooth L5 was close to the significance level ($P = 0.1072$). On the other hand, U6 MDb was not close to the significance level ($P = 0.413$). The comparison between MDo and MDb, revealed 2 common interaction effects in 2 teeth (L2 and L3) and additional one interaction for the former (U6) and one interaction for the other (tooth L5). Tooth U1, there was tendency of severe group MDo to be smaller than controls as was found with MDb. Tooth L7, on the other hand suggested differences between combined control group and combined mild and moderate hypodontia groups before final adjustment i.e. MDo in control > mild and moderate hypodontia. In MDb, only the mild group was different to controls.

The proportional mesiodistal dimensions to further evaluate the morphology of incisor teeth were used. Analysis of proportional MD measurements was generally in agreement to that of MDb suggesting the same trend discussed earlier for severity and gender. So, any of these four mesiodistal measurements (MDb, MD25, MD50 and MD75) of incisor teeth are suitable to reflect the difference between hypodontia and control measurements. Further tesing, in the future could be undertaken to evaluate the correlation between these variables.

The reduction in the mesiodistal dimension in hypodontia individuals had been documented. This may be seen locally or over the whole dentition. Rune and Sarnas (1974) pointed out that there is almost always difference in size between the control and hypodontia patients with the latter showing significantly smaller teeth. Lai and Seow (1989) also showed a significant association between hypodontia and microdontia. In his prevalence study in British population, Brook (1974a) demonstrated a 2.5% figure of microdontia affecting the whole permanent dentition, in which nearly 80% of this total was related to the maxillary lateral incisors (i.e. 2% prevalence). In another study (Brook 1984), it had been suggested that the relationship between these two anomalies to be significant ($P<0.001$). In that study all children with congenital absence of 6 or more teeth showed a clinically apparent reduction in their teeth sizes. Brook and John (1995) also reported a significant association between hypodontia and small tooth size ($P < 0.05$) in a Romano-British population. The results of the present investigation in a white British population support this trend across the whole dentition with some limited exceptions: In the measurements of the mesiodistal dimensions; 1) No significant difference was found in the measurement values of the mandibular 2nd molars between hypodontia and control groups. This may suggest more stability in the development of this tooth. 2) No significant difference was found among hypodontia groups, except the maxillary central incisors that showed a general trend of control > mild > moderate > severe hypodontia.

The pattern therefore suggests individuals in all severity groups were similarly affected by tooth size reduction. 3) No significant sexual dimorphism was revealed for different tooth types. Male measurements were larger than female measurements but only in the control canine teeth, a finding consistent with the opinion indicating that males exhibiting larger measurements.

Regarding difference in tooth types, the conventional concept suggests high stability in crown dimensions of canine and 1st molar. Baum and Cohen (1975) found in a hypodontia sample the opposite trend i.e. a significant low stability in these teeth and a greater variability in the anterior than the posterior teeth as both showed similar statistical analysis. The findings of this study also did not find differences between mesial and distal teeth of the same tooth class.

Sexual dimorphism in the mesiodistal dimension measurements in dentitions of different occlusions and populations was demonstrated by many studies and generally indicating bigger values in males than females (Miyabara 1916, Baum and Cohen 1971, Cohen 1971, Lavelle 1972, 1975, Bailit 1975, Richardson and Malhotra 1975, Perzigian 1976, Potter et al. 1981, Axelsson and Kirveskari 1983, Kieser et al. 1985, Alvesalo 1997, Yuen et al. 1997). In a Japanese sample, Miyabara (1916) found the greatest difference between males and females in canine teeth. Moreover, the mesiodistal measurements were larger and showed less variability in tooth form than Europeans. Lavelle (1972) found this phenomenon in Caucasian, Mongoloid and Negroid subjects. Perzigian (1976) reported that, with the exception of maxillary lateral incisors, males showed larger mesiodistal and buccolingual dimensions for an Indian Knoll population and the sexual dimorphism in tooth size being moderate. Axelsson and Kirveskari (1983) suggested that the maxillary 2nd premolar failed to show this trend whereas the canine teeth of both maxillary and mandibular arches demonstrated the biggest dimorphism. South African Caucasoid dentitions demonstrated more sexual dimorphism in mesiodistal dimension but were generally intermediate in size as compared to other Caucasian populations (Kieser et al. 1985). It has been pointed out that in humans, there are differential effects on development from X and Y chromosome genes that are likely to be responsible for gender differences in various somatic features e.g. the size, shape and number of teeth and statural growth (Alvesalo 1997). Accordingly, sexual dimorphism in average tooth crown size is expressed early and at different stages of dental development.

For dentitions with hypodontia, conflicting conclusions have been proposed. A greater crown size reduction was found in male teeth than females (Cohen 1971, Baum and Cohen 1971). An interesting finding suggesting a statistically larger 1st molar mesiodistal dimension in hypodontia males than control males had been also reported (Wisth et al. 1974a). Females with hypodontia showed only a tendency of size reduction with no significant difference compared to controls. Schalk-van der Weide (1992), in severe hypodontia sample, found significant reduction in mesiodistal measurements of different teeth in males and most of female teeth as well. On the other hand, no significant difference was shown in the amount of size reduction according to Rune and Sarnas (1974).

The findings of this study revealed one significant difference between genders related to L3 MDo measurements and was in control groups, suggesting larger measurements in males than females. It is also the same for L3 MDb measurements but before final adjustment. Moreover, a consistent differences between genders across groups (before final adjustment) of significance level, were also suggested, indicating larger dimensions in males than females: Buccally, for U6, U7, L2, L6 and L7 and occlusally, for U7 and L7. So, the findings are generally in agreement with opinion suggesting dimorphism in canine teeth in normal dentitions (Miyabara, 1916, Lavelle 1972, Axelsson and Kirveskari 1983) and with findings indicating size reduction in both genders with hypodontia dentitions (Rune and Sarnas 1974, Brook 1984, Schalk-van der Weide 1992).

Conclusions

1) There are differences in the mesiodistal dimensions (MDb and MDo, MD25, MD50 and MD75) between individuals with hypodontia and controls (Individuals with hypodontia subjects showed statistically smaller meaurements).

2) The measurement data of MDb and MDo, MD25, MD50 and MD75 dimensions suggested a strong relationship between tooth size, and hypodontia, with a tendency of increasing reduction in dimensions with the increase in severity of hypodontia.

3) The influence of tooth absence varies slightly in different tooth types, as did the effect of gender.

4) Both the mesial and distal teeth of each morphological class were similarly affected in individuals with hypodontia.

5) The measurements showed a tendency to be larger in males than females, but this was not significant for most teeth except L3 in controls.

8.5.3. Occlusogingival Dimension

The results of OG dimension measurements were presented in table 57. The data suggested that OG dimensions were also related to hypodontia. The influence of both hypodontia severity and gender indicated variation in results for different teeth with an overall trend suggesting OG in controls > mild, moderate and severe hypodontia groups. With the exception of teeth U7, L5 and L7, the trend was similar for each mesial and distal tooth of each tooth class of both jaws. These may indicate that all teeth are sharing the same aetiological element(s). Multi-group comparisons showed further reduction in the measurements in severe category (U6 and L2) and suggested a tendency of the same trend for other teeth (U1 and U6). Furthermore, teeth U7, L5 and L7, the results suggest that these teeth were more stable than their mesial teeth, a finding contradicting the field theory. They showed just a tendency of the trend mentioned-above i.e. they did not retain their significance after final adjustment as the mesial ones.

The difference between genders was not significant, although, a consistent difference between genders across groups was suggested before final adjustment, indicating larger figures in males than females for teeth U2, U5, U6, L3, L4 and L5. All the above demonstrate variation in findings and suggest a complex aetiology in different teeth in individuals with hypodontia.

Few studies in the literature (Miyabara 1916, Bolton 1958, Lavelle 1968, Volchansky and Cleaton-Jones 1981) referred to the OG dimension. These were not related to hypodontia and this did not allow comparison with findings for the present study. Miyabara (1916) pointed out that Japanese measurements were smaller than Caucasians except the maxillary lateral incisor. Lavelle (1968) compared the dimensions of Anglo-Saxon and modern British permanent teeth and found smaller dimensions in most of measurement in modern populations. The opposite was suggested for few cases i.e. in the maxillary central incisors for both genders and in the maxillary canines and mandibular canines, 1st

and 2[nd] premolars for males. In molars, the OG dimension was measured from the mesiolingual cusp tip to the amelocemental junction i.e. different from the measurement method of this study.

Conclusions

1) There are differences in the occlusogingival mean values of all the teeth between hypodontia and control subjects (Hypodontia subjects demonstrated statistically smaller measurements).

2) The differences in the OG dimension are slightly related to the severity of hypodontia.

3) The results showed variation between tooth types, arches and genders.

8.5.4. Buccolingual Dimensions (BL, BLm and BLd)

The main results were reported in table 66 for principal (central) BL dimension in all tooth types. Whereas, table 70 demonstrated the findings for mesial and distal buccolingual dimensions (proportional BLm and BLd respectively) that related to the molar teeth. The initial discussion will be for the principal BL results and then a comparison discussion will be made for the mesial and distal buccolingual dimension for the molars. The overall picture for these dimensions is in agreement with the results discussed for mesiodistal dimensions. So, measurements of BL dimension suggested that tooth size is smaller than in hypodontia. Apart from 2 tooth types (L1 and L6 suggesting inconsistent differences between males and females across severity groups), significant differences across the groups for both genders were revealed in all teeth and multi-group comparison tests indicated larger dimensions in controls than in hypodontia subjects. It is also true in L1 and L6, in which for each gender separately, there was also a relationship between severity of hypodontia and BL dimension measurement.

Apart from the mandibular 1[st] premolars BL, in which male measurements were larger than those of females, no significant sexual dimorphism was found. The overall gender assessment suggested greater measurements in males than in females across severity groups but this was not significant. Sexual dimorphism in the buccolingual dimension measurements was also reported in the literature. One conclusion matches the results of this investigation, which suggests that measurements generally larger in males than females in normal dentitions (Perzigian 1976, Potter et al. 1981, Axelsson and Kirveskari 1983, Kieser et al. 1985). Another conclusion indicated disagreement in tooth type difference. According to Axelsson and Kirveskari (1983), the greatest dimorphism was related to the canine teeth particularly the maxillary and the opposite was for the maxillary lateral incisors. It was the mandibular canine that showed the greatest dimorphism (Perzigian 1976). Potter et al. (1981) noted that the canines of both jaws demonstrated the biggest gender differences in both mesiodistal and buccolingual dimensions followed by the mesiodistal dimension of the maxillary central incisor and buccolingual of maxillary 1^{st} molar.

The pattern of hypodontia was almost the same in the mesial and distal member of the same tooth class in each upper and lower jaw. This, further supports previous notes made suggesting common aetiological factors behind the anomaly and measurements of all teeth. Another finding against the field concept suggested a significant low stability in 1^{st} molar and canine teeth and greater variability in the anterior than the posterior teeth (Baum and Cohen 1975).

To further evaluate the morphology of molar teeth, a comparison between the proportional mesiodistal (BLm and BLd that were obtained parallel to the BL in fixed proportion across MDo) and principal BL measurements is discussed. With the exception of L6, the analysis of data was generally in parallel to that of BL. The genders were separated in BL analysis and combined in BLm and BLd, although, the general trend was the same, bigger dimensions in control group than hypodontia. Any of these three buccolingual dimensions could be used to make comparison between hypodontia and normal dentitions for this sample. Future work should look for the correlation between the three variables.

Conclusions

The measurement analysis for buccolingual dimensions revealed the following:

1) There are differences in the buccolingual measurements (BL, BLm and BLd) between hypodontia and control subjects (Individuals with hypodontia subjects

showed statistically smaller measurements).

2) The pattern was found in all tooth fields with similar overall results in the mesial and distal tooth of the maxillary and mandibular arch.

3) Variation was also found with a tendency of increased reduction with an increase in severity in some cases.

4) Males showed tendency of having larger measurements than in females in all groups but not significant.

8.5.5. Perimeter and Area Measurements

The area was determined by the perimeter trace for both buccal and occlusal surfaces. Based on the results of Pb, Ab, Po, and Ao measurements (Tables 58, 59, 67, 68 respectively), which revealed that the perimeter measurements were in the same order with their corresponding areas, a combined discussion is made here for all these four variables. Superimposition for these summary result tables reveals very similar findings i.e., all hypodontia groups demonstrated smaller dimensions than the control group with few exceptions related to teeth U7 and L2 buccally and L3 occlusally. The Pb of U7 demonstrated the same trend in mild and moderate groups but the severe group had shown only a slight evidence (not significant) of the trend. The Ab analysis of the same tooth suggested that only the mild group was different from the control group. For L2 Pb, the difference between mild hypodontia and control group was not significant. On the other hand, L3 Po and Ao analysis showed that the mild group differed from the control group in females.

The findings also indicated a reduction in these dimensions with an increase in severity of hypodontia e.g. Pb and Ab of teeth U1, U6 and L2 (group 3 < group 0). Many other teeth showed a tendency of this trend but before the final adjustment of significance levels. Considering the tooth fields, in each the maxillary as well as the mandibular arch, the pattern was generally the same for the mesial and distal tooth. Tooth L7 (P2-values were not significant for most of multi-group comparisons) presented an exceptional case, in which a smaller hypodontia effect was found compared to the L6.

A part from the following exception, no statistical differences between males and females were revealed. In the buccal view, a consistent difference across groups was found for L3

Ab measurements, in which male mean values were larger than those of females. While for teeth L3 Pb, U6 Ab and U6 Pb measurements, some evidence for a difference (M > F) was found. In the occlusal view, a difference was also found between control subjects (M0 < F0) for L3 Ao measurements. Furthermore, an evidence for gender difference was suggested for teeth L3 Po (M < F), U6 Po, U6 Ao and L6 Po (M > F).

No similar studies could be found in the literature that have investigated these four dimensions to report comparisons. However, the overall observations supported those discussed in other variables (mesiodistal, buccolingual and occlusogingival dimensions) with regard to complex aetiology due to these mentioned variations in findings. Finally and for each view separately, either the perimeter or the area may be used to describe the trend of measurements in individuals with hypodontia and controls for this study sample. Further work to assess the correlation between the area and perimeter in each view should be done.

Conclusions

1) There are differences in the measurement mean values of perimeter and area from both buccal and occlusal views (Pb, Po, Ab and Ao) between hypodontia and control subjects (individuals with hypodontia showing smaller measurements).
2) The differences in these dimensions suggested a relationship between the severity of hypodontia and the reduction in measurement values.
3) There is variation in findings for different teeth in the upper and lower dental arches.
4) There are also differences between male and female subjects but not in all teeth.

8.5.6. Crown Index of Buccal Morphology 1

The effect of hypodontia was further investigated by means of combined measurements. The buccal surface of a tooth crown was investigated using an index i.e. the ratio of MD and OG dimensions (CIBM1: MDb/OG). The findings for crown index of the buccal morphology were reported in table 60. In comparison with the other variables, there is a similar overall effect in control and hypodontia groups. A possible explanation is the fact that both the MDb and OG dimensions were similarly affected by the anomaly as presented earlier i.e. generally, the measurements in hypodontia groups are less than the control group. However, multi-group and subgroup comparison tests revealed four significant differences related to teeth U6, L6 and L3 and suggesting an index values being in severe hypodontia greater than the control group (U6 both genders and L3 females) and than the mild hypodontia group (L6 both genders and L3 females). This could be explained as, a greater reduction occurred in the occlusogingival than the mesiodistal dimension and was associated with severity of hypodontia. Apart from these findings, the morphology of crown defined by the OG and MDb was generally the same in all study groups.

Finally, the figures suggested variations between individuals and between teeth of both jaws. No research has been found in the literature investigated this ratio to permit comparison with the above findings.

Conclusions

The crown index of buccal morphology 1 measurements (CIBM1) indicated the following overall conclusions:

1) In general, the measurements were not directly related to hypodontia. This was based on exclusion of the few cases (teeth U6, L6 and L3) that revealed bigger index value in severe hypodontia measurements than in the mild hypodontia and control groups.

2) The effect of gender was also weak on the value of this ratio as no significant difference was shown between groups.

8.5.7. Crown Index of Occlusal Morphology 1

The occlusal surface was investigated using composite measurements i.e. the ratio of MD and BL dimensions. This was suggested by Garn et al. (1967) to examine gender differences in tooth shape and their ratio was BL/MD. Lavelle (1968, 1970) suggested the crown index to investigate crown morphology i.e. the ratio of the buccolingual and mesiodistal crown dimension expressed as a percentage. The same ratio was utilised by Peck and Peck (1972a,b, 1975) to investigate the relationship between crown dimensions and dental crowding. In this study, the formula used was the mesiodistal dimension divided by the buccolingual dimension (MDo/BL) which represents the 1st occlusal index of tooth crown. Since significant differences were found between the control and hypodontia groups' mesiodistal and buccolingual dimensions (Tables 65 and 66), one would expect no difference in the morphology combining these two dimensions. This is true only if the amount of differences for the original dimensions were the same. The findings of this variable (Table 69) suggest no differences between severity groups and genders. The only exception was related to the maxillary 1st premolar and mandibular 2nd promlar teeth in which only the severe hypodontia group was significantly different from the control values. The severe hypodontia group findings showed greater mean values than control group for both genders in the former and only for females in the later tooth. This may suggest more reduction in the buccolingual than mesiodistal dimension in the hypodontia group in this tooth, whereas a similar reduction appear to affect these two dimension for other teeth i.e. keeping the overall morphology value the same in all groups.

In their studies to determine the link between the shape of tooth crown and crowding for the mandibular incisor of female subjects, Peck and Peck (1975) pointed out that a low index values (< 90%) is a feature of hypodontia. Comparing their figures for control subjects with the present study control and hypodontia suggests the following: For the central incisor, they presented mean 94.4 and standard deviation as compared to 87 and 5 respectively (for hypodontia groups the mean was ranged between 86 to 91 in the present study). For the lateral, their mean 96.8 and standard deviation 5.2 as compared with 88 and 4 respectively (in hypodontia groups, the mean ranges between 90 and 95 in this study). The present investigation therefore, does not support their statement. That was also confirmed in the findings of the other teeth (Table 69) suggesting similarity in the overall figure for this variable.

Some reports in the literature pointed out that the buccolingual and mesiodistal dimensions could be determined multifactorially (Cohen 1971, Potter et al. 1976, Dempsey et al. 1995). In a study for twins, Potter et al. (1976) noted that more genetic elements appear to play in the development of mandibular than the maxillary teeth. Dempsey et al. (1995) on the other hand suggested a general genetic influence, due to one or more genes, that affected the mesiodistal dimensions for maxillary and mandibular incisor teeth and with a role for environmental factors.

Conclusions

1) Generally, there are no differences in the values of the crown index of occlusal morphology 1 (CIOM1) between hypodontia and control groups, apart from the upper 1st and lower 2nd premolars.

2) The crown index of the occlusal morphology was therefore, not related to hypodontia and gender.

8.5.8. Db Dimension and Crown Index of Buccal Morphology 2

From the buccal aspect, the level of the mesiodistal dimension was examined across the occlusogingival dimension to define differences between hypodontia and control groups. Linear measurement was obtained (Db) from the line of occlusion to the MDb and then an index was used to count the ratio of this measurement to the whole OG dimension (i.e. CIBM2 = Db/OG). For the Db dimension (Tables 62 and 63 for maxillary and mandibular teeth respectively), there was a trend particularly in the incisor teeth suggesting larger dimensions in hypodontia than in control subjects. The analysis revealed that in general, there is a tendency of the MDb to be located gingivally in the incisor, canine and premolar teeth in hypodontia groups than in controls. This conclusion further supports other results reported in the present study indicating tapering tendency in the incisor teeth (tooth taper index, tables 32-55 and figures 36-44) and other reports in the literature.

In addition to this variation between tooth types, the analysis of data also revealed variation between genders related to both Db (teeth 11, 21 and 41, tables 62 and 63) and CIBM2 (teeth U1, U5, L1, L3 and L4, table 64) variables. These all suggest that the difference between hypodontia and control subjects were related to females only. Variation in severity was also found that in few cases that generally suggesting, severe hypodontia showed more difference than control group. There was no research in the survey of the literature had looked at these variables objectively. The above discussion supports the opinion suggesting a complex aetiology behind for these variations.

Conclusions

1) There are differences, in the location of mesiodistal dimension and crown index of buccal morphology as revealed by Db and CIBM2 values, between hypodontia and control subjects (MDb in hypodontia was located more gingivally than in control subjects, particularly the anterior and premolar teeth).

2) Both variables are related to the severity of hypodontia.

3) Variations were found in the measurements for different teeth and genders.

8.5.9. Do Dimension and Crown Index of Occlusal Morphology 2

Comparing the differences in the level of the mesiodistal dimension from the occlusal aspect across the buccolingual dimension in hypodontia and control groups made further morphology assessment. Similarly to those of the buccal view, linear measurements were obtained (Do) in the occlusal view from buccal border of tooth crown to the MDo and an index was used to count the ratio index (i.e. CIOM2 = Do/BL). Superimposition the findings for DO (Tables 71 and 72) with those for the index (Tables 73 and 74) did not suggest matching results. Variation in severity and tooth type was found in the Do measurements in some cases. However, the overall trend suggests smaller Do measurements in hypodontia groups than the control group and the differences were mainly related to the incisor and canine teeth. The difference in Do supports the findings reported earlier suggesting larger BL in control than hypodontia.

The pattern in MDo and BL was nearly the same (i.e. both dimensions in hypodontia < control), thus no difference in the index combining Do and BL variables was found. Apart from the mandibular left 1st molar, no significant difference was found in any tooth for this index. The findings indicated that the location of the mesiodistal dimension was generally in the buccal half for the buccolingual dimension. No similar study could be found in the literature that had investigated these variables. Finally, the change in linear (size) measurements for groups does not necessarily imply a change in shape

Conclusions

1) There are differences in Do measurements between hypodontia and control subjects (measurements of most the teeth were smaller in hypodontia subjects).

2) The effect of the severity of hypodontia and gender in Do measurements is generally weak.

3) On the other hand, there are no significant differences in the value of crown index (CIOM2) between hypodontia and control groups, apart from the lower left 1st molar suggesting no difference in the location of the mesiodistal dimension for all teeth form the occlusal aspect.

4) Therefore, CIOM2 is not related to hypodontia and gender.

8.6. ADDITIONAL FINDINGS

8.6.1. Symmetry Investigation

The agreement between the right and left measurements (absolute differences) was investigated to determine whether there is symmetry or asymmetry for the mesiodistal dimension of all teeth and for tooth taper of the incisor teeth. No significant difference between bilateral measurements of MDb and tooth taper index was revealed for any of the subgroups investigated after the final adjustments of the significance levels. The limits of agreement were calculated for all severity subgroups and the results for hypodontia groups were always looked against that of control group for male and female (Tables 75-92). Then, the interpretation of the symmetry evaluation was made.

Asymmetry in bilateral tooth measurement may be found due to a number of possible factors: The 1st one, as a result of true asymmetry values. The 2nd factor, due to the nature of the anomaly investigated such as hypodontia. The 3rd possible reason is the errors in measurements system. However, these have been shown to be comparable for hypodontia and controls (Chapters 5 and 6).

The number of tooth pairs examined varied reflecting the nature of hypodontia and/or tooth development. In some cases, it did not show a sufficient number of tooth pairs for statistical interpretation and therefore, the conclusions should be stated with caution. Ideally, the size of each subgroup should be increased to allow adequate number of each tooth type ($N \geq 20$). This problem particularly occurred in the maxillary lateral incisors and maxillary and mandibular 2nd premolars and 2nd molars as well as some severe and moderate subgroups of other tooth types (maxillary canines and 1st premolars and mandibular central incisors and 1st premolars). Considering the above guidelines and accepting the problem associated with the sample, the following points are reported.

8.6.1.1. Symmetry of MDb

The findings were shown in tables 75-88 and the data of hypodontia subjects was compared to that in controls. The discussion was made according to the tooth type of each jaw. In the maxillary jaw: For the maxillary incisor teeth (Tables 75 and 76), there was asymmetry in measurements in all control and hypodontia groups. However, based on the limits of agreement assessment, the central tooth symmetry was generally unrelated to hypodontia, whereas the lateral tooth was related to hypodontia (but only for male mild and female moderate hypodontia subgroups). This supports the field theory, which suggest that the lateral incisor is less stable than the central. In the maxillary canine teeth (Table 77), although the findings of the limits of agreement showed asymmetry in bilateral measurements, the overall picture suggested that the measurements were not related to hypodontia.

In maxillary premolars (Tables 78 and 79), there was asymmetry in measurements in all groups. However the agreement limits assessment suggested that the 1st premolar appeared to be related to hypodontia (but only in female severe hypodontia), whereas the 2nd premolar was generally not related to hypodontia. In maxillary molars (Tables 80 and 81), the limits demonstrated asymmetry in measurements for all groups. However, the 1st molar was generally unrelated to hypodontia, whereas the 2nd molar showed some relationship to severity of hypodontia (only for male severe hypodontia). Again this is generally in agreement with the field theory.

In the mandibular jaw: For mandibular incisor teeth (Tables 82 and 83), the measurements suggested asymmetry in all groups by means of limits of agreement. However, such asymmetry appeared to be more related to the severity of hypodontia (only male severe hypodontia) for both the central and lateral incisors. In the mandibular canines (Table 84), again the measurements suggested asymmetry in all groups according to limits of agreement. Although, only female mild hypodontia cases appeared to be related to hypodontia.

In mandibular premolars (Tables 85 and 86), there was asymmetry in measurements in all groups. In spite of this, the 1st premolar measurements were generally not related to hypodontia. The 2nd premolar, on the other hand, appeared to be related to severity of hypodontia (only in male severe hypodontia). These findings support the field's concept. Finally, for mandibular molars (Tables 87 and 88), although there was asymmetry according to the limits in all groups, the overall results revealed that the measurements of both 1st and 2nd molars to be unrelated to hypodontia.

There have been studies in the literature attempted to investigate symmetry in measurements. According to Ballard (1944), a right-left discrepancy in measurement was found in 448 individuals (90% of the sample) of 0.25 mm or more. Out of these cases, 408 showed 0.5 mm or more of discrepancy while 40 demonstrated a range between 0.25 mm and less than 0.5 mm. The jaw distribution suggested the lateral incisors and the 1st molars were most frequently involved in the maxilla and the canines and the 1st premolars in the mandible. Garn et al. (1967) have suggested that the size symmetry is inherited more frequently in males than females, which in turn leads to greater shape variation in the male. The mandibular 2nd premolar as well as 2nd molar and the maxillary lateral incisors were the teeth, which demonstrated greatest gender difference in tooth shape.

For most population studies on tooth size reported earlier, no a symmetry was revealed. This was supported by Potter et al. (1981) and Axelsson and Kirveskari (1983) for Filipino and Icelandic dentitions respectively. Furthermore, no differences were found in the symmetry of mesiodistal and buccolingual dimensions between monozygotic and dizygotic twins, according to Potter and Nance (1976).

A significant difference in the amount of asymmetry has been suggested, between South African Negroid and Caucasoid, in which the formers demonstrated more asymmetry in their mesiodistal and buccolingual dimensions than the later (Kieser and Groeneveld 1988). They suggested some environmental factors to take part in the aetiology e.g. a high susceptibility to diseases and poor nutrition that were related to Negroids. More asymmetry was found in canines, central incisors and premolars. They added that the mandibular incisors and premolars asymmetry appears to be smaller in the distal than the mesial tooth. The difference in asymmetry was not restricted to a particular side and is known as a fluctuating asymmetry.

8.6.1.2. Symmetry of tooth taper

Tables 89-92 demonstrated the results of symmetrical evaluation between right and left measurements for incisor teeth, in which an overall comparison was made between hypodontia and controls. For the maxillary incisor teeth (Tables 89 and 90), there was asymmetry in tooth taper measurements in all hypodontia groups as well as controls. However, based on the limits of agreement assessment, the central tooth symmetry appears to be related to hypodontia (but only in female mild and male severe hypodontia). This supports the ICC test calculated earlier to decide whether to or not to combine right and left measurements in the main analysis. The ICC results for tooth taper suggested separating the right from left.

Finally, for the mandibular incisor teeth (Tables 91 and 92), all groups as in the above cases presented asymmetry in tooth taper measurements according to the limits of agreement values. However, the results did not indicate a relationship of hypodontia in the central incisor tooth taper, whereas the lateral incisor tooth was slightly related to hypodontia (only in female severe hypodontia).

In individuals with congenital absence of teeth, asymmetry in tooth morphology was also documented. According to Sofaer et al. (1971), different pictures of morphological asymmetry for the maxillary incisor teeth were reported. A unilateral hypodontia of the lateral incisor was associated with an increase in the size of central incisors and the central incisor adjacent to hypodontic lateral demonstrated larger mesiodistal dimension than the central of the opposite side. The peg-shaped lateral incisors on the other hand were associated with smaller mesiodistal dimensions of the central incisors than normal.

The analysis of data of this investigation demonstrated variation within groups and subgroups and this indicates a complex aetiology for the development of tooth asymmetry in a hypodontia sample and this may suggests a number of genetic and environmental factors influencing the mechanism of tooth symmetry.

Conclusions

1) No significant difference was found in the degree of asymmetry, in bilateral mesiodistal and tooth taper measurements for mesiodistal and tooth taper variables, between hypodontia and control groups. However, some hypodontia subgroup measurements suggested a tendency of asymmetry in tooth morphology.

2) For the mesiodistal dimension, measurements of some subgroups suggested a tendency to asymmetry in hypodontia (U2s, U4s, U7s, L1s, L2s, L3s and L5s).

3) From tooth taper measurements, in hypodontia subjects there is some asymmetry in the upper central and lower lateral incisor teeth for some subgroups.

4) Variations in symmetry evaluation were related to the severity of hypodontia and gender.

8.6.2. Intermaxillary Ratios

The general pictures for the tooth size of different arch segments were investigated to test the effect of hypodontia severity and gender factors. The percentages of the lower teeth to the upper teeth were counted according to anterior, posterior, overall and grand total ratios and demonstrated in tables 93 and 94 for buccal and occlusal view measurements. The findings suggested larger figures for all ratios in individuals with hypodontia than in control subjects. The possible cause suggests a greater reduction for the mesiodistal dimensions in the maxillary than in the mandibular teeth. Furthemore, the severity of hypodontia was related to these differences as the figures were increasing with an increase of the severity of the anomaly.

The conclusions of the findings should be addressed with caution for two main reasons. The 1st one, because no significance levels of differences were presented. The 2nd reason, for certain tooth types, such as maxillary lateral lateral incisors and maxillary and mandibular 2nd premolars and molars, smaller sample sizes (group or subgroup) were investigated due to either the nature of hypodontia pattern or the age of patient or both of these factors. Future study should further investigate this issue in an appropriate statistical approach.

The findings for control group are comparable to Lundstrom (1954), in which three mean values of 78.5%, (range 73-84.5), 95.3%, (range 88.5-100.5) and 92.3%, (range 88-97.5) for the anterior teeth, posterior teeth and total number of teeth were reported, respectively. The posterior ratio was bigger (105.69) in this study compared to that of Lundstrom. Very similar figures have been published in other studies. The upper six anterior teeth are 22% (18%-36%) larger than the lower six teeth. It was concluded that, if the figure is below the average, stripping or extraction in the lower arch might be necessary (Neff 1957).

According to Bolton (1958, 1962), the overall ratio was 87.5 to 94.8% (91.3% mean). While the anterior ratio was 74.5-80.4% (77.2 mean). Stifter (1958) suggested overall and anterior ratios to be 91.04 and 77.55 %, respectively. In American Negroids, the figures were 90 and 77% for overall and anterior ratios respectively (Richardson and Malhotra 1975). Similarly, it was 90.9 and 77.6 % for Chinese population with Class I occlusion (Ta et al. 1999).

Conclusions

The intermaxillary ratios suggested smaller anterior, posterior, overall and grand arch segments in the mandible than the maxilla in all hypodontia and control groups. According to the descriptive data, the ratios tend to be larger in individuals with hypodontia than controls and tend to increase in the severity of hypodontia.

8.6.3. Cusp Number

The number of tooth cusps was briefly investigated to examine the possible effect of hypodontia on development of premolar and molar cusps. Descriptive data analysis was utilised (Tables 95-102). No standard deviations were calculated because it was inappropriate; also there was a small sample size particularly the 2nd premolar and 2nd molar teeth. Therefore, the findings should be considered with caution. The results revealed a tendency for cusp reduction in hypodontia groups. Generally, it was due to lingual cusp reduction in most teeth and buccal cusps in the mandibular molars.

The malformation of tooth cusps has been examined in the literature. Foster and Van Roey (1970) reported on the overall form and structure of the cusp and found the deficiency to be related to the palatal cusp of the upper 1st premolar or of one or more cusps of the permanent 1st molars. Some incisor teeth demonstrated deficiency with irregular formation for their crown. According to Lavelle et al. (1970), hypodontia of the 3rd molars has been found to be associated in absence of the distolingual cusp. On the other hand, the present investigation evaluated the deficiency in the number of cusps in individuals with hypodontia of different severities and compared to control subjects.

Conclusions

Based on the descriptive data, there is a tendency of reduction for the cusp number in premolar and molar teeth of hypodontia subjects compared with controls. The number of cusps tends to be smaller with increasing in severity of hypodontia.

8.7. SUMMARY OF THE DISCUSSION

The literature illustrates limitations in the knowledge of tooth morphology for individuals with congenital absence of teeth. The available information is mainly related to the mesiodistal dimension of teeth with less data for the buccolingual dimension. The maxillary lateral incisor tooth is the most frequently investigated tooth. Hypodontia of any one tooth is not an isolated anomaly but is related to the congenital absence of other teeth and/or alteration in the morphology of the remaining teeth. This study was therefore concerned with the investigation of morphological variations, associated with non-syndromic hypodontia. It considered various degrees of severity of hypodontia and gender factors. It utilised comprehensive tooth crown measurements. No previous study has been carried out to achieve these aims, using such extensive measurements of the tooth crowns (Tables 4 and 5).

Part of this investigation was related to the maxillary and mandibular incisor teeth. The relationship between hypodontia and tooth taper and proportional mesiodistal measurements was determined and explained (Tables 32-55 and 61 respectively). Another part investigated the posterior teeth. A number of buccolingual dimensions were measured in molar teeth (Table 70). The number of cusps, in premolars and molars was investigated (Tables 95-102). While the rest of variables from both views, were examined in all teeth including the linear dimensions, area, perimeter, and crown morphology indices (Tables 56-74). Symmetry evaluation was also performed but for the mesiodistal and tooth taper variables from the buccal aspect (Tables 75-92) and intermaxillary ratios were also investigated in all groups (Tables 93-94).

There was a general trend suggesting the formed teeth in hypodontia subjects tend to be smaller in size and more tapered, less symmetric and deficient in the number of cusps when compared to same tooth types in control subjects. Some factors might be related to this variation in findings:

Firstly: Variation is possible due to differences in the involvement of genetic and environmental factors in early odontogenesis (Alvesalo and Portin 1969, Sofaer et al. 1971, Cohen 1971, Suarez and Spence 1974, Alvesalo and Tigerstedt 1974, Bailit 1975, Garn et al. 1980, Brook 1984, Aberg and Thesleff 1997). The heritability of tooth dimensions (mesiodistal and buccolingual dimensions) was examined by Alvesalo and Tigerstedt (1974). The results suggested variations in which some teeth were not in agreement with the field and evolution concepts. Heritability of the mesiodistal dimension of upper 1st molars was higher than that of the 2nd ones. A low heritability was suggested for the mesiodistal dimension of the lower canines. The role of environment was therefore suggested to be important for those with low heritabilities during early dental development.

Secondly: Variation could also happen as a result of various combinations for hypodontia of different tooth types. For instance, a larger maxillary central incisor than normal was shown when its neighbour lateral tooth is congenitally absent, while a peg-shaped lateral was associated with a microdontia of central tooth (Chung et al. 1971, Sofaer et al. 1971). In cases with hypodontia of 4 or more teeth, the mesiodistal dimensions were almost always smaller than controls (Rune and Sarnas 1974) and also smaller in individuals with hypodontia of 6 teeth and more (Brook 1984). The difference in the measurements of the mesiodistal and buccolingual dimensions between hypodontia and control subjects exists for this sample. The estimated mean values of the observations for all subgroups and groups indicated an increase in the degree of microdontia with an increase in severity of hypodontia in one side, and larger mean values in males than females in the other side. The reduction in tooth size and tendency of further size reduction with an increase in severity of hypodontia corresponds fairly well with Brook's model discussing the anomalies of tooth size and number (Brook 1984). On the other hand, no gender difference was found in most of the measurement variables.

The findings of this study revealed that, although no significant differences between genders were found in most of the measurements, there was, on an average, a tendency of larger crown measurements (e.g. MDb, OG, Pb, Ab, MDo, BL, Po and Ao) in males than females. This dimorphism occurred in all severity groups and this further complicates the interpretation of the aetiology.

Considering the above-mentioned discussion, there is a considerable variation in findings between and within groups of this study with regard to various tooth morphology measurements. A complex aetiology is, therefore, evident for the patterns of hypodontia in this study population. Several investigators believed that the pattern of size reduction to be complicated (Garn and Lewis 1970, Cohen 1971, Baum and Cohen 1971, 1975, Rune and Sarnas 1974, Schalk-van der Weide 1992, Baccetti 1998).

8.8. OVERALL CONCLUSIONS

This study utilised a new measurement system to investigate the morphology of tooth crowns in hypodontia and control subjects and revealed the following overall conclusions:

1) The image analysis system is a reliable new technique, which permits comprehensive dental measurements from digital images with a good level of reproducibility. The system has been validated against the traditional manual measurement for linear measurements.

2) Taper index is a reliable new method to objectively determine the degree for tapering of the incisor teeth with good levels of reproducibility. It removes the need for subjective scoring and is particularly useful in borderline cases. It can be used in aetiological studies.

3) Comprehensive buccal and occlusal measurements (15 variables) were obtained and a number of indices (5 variables) evaluating tooth crown morphology were calculated for different tooth types and the analysis of data indicate that:

   a) Generally, there is no significant difference in one buccal (CIBM1) and two occlusal variables (CIOM1 and CIOM2) between hypodontia and control groups.

   b) There are significant differences in all the rest of the buccal and occlusal measurement variables between hypodontia and control groups. Thus, a general trend for the crown dimensions of all teeth in hypodontia subjects to be reduced relative to the control group is suggested.

   c) The differences are generally related to severity of hypodontia. This suggests a trend for greater reduction in crown dimension associated with an increase in severity of tooth absence and fits with the model proposed by Brook (1984).

   d) There are also gender differences in some variables and teeth. Males generally show larger measurements than females.

4) Further information was also gained concerning:

   a) Symmetry for the mesiodistal dimension and tooth taper measurement variables: A tendency of asymmetry in hypodontia measurements than control group was found but only in some subgroups.

b) Intermaxillary ratios: Based on the descriptive data, all the anterior, posterior, overall and grand ratios tend to be larger in hypodontia than control group and tend to increase with an increase in severity of hypodontia.

c) Number of tooth cusps: Based on the descriptive data, there is a tendency for more reduction in the number of cusps in premolar and molar teeth of hypodontia subjects than controls. With an increase in the severity of hypodontia, a tendency of further reduction in cusp number was found.

5) There were individual variations in the observations for different tooth types, genders and severities.

6) The above findings indicate different patterns for hypodontia in the morphology (size and shape) of human tooth crowns. A complex aetiology for hypodontia is, therefore, suggested.

7) The above conclusions, therefore, lead to the rejection of all the null hypotheses proposed earlier (section 3.3.).

8.9. RECOMMENDATIONS FOR FURTHER WORK

1) Future research should evaluate the trend of asymmetry in tooth measurement variables for hypodontia and control groups.

2) The number of tooth cusps in different hypodontia severity groups should be further investigated.

3) The differences in intermaxillary ratios between hypodontia and control groups should be further investigated.

4) Hypodontia of the 3rd molars was not considered in the present study. It would be of interest to assess its influence on the measurement analysis.

5) It would be of great value to increase the sample size in each subgroup to provide a powerful hypodontia database, to allow investigation of variation in tooth morphology for locations (i.e. different independent morphological fields) and to reduce the age range of study population.

6) The study of the morphology for tooth roots of the sample would add further information.

7) The assessment of the morphology of the upper and lower dental arches for study groups is also of interest.

8) The present study investigated unrelated subjects; therefore, comparing their measurement data with data of their 1st and 2nd degree relatives would add valuable information for the pattern of hypodontia.

9) Furthermore, it is recommended to compare the data of this study population with that of other British populations and individuals of other ethnic origins to further elucidate aetiological mechanism of hypodontia.

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