A Study of the Clinical and Radiographic Outcomes of Root Canal Obturation with Obtura-II System using Thermoplasticised Gutta-percha in Traumatised and Auto-transplanted Teeth

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Dedication

Dedicated to my family

My mum, dad, sisters and brother

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Abstract

Background: Obtura-II injectable thermoplasticised gutta-percha technique has been available for several years. However, thus far, there are no published studies that have evaluated its clinical and radiographic success in non-vital young traumatised permanent incisors in children where teeth are expected to survive for the life-span of the patient.

Aim: Evaluating the clinical and radiographic success of Obtura-II system in the root canals of non-vital young traumatised permanent incisors in children; studying the effect of different demographic and prognostic factors on the success rate of the technique; and investigating the outcome for this technique when used to obturate auto-transplanted teeth in children and adolescents.

Method: This study was a retrospective study evaluating the Obtura-II treatment outcomes. Clinical dental records and periapical radiographs of 667 patients who attended the trauma clinic at the Paediatric Dentistry Department at Leeds Dental Institute during the period 2003–2011 were screened. The obturated teeth were classified as either successful or failure according to criteria developed for this study. Various prognostic factors that could influence the clinical and radiographic outcome of the technique were recorded using a special data extraction proforma. The data were entered into SPSS, with simple descriptive analysis and bivariate analyses conducted subsequently. Furthermore, a logistic regression analysis was carried out with the aim of obtaining the relation between different prognostic factors and the treatment outcomes.

Results: According to the study criteria, 235 cases with 275 non-vital young permanent incisors with various stages of root development were included, in addition to 49 auto-transplanted teeth. The mean age of patients at the time of trauma was 10.2 years. The cases considered clinically successful accounted for 92.7% whilst the cases considered radiographically successful were 85.4% over a mean follow-up period of 51 months for the traumatised teeth. In addition, the clinical and the radiographic success for the auto-transplanted teeth were 97.9% and 93.8%, respectively. The logistic regression analysis showed a significant association between some of the prognostic factors, such as the type of trauma, the duration of $Ca(OH)_2$ dressing, and the quality of obturation and the Obtura-II technique treatment outcomes in treating traumatised teeth. However, none of the factors associated significantly with the treatment outcomes in the cases of the auto-transplanted teeth.

Conclusion: Obtura-II technique in the root canal treatment of the traumatised teeth was considered clinically successful in 92.7% and radiographically in 85.4% of the cases over a long follow-up period. In addition, when treating auto-transplanted teeth, the technique was clinically successful in 97.9% and radiographically in 93.8% of cases.

Contents

List of Tables

List of Figures

List of Abbreviations

B	Unstandardised coefficient
df	Degree of freedom
DREC	Dental Research Ethics Committee
FDI	World Dental Federation, notation system
LDI	Leeds Dental Institute
NRES	National Research Ethic Service
PA	Periapical
PDL	Periodontal ligament
PMT	Premolar Transplant
SD	Standard deviation
SE	Standard error
Sig	Statistical significant level
SPSS	Statistics Package for the Social Sciences
TDIs	Traumatic dental injuries
TPG	Thermoplasticised gutta-percha

Chapter One

Literature Review

1.0 Introduction to Literature Review

With the aid of various available search engines, the relevant published literature has been explored in order to establish a reasonable knowledge about the current views on the use of the thermoplasticised gutta-percha technique for the obturation of root canals as an endodontic treatment modality in children.

1.1 Traumatic Dental Injuries in Children

Trauma has been defined as a reasonably severe, non-physiological lesion to any part of the body. Any thermal, chemical or mechanical lesion affecting the dentition should be analysed as a dental trauma and its effect as a traumatic dental injury (Feliciano and Caldas, 2006). Traumatic dental injury (TDI), which is an irreversible pathology, involves injury to a number of highly specialised cells in the pulp and the supporting structures (Andreasen, 1985). It may exceed dental caries and periodontal diseases as the most significant threat to dental health amongst young children (Chan et al., 2001).

It is well-documented that the maxillary incisor teeth are the most susceptible teeth to traumatic dental injuries. They are more likely to sustain damage mainly as a result of their position. Traumatic dental injuries to anterior teeth account for one-third of all traumatic injuries in boys and one-quarter in girls (Gassner et al., 1999).

It is also well-documented that traumatic dental injuries occur with great frequency in preschool, school-aged children, and young adults, accounting for 5% of all injuries for which people seek treatment (DiAngelis et al., 2012).

Traumatic dental injury in children has been considered a serious public health problem due to its high prevalence, clinical complications and social impact. Because of its high prevalence, traumatic dental injuries account for a high percentage of attendance in paediatric emergency dental services. It has been reported that traumatic dental injuries were the most commonly observed conditions in children attending the after-hours dental emergency services at Children's Hospital of Buffalo at the United States (Majewski et al., 1988). Bhat and Li (1990) highlighted that 75% of all cases of dental trauma treated in the United States hospital emergency rooms were amongst children less than 15 year of age (Bhat and Li, 1990). The emergency dental services at The Royal Belfast Hospital for Sick Children observed that traumatic dental injuries represented 39% of all the emergency cases (Fleming et al., 1991). Similarly, in 2002, Al-Jundi showed that 31% of children who attended emergency clinics in Jordan presented with complications secondary to traumatic dental injuries (Al-Jundi, 2002). In addition to the direct adverse effects of trauma on the children afflicted, there are also indirect consequences both for the children and their families. Several aesthetic and functional alterations could result from traumatic dental injuries, such as fractures, colour alteration, pain, mobility, and in more severe cases, loss of teeth. It has been reported that the children afflicted avoid laughing or smiling, and also have difficulties in speech; these results can adversely affect their social relationships. These children have also reported difficulties in eating, enjoying food and brushing their teeth (Ilma de Souza Cortes et al., 2002). The adverse effects resulting from traumatic dental injuries have negative impact on the quality of life of the children (Fakhruddin et al., 2008). In addition, the management of traumatic dental injuries is a challenging task for the dentist and usually involves a lengthy treatment plan.

Child patients may suffer from emotional stress, pain and discomfort during the treatment period. Furthermore, parents or carers may have to give up their usual commitment in order to take the child in order to receive treatment. In an attempt to reflect the actual societal costs for the management of traumatic dental injuries, both the direct and the indirect time required for the treatment should be included. Direct time is the clinical time spent by the dentist treating the patient, while indirect time is the non-clinical time spent by the patients and the carer in transport and waiting. In Sweden, it has been reported that the average indirect costs associated with managing traumatised permanent teeth in children was £350 per child. In addition, it was shown that the total time involved in the treatment of traumatic dental injuries to children and adolescents was seven times more extensive when adding the indirect time, compared with direct time alone (Glendor et al., 2000). Moreover, in the United Kingdom, it has been estimated that the average cost for treating a young patient with a traumatic dental injury is £856. This estimate was made in consideration to the average number of visits, which was found to be seven (Wong and Kolokotsa, 2004). Finally, in the United States, an estimate of £9,000 has been stated as the lifetime rehabilitation cost, per tooth, for the loss of permanent teeth in children (McTigue, 2000).

1.2 The Prevalence of TDI in Children

Traumatic dental injuries are unfortunately very common amongst children. In a 12-year review of the literature, Glendor (2008) reported that 25% of all school children experience traumatic dental injuries (Glendor, 2008). Furthermore, 33% of adults suffered traumatic dental injuries to permanent dentition, with most of the incidences occurring before the age of 19 years. Many authors have reported the prevalence of TDI in different children populations. The prevalence levels range from 1.8% in Norway (Skaare and Jacobsen, 2003) to 34% in Saudi Arabia (Al-Majed et al., 2001). The difference in the prevalence reported is mainly due to the implementation of different epidemiological methodologies when conducting these studies. In addition, these data reflect different socio-economic, behavioural and cultural diversities (Glendor, 2008). The Children's Dental Health Survey, carried out in the United Kingdom in 1993, showed that one in five children experienced traumatic dental injuries to their anterior permanent teeth before leaving school (O'Brien et al., 1994). In 2003, this survey reported 5% TDIs to permanent incisors at age 8 years and 11% at age 12 years (Chadwick and Pendry, 2003). Nevertheless, the prevalence of traumatic dental injuries may be much higher than those reported in a cross-sectional survey. Similarly, the results of two large national survives in the United States recognised that one in six adolescents showed evidence of traumatic dental injuries (Kaste et al., 1996, Shulman and Peterson, 2004).

1.3 Background Factors associated with TDI in Children

1.3.1 Age

Age is a well-known risk variable. Many studies have reported that the majority of traumatic dental injuries occur during childhood and adolescence.

The peak incidence of TDI in permanent teeth varies between 7 and 10 years of age (Al-Jundi, 2002, Glendor, 2008, Andreasen, 2013); this is due to the fact that this age group is more involved in sports and physical activities, and, as a consequence, more prone to TDI. Furthermore, several prevalence reports from different counties indicate that TDIs occur most frequently in children aged between 10 and 12 years (Hamdan and Rock, 1995, Al-Jundi, 2002). The results of several studies have demonstrated an adverse relation between TDI and age. Traumatic dental injuries reduce in their occurrence with the increase in age. It has been reported that the decrease occurs after 24–30 years of age (Holland et al., 1994, Shulman and Peterson, 2004).

1.3.2 Gender

Many studies in different countries have considered gender to be a well-known risk variable. For a long time, it has been reported in the literature that boys experience traumatic dental injuries significantly more so than girls, with a mostly male–female ratio of 2:1 (Glendor, 2008). This was explained by the higher participation of boys in leisure activities and contact sports. Some studies, on the other hand, have found a gender difference, yet the difference was not statistically significant between boys and girls in the prevalence of TDI (Soriano et al., 2007). On the other hand, some recent studies have indicated changes in the gender prevalence and higher TDI prevalence in girls. This is due to the fact that girls are more involved in sports that were traditionally considered boys' sports (Glendor, 2008, Andreasen, 2013).

1.3.3 Race and Ethnicity

There is no clear relationship between TDI, race and ethnicity. Ethnic minorities live in deprived areas with limited resources and poor financial status, making it difficult to clearly analyse the effects of such factors on the prevalence of TDI.

In a study carried out in the United States, it was recognised that Hispanics and African Americans have a slightly higher prevalence of TDI than Whites. Nevertheless, these differences were not statistically significant (Alonge et al., 2001, Glendor, 2008).

1.3.4 Socio-economic Status

The results available in the literature concerning the association between socio-economic status and the prevalence of TDI are conflicting. In the United Kingdom, Hamilton (1997) reported an inverse relationship between socio-economic status and the prevalence of TDI. Further data from the United Kingdom have shown higher prevalence of TDI in deprived areas, such as 43.8% in Newham, and 34.4% in Bury and Salford compared with an overall 15% recorded TDI in England (Marcenes and Murray, 2001). On the contrary, other studies found higher prevalence of TDI in high socio-economic status. This was explained as children from higher socio-economic status have more access to horse riding, swimming pools and contact sports, as well as having the ownership of skateboards and bicycles (Soriano et al., 2007, Glendor, 2008).

1.4 Aetiology and Predisposing Factors associated with TDI in Children

1.4.1 Aetiology

1.4.1.1 Unintentional Causes of TDI

Falls and Collisions

Results from various studies in the literature have categorised falls and collisions as being the most common causes of traumatic dental injury in children. Due to the lack of experience and coordination, children are at a high risk of trauma, secondary to falls, when they start walking.

Although falls have been stated as the most commonly reported cause of trauma in children and adolescents, the event causing the fall is the actual cause of TDI and what needs to be recorded (Glendor, 2009, Andreasen, 2013).

Sports and Physical Activities

Traumatic dental injuries during teenage years are often secondary to sports. It has been reported that contact sports account for at least one-third of all cases of TDIs in adolescents. According to the Federation Dentaire International (FDI), high-risk sports, such as American football, hockey, rugby and skating are more commonly associated with TDIs as opposed to medium-risk sports (Andreasen, 2013).

Traffic Accidents

Traffic accidents include pedestrian, bicycle and car-related injuries. Traumatic dental injuries secondary to car accidents are seen mainly in late teens (Andreasen, 2013).

Results from the study by Acton *et al*. (1996) have demonstrated that 31% of children under the age of 15 years experienced facial and traumatic dental injuries as a result of bicycle accidents (Acton et al., 1996).

The Presence of illness, Physical Limitations or Learning Difficulties

Epilepsy: Epileptic patients are considered to have a special risk with regard to traumatic dental injuries. In a study conducted by Besserman (1978), 473 epileptic patients were included (Bessermann, 1978). It was found that 52% of these patients experienced TDIs, many of which were of a repetitive nature (Andreasen, 2013).

Cerebral Palsy: Traumatic dental injuries occur in a higher frequency amongst cerebral palsy patients with a percentage of 57% compared with healthy individuals.

It has been reported that the uncontrolled head movement is the major factor increasing the risk of TDIs in this at high-risk group (Glendor, 2009).

Learning Difficulties: It is well-documented in the literature that traumatic dental injuries occur in a high frequency amongst children with learning difficulties. This could be due to several factors, such as a lack of motor coordination, crowded conditions in institutions or concomitant epilepsy (Glendor, 2009, Andreasen, 2013).

Hearing or Visual Impairment: It has been stated in the literature that totally blind children are at a higher risk to traumatic dental injuries compared with sighted or partially-sighted children. Furthermore, children with hearing impairments are at a higher risk of sustaining TDIs than visually-impaired children. This is explained due to the fact that children with hearing impairments have more opportunity to move freely and play than visually-impaired children (Andreasen, 2013).

1.4.1.2 Intentional Causes of TDIs

Physical Abuse and Violence

Physical child abuse is unfortunately not uncommon, and is recognised as a tragic cause of traumatic dental injuries. Data from the United States has revealed that 75% of children subjected to physical abuse and referred to major hospitals suffered injuries to the head, neck, mouth and teeth (Glendor, 2009). Oral and head injuries have been reported as the most common reasons for hospital admission for physically abused children (Andreasen, 2013).

Violence and fights are more common amongst adolescents, and are considered to be a well-known cause of TDIs in this age group. A study including 10,000 children in Iraq and Sudan was carried out with the objective to explore the aetiological factors of TDIs, and stated fights as the second most common cause (Baghdady et al., 1981).

The act of violence was reported more frequently in cities compared with rural areas. In addition, it has been noted that acts of violence increase with age (Glendor, 2009). Finally, Dimitroulis and Eyre (1991), during the course of a 7-year review of maxillofacial trauma in a central London hospital in the United Kingdom, reported that 62% of all injuries to the face were due to assaults (Dimitroulis and Eyre, 1991).

Iatrogenic Procedures

Traumatic dental injuries can result from iatrogenic procedures because of prolonged intubation. Direct pressure during laryngoscopy and intubation could result in different types of TDI. Chadwick and Lindsay (1998) have found that peri-anaesthetic TDIs was the most common anaesthesia-related cause of claims in the United Kingdom (Chadwick and Lindsay, 1998).

1.4.2 Predisposing Factors

It is well known that children and adolescents with increased overjet, protrusion and inadequate lip coverage are at a higher risk of TDI to permanent maxillary incisor teeth.

Moreover, it has been reported that adolescents with overjet greater than 5 mm had a threefold higher risk of TDI to their permanent incisors (Soriano et al., 2007). In addition, Shulman and Peterson (2004) considered the overjet to be the only occlusal covariant significantly associated with TDI after adjusting for age, gender and ethnicity. They also found that the odds of trauma increased markedly as the overjet increased (Shulman and Peterson, 2004).

In their epidemiological study, Soriano *et al*. (2007) found a statistically significant association between inadequate lip coverage and high prevalence of TDI amongst adolescents (Soriano et al., 2007). It has been reported that children with inadequate lip coverage have a fourfold higher risk of TDI compared with those with merely adequate lip coverage (O'Mullane, 1973, Glendor, 2009).

1.5 Types of Traumatic Dental Injury

Traumatic dental injuries in children can result in fracture or luxation of the teeth. These injuries can also occur in combination with injuries to the supporting soft or hard tissues.

1.5.1 Fracture Injuries

Fracture injuries are the most common type of TDI to occur in permanent teeth. The most common reported type of fracture is enamel fracture, followed by uncomplicated crown fracture (Andreasen, 2013).

1.5.2 Luxation Injuries

Luxation injuries are the most common TDI in the primary dentition (DiAngelis et al., 2012). However, they are also common in young permanent dentition owing to the resilient bone in children. Concussion and subluxation are the most common types of luxation injury in permanent teeth, occurring at a frequency of 23% and 21%, respectively. On the other hand, it is well known that intrusion is the least likely to occur in permanent teeth (Andreasen, 2013).

1.5.3 Soft Tissue Injuries

Most TDI cases are associated with injuries to the lip, gingiva and oral mucosa. One-third of all patients treated in dental settings, as well as more than half of all patients treated in hospital emergency settings, secondary to TDIs, suffered a combination soft tissue injury (Andreasen, 2013).

1.5.4 Hard Tissue Injuries

Injuries to hard tissues are usually associated with luxation rather than fracture injuries. The reason for this could be that, in fracture cases, the greatest part of energy of the impact is expended to create the fracture as opposed to being transmitted to the root portion. Some (9%) of hard tissue injuries are categorised as alveolar process fractures. Labial and lingual bone plate fracture accounted for 5% of the cases. Finally, fractures of the mandible or the maxilla account for 2% of the cases (Andreasen, 2013).

1.6 Complications associated with TDIs

Although TDIs are a serious problem and associated with major adverse lifelong outcomes when occurring in children, it is nevertheless a neglected condition. In the literature, it has been reported that most children with TDIs did not seek dental treatment and TDIs remained untreated. In addition, children seek dental treatment following TDIs mainly due to pain and aesthetic reasons (Hamilton et al., 1997, Alonge et al., 2001). In the United Kingdom, it was shown that, amongst children 12 years old and younger who suffered TDIs, only 20% were treated (O'Brien et al., 1994). The delay in providing efficient treatment in the first 24 hours following TDIs adversely reflects on the outcomes and prognosis of the injured teeth (Rock et al., 1974). As a result of delayed treatment and overlooked TDIs in children, Al-Jundi (2002) reported that 12.1% of uncomplicated crown fracture in permanent incisors required root canal therapies (Al-Jundi, 2002).

When it occurs in children, traumatic dental injuries are associated with serious complications. It is recognised that TDIs are the most common cause of the loss of pulp vitality in immature teeth.

Although they might not directly affect the pulp, they may still result in loss of vitality and the cessation of root formation in developing teeth (Rock et al., 1974, Sarris et al., 2008).

The treatment option in children with traumatised immature incisors is mainly pulp therapy, ranging from pulpotomy to complete root canal treatment.

1.7 Immature Permanent Teeth

Root development starts when the enamel and dentine formation reaches the level of the future cemento-enamel junction. The inner and outer epithelial layers, which were separated by the stratum intermedium and the stellate reticulum, fuse together at this stage, forming the cervical loop. As a result, Hertwig's epithelial root sheath develops. The Hertwig's epithelial root sheath is the structure responsible for the development of the root and the epithelial diaphragm that surrounds the apical opening to the pulp, and becomes the apical foramen. As a consequence, Hertwig's epithelial root sheath is responsible for determining the shape of the root. When the differentiation of the radicular cells into odontoblast starts and the first layer of dentine has been laid down, Hertwig's epithelial root sheath loses its continuity and disintegrates. In addition, its remnants persist as an epithelial network of strands or tubules near to the external surface of the root (Rafter, 2005, Kumar and Bhaskar, 2012).

The completion of root development and the apical closure occur approximately three years after tooth eruption. The presence of a vital pulp is a major factor to insure the proper formation of the root in developing teeth. Traumatic dental injuries in young patients can lead to the loss of vitality in developing teeth and the destruction of the Hertwig's epithelial root sheath. Hertwig's epithelial root sheath is very sensitive to TDIs, yet because of its high vascularity and cellularity, root formation can continue irrespective of the presence of necrotic pulp.

It is important in providing a source of undifferentiated cells that can result in further hard tissue deposition and protect against the ingrowth of periodontal ligament cells in the root canal. Yet, if the TDI is severe enough to cause a complete destruction of the Hertwig's epithelial root sheath, the root development will cease resulting in an immature wide open apex root (Rafter, 2005, Kumar and Bhaskar, 2012).

According to a policy document on the management of immature non-vital teeth by the British Society of Paediatric Dentistry (BSPD), the incidence of loss of vitality of immature permanent incisors due to trauma is 6% (Mackie, 1998). In immature non-vital teeth, the necrotic pulp acts as an irritant to the periapical tissues. It is known that the bacteria in the root canal system are the main cause of apical periodontitis (Bakland and Andreasen, 2012). In order to achieve healing of the periodontal tissues and thus to maintain the traumatised immature teeth for the child's life, a complete root canal treatment is required.

Endodontic treatment of immature permanent incisors is a challenging task facing clinicians. These teeth present wide open apices. The apical diameter of the canal can be larger than the coronal diameter resulting in difficult debridement. In addition, the lack of apical stop complicates the obturation procedure, making it, in all diameters, virtually impossible and technically difficult. Finally, the immature teeth have thin dentinal walls of the root canals making them more prone and liable to fracture—even under physiological forces (Al Ansary et al., 2009). Cvek (1992) has explained that the risk of root fracture is quantified by the maturity of root formation; the risk is higher with less mature roots (Cvek, 1992). Furthermore, it was found that 60% of immature endodontically treated teeth had cervical fractures either spontaneously or secondary to minor impacts (Al Ansary et al., 2009).

It is important to carry out a careful assessment in order to establish an accurate diagnosis prior to starting a root canal treatment in the case of immature traumatised incisors in children.

A thorough history-taking, followed by careful clinical examination and appropriate radiographic examination, is essential. The pulpal diagnosis of the traumatised immature teeth can be confirmed by conducting further tests, such as thermal and electrical pulp tests, if possible. Following the establishment of a diagnosis, one of the vital aims of the treatment in these cases is to produce a barrier against which a root canal material can be condensed, preventing its extrusion beyond the apex into the surrounding periapical tissues.

Numerous materials and procedures have been suggested to achieve this aim, such as no treatment, infection control, induction of blood clot in the peri-radicular tissue, antibiotic pastes, calcium hydroxide ($Ca(OH)_2$), and mineral trioxide aggregate (MTA) (Shabahang et al., 1999). The most commonly used are apexification with calcium hydroxide and mineral trioxide aggregate apical plug (Al Ansary et al., 2009). This step is followed by filling the root canal system, utilising a suitable biocompatible obturation material and a technique appropriate in these cases.

1.8 Apexification

According to the American Association of Endodontics' Glossary of Endodontic Terms (2003), apexification is defined as a technique used to induce the formation of mineralised tissues to act as an apical stop in immature permanent teeth with open apices. Many materials have been reported in the literature that can be used to induce apexification. For many decades, calcium hydroxide has been known to be the most widely used material to successfully achieve apexification in immature teeth (Bakland and Andreasen, 2012). Nevertheless, many clinicians in different areas have shifted to using MTA instead.

1.8.1 Calcium Hydroxide Ca(OH)2

Limestone is a natural rock chiefly composed of calcium carbonate ($CaCO_3$). It forms mainly as a result of the crystallisation of calcium carbonate solution existing in mountains and sea water. The combustion of limestone between 900˚C and 1200˚C causes a chemical reaction, resulting in the formation of calcium oxide (CaO). The formed calcium oxide is referred to as quicklime and has a strong corrosive activity. Moreover, when it comes into contact with water, calcium hydroxide forms (Fava and Saunders, 1999).

Calcium hydroxide is an odourless white powder with a molecular weight of 74.08. It is classified as a strong alkaline with a high pH value ranging between 12.5 and 12.8.

It has been stated that calcium hydroxide has a low water solubility of 1.2 g/L at a temperature of 25˚C. Moreover, calcium hydroxide is insoluble in alcohol. This low solubility is of a significant clinical value, as a long period of time is required before calcium hydroxide becomes soluble when in direct contact with tissue fluids (Estrela et al., 1999, Fava and Saunders, 1999).

Calcium hydroxide was first introduced to dentistry by Hermann in 1920 when it was used for pulp-capping. Since then—and mainly after the Second World War—it gained more acceptance, and has been indicated to promote healing in several clinical situations (Fava and Saunders, 1999). Apexification using calcium hydroxide was first introduced by Kaiser in 1964 at the annual meeting of the American Association of Endodontics. He proposed that the induction of a calcific barrier at apices of immature teeth could result from applying a mixture of calcium hydroxide and camphorated parachlorophenol in the canals (Kaiser, 1964). This technique has been popularised and described step-by-step later by Frank in 1966. Frank (1966) described four types of apical closure, and highlighted the importance of reducing the contamination of the root canal system through instrumentation, utilising intra-canal medications, and adequately sealing the root canal.

In addition, he suggested that calcium hydroxide should contact vital tissues in order to facilitate the calcific barrier formation (Frank, 1966). Before the establishment of this technique, the immature traumatised permanent teeth were usually extracted (Rafter, 2005).

In principle, calcium hydroxide paste, which is used in endodontic therapies, is composed of a powder, vehicle and a radio-pacifier. In order to prepare calcium hydroxide paste, the powder should be mixed with a suitable vehicle.

Mixing calcium hydroxide powder with water until reaching the desired consistency is the easiest preparation method; however, many researchers have commented on such a preparation method to yield a paste with poor physic-chemical properties—mainly owing to its high tissue solubility. In order to overcome this problem, it has been recommended that other substances be added to the paste in order to maintain its consistency, flow, high pH, ease of clinical use and its radio-opacity features (Fava and Saunders, 1999).

Calcium hydroxide has been used successfully in the induction of apical calcific barrier in immature non-vital teeth; however, its mechanism of action is still a controversial issue (Rafter, 2005, Yassen et al., 2012). Some researchers believe that the root sheath remains intact and resumes its function again after eliminating the infection in the root canal system (Mohammadi, 2011). Furthermore, others believe that cells of the dental sac around the apex retain their genetic code, facilitating their formation into cementoblast (Klein and Levy, 1974). On the contrary, many studies have found no evidence of any root sheath in any section of the teeth with either partial or complete root closure. In a case reported by West and Lieb (1985), calcium hydroxide apexification was successful in an incisor tooth following its periapical curettage (West and Lieb, 1985). In addition, calcium hydroxide has the ability to prevent the ingress of granulation tissue into the root canal, and inhibits peri-radicular osteoclastic activity.

Bakland and Andreasen (2012) stated that the ability of calcium hydroxide to induce a hard tissue formation is related to its effect in initiating zones of liquefaction and coagulation necrosis next to the apical tissues (Bakland and Andreasen, 2012). In their study of osteogenic potential of calcium hydroxide when implanted in connective tissue of rats, Mitchell and Shankwalker (1958) concluded that calcium hydroxide has a unique potential inducing the formation of heterotopic bone (Mitchell and Shankwalker, 1958). Furthermore, Holland *et al*. (1977) stated that the reaction of periapical tissue toward calcium hydroxide is similar to that of the pulp tissue (Holland et al., 1977). This chemical has the ability to produce a multi-layered necrosis with subjacent mineralisation. It has been postulated that the layer of firm necrosis generates a low-grade irritation of underlying tissue sufficient to produce a matrix that mineralises. Calcium is attracted to the area, which initiates the mineralisation of the newly formed collagenous matrix from the calcific foci (Schröeder and Granath, 1971, Rafter, 2005). It has been stated clearly in the literature that the high pH of calcium hydroxide plays an important role in the formation of calcific apical barrier in immature non-vital teeth. In a comparison study aiming to evaluate the effectiveness of calcium hydroxide (pH of 11.8) and calcium chloride (pH of 4.4) in inducing the formation of calcific apical barrier in pulpless immature monkey teeth, it was concluded that periapical repair and apical barrier formation are more apparent in the presence of calcium hydroxide (Javelet et al., 1985). Moreover, it has been shown that the formation of calcific apical barrier is more clearly observed in the absence of contamination and microorganisms in the root canal system. Most of the pathogenic microorganisms in the root canal system are unable to survive in the highly alkaline environment provided by calcium hydroxide. In addition, the antibacterial activity of calcium hydroxide has been well-established and it is due mainly to the release of hydroxyl ions in aqueous environment. The hydroxyl ions are highly oxidant-free radicals that rarely escape from the site of generation (Freeman and Crapo, 1982).

Finally, their lethal effect on bacterial cells could be due to a different mechanism of action (Siqueira and Lopes, 1999), including the damage to bacterial cytoplasmic membrane (Contran et al., 1999), bacterial protein denaturation (Voet and Voet, 1995), and damage to bacterial DNA (Kontakiotis et al., 1995).

The success rate of apexification using calcium hydroxide ranges between 74 -100%, with an average of 95% (Cvek, 1972, Mackie et al., 1988, Kleier and Barr, 1991, Finucane and Kinirons, 1999, Walia et al., 2001, Dominguez Reyes et al., 2005, Yassen et al., 2012). The time period required to induce the calcific apical barrier ranges considerably between different studies. This calcific apical barrier has been defined as a cap, bridge or ingrown wedge, and may be composed of cementum, dentine, bone or osteodentine (Ghose et al., 1987).

Various factors have been reported to affect the speed of calcific apical barrier formation. Examples of these factors include patient age, apical width, type of injury and the presence of abscess, the presence of periapical radiolucency at the beginning of the treatment, inter-appointment symptoms, and the frequency of changes of calcium hydroxide. Some investigators have reported an inverse relation between the stage of root development and the time required to induce a calcific apical barrier (Yates, 1988, Finucane and Kinirons, 1999, Mackie and Hill, 1999). On the other hand, Ghost *et al.* (1987) and Kleier and Barr (1991) did not find any significant association between the age of the patient, the stage of root development, and the time period required to induce a calcific apical barrier in immature non-vital teeth (Ghose et al., 1987, Kleier and Barr, 1991). Several papers have reported a longer time required to form a calcific apical barrier when the teeth suffered luxation injuries (Mackie et al., 1988, Finucane and Kinirons, 1999, Yassen et al., 2012). Although, the presence of an abscess at the start of the treatment has been reported as a factor associated with prolonged treatment, Finucane and Kinirons (1999) reported that it is the weakest factor affecting the apexification treatment period using calcium hydroxide (Finucane and Kinirons, 1999).

Some studies have also demonstrated that the frequency of changing the intra-canal medicament calcium hydroxide could affect the speed of the calcific apical barrier formation. The frequency of changing calcium hydroxide during the treatment is a controversial issue. Some researchers, such as Chawla (1985) and Chosack *et al*. (1997) believed that a single calcium hydroxide application is enough to induce a sufficient calcific apical barrier (Chawla, 1985, Chosack et al., 1997). On the contrary, Mackie (1998) showed that calcium hydroxide is better to be changed after one month from its initial application, then subsequently at three-month intervals (Mackie, 1998). Ghose *et al*. (1987) advised a change of calcium hydroxide after one month, and then 6–8 months until the calcific apical barrier is evident (Ghose et al., 1987). Similarly, Finucane and Kinirons (1999) found that the frequency of changing calcium hydroxide is the strongest predictor factor in inducing calcific apical barrier (Finucane and Kinirons, 1999).

Cvek (1972) believed that calcium hydroxide should only be replaced if symptoms develop during the period of treatment, or otherwise if there is radiographic evidence that calcium hydroxide has been washed away from the root canal system before the final development of calcific apical barrier (Cvek, 1972). Finally, in a recent study investigating the effects of different factors on the frequency of changing calcium hydroxide, it was concluded that there is no significant difference between different operators of various clinical training levels (Yassen et al., 2012).

Despite the fact that calcium hydroxide is available widely, is an inexpensive dental material, and is easy to use with high success rates in apexification of immature non-vital teeth, calcium hydroxide has some inherent disadvantages that have been highlighted in various studies. This technique is considered a time-consuming treatment requiring multiple visits over a long period of time. The time required to form a calcific apical barrier ranges from between 6 and 18 months, with an average of 9 months (Bakland and Andreasen, 2012). Patient compliance may be lost during the treatment period.

In addition, the temporary restoration could also be lost at any point during the treatment, thus elevating the risk of bacterial contamination and reducing healing susceptibility. Moreover, it is well-documented in the literature that the long-term exposure to calcium hydroxide can weaken the dentine and increase the risk of root fracture. The main reason for this could be attributed to the proteolytic capacity of calcium hydroxide in the desiccation of dentinal protein (Andreasen et al., 2006). In a 4-year retrospective clinical study evaluating the prognosis of luxated non-vital immature teeth treated with calcium hydroxide apexification, Cvek (1992) reported a 40% cervical root fracture amongst 885 teeth (Cvek, 1992). In addition, in an *in vitro* study carried out on sheep teeth, a significant reduction in the fracture resistance (22%) was noticed in the long-term (3 months and more) use of calcium hydroxide (Andreasen et al., 2006).

1.8.2 Mineral Trioxide Aggregate (MTA)

Mineral trioxide aggregate (MTA) is a biomaterial that was first investigated for endodontic applications in 1990. It was not until 1993 when MTA has been first described in the dental literature. Moreover, this material was approved by the Food and Drug Administration (FDA) in 1998 to be used as an endodontic treatment material (Lee et al., 1993, Rafter, 2005). MTA has several clinical applications in the endodontic field, such as its use in pulpotomy, pulpectomy, root canal filling material, to repair perforations, and as a pulp capping material. In addition, it has been used to induce an apical barrier in immature permanent teeth prior to obturation.

MTA was first introduced as a grey material; however, owing to its discolouration potential, white MTA was developed (Kratchman, 2004). Several studies have shown that white MTA has lower amounts of iron, aluminium and magnesium compared with grey MTA (Asgary et al., 2006; Parirokh and Torabinejad, 2010b).

In addition, qualitative surface analysis showed that the crystal size of grey MTA is approximately 8 times larger than the white ones (Asgary et al., 2006). Furthermore, it has been demonstrated from the map images that oxygen is distributed throughout both crystalline and amorphous phases of grey and white MTA; therefore, all elements are presented in their oxide form, and MTA is marketed in both white and grey forms (Asgary et al., 2006). However, even white MTA has been demonstrated to cause discolouration due to the presence of bismuth oxide in both grey and white MTA, an ingredient used to make the material more radiopaque.

MTA consists of a mineral powder containing tricalcium silicate, tricalcium aluminate, tricalcium oxide, and other mineral oxides. It shares several similarities in its chemical composition with Portland cement; however as mentioned above, MTA contains bismuth oxide, which does not exist in Portland cement, and it is the element giving MTA its higher degree of radio-opacity (Torabinejad et al., 1995).

A colloid gel forms when MTA powder is mixed with sterile water in a 3:1 ratio of powder to liquid. This gel has the ability to solidify and form a hard structure in a mean time of 3–4 hours (Parirokh and Torabinejad, 2010a). It has been reported that MTA has antibacterial and antifungal properties, which is due mainly to its high alkalinity. MTA has a pH of 12.5, which activates the alkaline phosphatase and induces antibacterial activity (Pradhan et al., 2006). Moreover, studies regarding MTA solubility have reported low tissue solubility of the material (Torabinejad et al., 1995).

Although MTA has been used a relatively a long period of time, there remains a limited body of clinical studies showing favourable results comparable with or superior to calcium hydroxide apexification in immature permanent teeth (Sarris et al., 2008). However, MTA has been confirmed to be a biocompatible material with hard tissue conductive and inductive properties, with several advantages over calcium hydroxide.

Several *in vitro* studies have evaluated the biocompatibility of MTA and compared it to calcium hydroxide, with most of these studies drawing the conclusion that MTA has a histological ability in periodontal ligament regeneration similar to calcium hydroxide (Felippe et al., 2006, Panzarini et al., 2007). One of the main advantages of MTA is its ability to reduce the treatment time to induce apical barrier in immature teeth. When using MTA, an apical barrier could be induced in a single visit compared with the multiple visits when calcium hydroxide is used. In addition, MTA helps in avoiding the disadvantages associated with the delay in placing a definitive coronal seal. Moreover, it avoids the changes in the mechanical properties of the dentine caused by the prolonged application of calcium hydroxide. As a consequence, MTA reduces the risk of root fracture associate with endodontically treated teeth.

Recently, several studies have supported the use of MTA in inducing an apical barrier than calcium hydroxide, with favourable results showing when this technique was applied.

Sarris *et al*. (2008) evaluated the success rate when a single visit apexification was conducted. After evaluating 17 non-vital immature permanent incisors in children, the success rate was found to be 94% (Sarris et al., 2008). In addition, Simon *et al*. (2007) prospectively evaluated the outcome of MTA apical barrier in 57 immature teeth. Patients were followed for a period ranging between 6 and 36 months. It was found that 81% of the cases had a reduction in the pre-operative periapical lesions (Simon et al., 2007). Similarly, Mente *et al*. (2009) reported a healing of 78% of periapical radiolucency when using MTA plug in their retrospective study (Mente et al., 2009). Finally, Albadri *et al*. (2012) showed in their case series three individual cases in which MTA was used as apical plug in immature teeth in children. After 12 months’ follow-up, all cases showed the resolution of the periapical areas radiographically. They confirmed results of their report that MTA provides a viable alternative to achieve apical barrier in immature teeth even those with a very wide open apices (Albadri et al., 2012).

Despite all the aforementioned advantages of using MTA in inducing an apical barrier, some drawbacks of this material nevertheless have been highlighted in the literature. It has been noted that MTA has a discolouration potential. Although white MTA has been introduced with the aim of overcoming the discolouration problem induced by grey MTA, it remains that both white and grey have been shown to have the potential of discolouration. Another disadvantage could be the difficult handling of the material. Some researchers have reported that the handling of MTA is not easy, and that special practice is required. Furthermore, Pitt Ford *et al*. (2007) indicate that some dental students in the United Kingdom do not have the opportunity to work with MTA before they qualify (Pitt Ford et al., 2007). The high cost of MTA has been highlighted as one of the major disadvantages. In a survey carried out in the United Kingdom, it has been found that 63.6% of the consultants in paediatric dentistry were concerned with the cost of MTA and the special instruments required for the procedure of producing apical barrier (Mooney and North, 2008). Moreover, a recent study indicates that MTA may have a weakening effect on the dentine. In conclusion, with the knowledge available surrounding MTA, it seems necessary to conduct more clinical long-term studies with the objective to evaluate this material in producing an apical barrier in immature non-vital teeth.

1.9 Thermoplasticised Gutta-percha (TPG)

The root canal system is complex with various anatomical variations, including fins, deltas, isthmuses, accessory and lateral canals. In addition to these variations, the immature permanent incisors present with wide open apex and thin dentinal walls. When these teeth are traumatised and necrotic accordingly, a communication between the oral bacterial flora, the root canal system and the periapical tissues occurs. It has been reported that the bacteria in the root canal system are the main cause of apical periodontitis.

In order to preserve these teeth and to achieve the healing of the periodontitis, a combination of chemomechanical disinfection and a good obturation is required. An adequate three-dimensional obturation is a key factor in successful endodontic treatment. It has been stated that incomplete obturation of the root canal system can ultimately lead to endodontic failure. Approximately 60% of reported failures in endodontic cases can be attributed to incomplete obturation of the root canal system (Ingle and Bakland, 2002).

Several materials have been used to obturate root canal systems. The ideal obturation material should be biocompatible, insoluble in tissue fluids, manipulated easily, radiopaque, stable, and adaptable in root canal irregularities (McElroy, 1955). Gutta-percha is the most commonly used obturation material. Owing to its physical and chemical properties, Gutta-percha is considered an ideal obturation material used in different obturation techniques. Gutta-percha was first introduced by Bowman in 1867 (Anthony and Grossman, 1945). It is a natural product consisting of a purified coagulated exudate of mazer wood trees from Malay Archipelago or from South America. Gutta-percha is a reddish-tinged grey translucent material with a high molecular weight.

In addition, it is solid and ridged at room temperature. Although the composition of gutta-percha varies considerably between different manufacturers, there are main elements essential to present in all different commercial gutta-percha types. These elements include 18–22% gutta-percha as matrix, 59–76% zinc oxide as filer, 1–4% waxes or resins as plasticiser, and 1–18% barium sulphate as a radiopaque material. Finally, there are two different forms of gutta-percha relevant to dentistry α- and β-form: the β-form gutta-percha is less brittle than the α-form, and is used in most gutta-percha cones; on the contrary, α-form has better flow characteristics and therefore is used more in injectable products (Bergenholtz et al., 2009).

There are different obturation techniques that can be used in order to achieve a good root canal treatment. For a long period of time, lateral condensation had been known to be a very popular and clinically effective obturation technique. In addition, it was the obturation technique taught in most dental schools. Cailleteau and Mullaney (1997) reported that lateral condensation is the obturation technique taught in 89.6% of the United States' dental schools (Cailleteau and Mullaney, 1997). Despite its advantages and popularity, some researchers have commented on the disadvantages of this technique in their studies. It has been reported that the lateral condensation technique lacks, for example, the ability to adequately obturate the root canal system in three dimensions. Lateral condensation produces numerous irregularities and lacks a homogenous mass of gutta-percha. Some voids may be created due to the use of spreaders and accessory cone, with such voids either remaining empty or becoming filled with sealer (Brayton et al., 1973, Goodman et al., 1981, Budd et al., 1991).

In order to overcome the drawbacks of lateral condensation, researchers introduced other obturation techniques. Thermoplasticised gutta-percha was first introduced by Schilder in 1967, who obtained the warm vertical compaction technique, aiming for a three-dimension obturation of the root canal system.

The vertical compaction technique has been defined as the technique providing apical control similar to lateral condensation whilst providing homogenous, three-dimensional obturation advantages of the thermoplasticised gutta-percha (Schilder, 2006). Studies have shown that this technique can optimally fill the root canal system, the accessory canals in the middle and the apical thirds, in addition to the apical deltas. Furthermore, it requires a microfilm of sealer surrounding the homogenous bulk of the gutta-percha. Despite its advantages, some studies have reported various drawbacks of this technique. This approach could be time-consuming. In addition, when improper plungers are used, excessive condensation pressure could be applied, consequently resulting in higher chances of vertical root fracture (Lugassy and Yee, 1982).

One of the most obvious disadvantages of this technique is the need for an open flame to heat the heat carrier before thermoplasticising the gutta-percha in the canals. Smith *et al*. (2000) reported that the deeper the heat penetration during the warm vertical condensation of gutta-percha, the better the three-dimensional obturation of the root canal space (Smith et al., 2000). Hand *et al*. (1976) conducted a study on the effects of warm gutta-percha technique on lateral periodontium. They stated that heating an instrument in this manner was inconsistent, and had the potential to attain a temperature of 380˚C at the time of insertion to the root canal system. Moreover, this process could lead to procedural accident and injury to the dentist, as well as to the patient's lip or periodontal ligament (Hand et al., 1976).

Yee *et al*., in 1977, were the first to introduce the usage of injectable thermoplasticised gutta-percha as an alternative obturation technique to overcome the disadvantages of other old techniques. Their study was carried out in two different stages: the initial work was directed toward the selection of the needle, temperature required for plasticising dental gutta-percha, and the pressure necessary for generating the flow of the heated gutta-percha, with their laboratory experimentation coming to a conclusion that unstrained flow of gutta-percha could be repeatedly achieved through an 18-gauge needle with a pressure syringe heated to 160˚C. The second stage of this preliminary study was an *in vitro* evaluation of the thermoplasticised gutta-percha as an endodontic obturation technique, which was an approach implemented on freshly extracted human incisor and premolar teeth. Obturation was performed with and without the use of sealer. Moreover, the quality of injectable thermoplasticised gutta-percha was evaluated radiographically and visually through the application of the dye-penetration technique. The results of this study demonstrated that effective root canal obturation could be accomplished with injectable thermoplasticised gutta-percha. The syringe technique also offered potential advantages, such as the following: a simpler method for introducing sufficient gutta-percha to fill the canal and the deposition starting at the apex.

In addition, this technique helped in terms of achieving the reduction in chair-side time because the syringe could be prepared by the assistant, as well as when considering the reduction in the amount of manipulative procedures necessary for condensation of gutta-percha (Yee et al., 1977).

Since the introduction of injectable thermoplasticised gutta-percha aiming to improve the obturation-related outcomes of the prepared root canal system, various studies have evaluated this technique from several different perspectives. The technique has been evaluated both scientifically and clinically, with the data for most of these studies favouring its usage. On the other hand, the injectable thermoplasticised gutta-percha technique has never been evaluated in children, although it is fairly commonly used in the obturation of immature permanent incisors in this age group. In addition, despite all its advantages, Abou-Rass (1984) highlighted some of the injectable thermoplasticised gutta-percha disadvantages, criticising the technique regarding its lack of material control, excessive canal enlargement to accommodate the injection needle, and the lack of measurement guidelines to monitor the progress of the filling procedure. Furthermore, the rapid cooling of the material resulting in poor condensation and voids (Abou-Rass, 1984). It has been highlighted in the literature that any method manipulating gutta-percha using heat will result in some shrinkage ranging between 1-2% of the material. This is due to the fact that gutta-percha undergoes phase transition when heated from beta to alpha phase at around 46 ˚C. At a range between 130 ˚C to 140 ˚C an amorphous phase is reached. When cooled at a slow rate the material will recrystalise to alpha phase. Nevertheless, this is not easy to achieve and usually under normal conditions the material returns to the beta phase. The softening point of gutta-percha was found to be 64 ˚C. The phase transformation is important in the thermoplastic obturation techniques (American Association of Endodontics, 2009). Compaction with spreaders, condensers or carriers is usually required to overcome the shrinkage disadvantage of the thermoplasticised gutta-percha technique (McElroy, 1955).

Furthermore, thermoplasticised gutta-percha has a potential for equipment-related problems, such as needle breakage or gutta-percha leakage, and the presence of under condensed, slender filling in apical third of the canal, were some of the highlighted drawbacks of the technique (Abou-Rass, 1984).

Moreover, the injection of high heat material into the root canal system has also been cited as one of the disadvantages (Michanowicz and Czonstkowsky, 1984, Czonstkowsky et al., 1985). In order to overcome these drawbacks, several injectable thermoplasticised gutta-percha methods have been established since introducing the idea of this technique. One of the most popular and superior techniques is the high-temperature thermoplasticised gutta-percha system (Obtura-II, Obtura Spareran, Fenton, MO).

This system consists of a control unit—a handheld gun containing a chamber surrounded by a heating element into which a pellet of gutta-percha is loaded, and heated to a temperature of a minimum of 160˚C. When plasticised, the gutta-percha is injected through a silver needle into the prepared root canal (Lipski, 2006). The superiority of the Obtura-II technique, when compared with other obturation techniques from several different aspects, has been cited in various studies (Budd et al., 1991). However, this technique has never been evaluated when used clinically as a root canal filling technique in immature permanent incisors in children.

1.9.1 Temperature Produced by Obtura-II TPG Technique

It has been acknowledged that the heat produced during thermoplasticised gutta-percha techniques increased the flow of the obturation material and subsequently produced a homogenous and well-adapted root canal filling (Budd et al., 1991, Weller and Koch, 1995). Nevertheless, concerns have arisen regarding the possible detrimental effects of the high temperature produced during obturation in the root canal and on the root surface (Czonstkowsky et al., 1985). The heat generated in the root canal system can dissipate through the root dentine and adversely affect the cementum, the periodontal ligament and the alveolar surrounding bone (Atrizadeh et al., 1971). Up until the present date, the actual time–temperature relationship that leads to irreversible damage to the attachment apparatus has not been determined.

However, generally, it is accepted that the temperature rise of approximately 10˚C above normal body temperature is the most critical and causes damage to the tooth's surrounding structures. In addition, this elevated temperature of 47˚C should be maintained for an extended period of time in order for the damage to occur (Eriksson and Albrektsson, 1983).

The Obtura-II injectable thermoplasticised gutta-percha is a high-temperature injection delivery system. It has an adjustable temperature setting on the control unit. The working temperature of the gutta-percha can be increased to a maximum temperature of 200˚C. According to the manufacturer’s recommendations, it is best to set the temperature to approximately 185˚C (Obtura II Operator's Manual, 1993).

Molyvdas *et al*. (1989) conducted an *in vivo* study to evaluate the possible histological effects of heat transmission to the periodontal tissues when using the Obtura system in the root canal treatment. Two healthy 8-month-old beagle dogs were used. Thirty-six completely formed intact incisor and premolar teeth with 56 canals were used. Teeth were divided into two groups: the control group received an endodontic treatment with the traditional lateral condensation technique with sealer; Obtura without sealer was utilised in the treatment group. The treatment was conducted under general anaesthesia. An observation period of 1, 3, 7, 28, and 56 days took place. The researchers conducted a radiographic examination prior to the histological examination, which revealed no adverse changes in the periodontal ligament and surrounding bone in both groups. Similarly, light microscopic examination showed an intact founding alveolar bone, roots and periodontal ligament on the sides of all teeth in both groups. On the contrary, histological examination showed inflammatory changes and the destruction of the collagen, which was localised at the apical foramen areas in Obtura group in all observation periods. However, in the 56 days' observation period, this destruction was noticed only in two instances, indicating the progress of periapical healing. Researchers concluded that the observed injuries were caused by the heat generated by thermoplasticised gutta-percha obturation technique (Molyvdas et al., 1989).

Weller and Koch (1995) conducted an *in vitro* study to measure simultaneously the temperature within the root canal system and on the root surface when using Obtura-II technique.

In this study, the gutta-percha was heated to 160˚C, 180˚C and 200˚C, and injected into a prepared canal. The split-tooth temperature measurement system was used in this investigation. This system is unique as both intra-canal and root surface temperatures were recorded at the same time. Moreover, this system allowed the repeated obturations of the same root canal so as to achieve a direct comparison of the obturation technique at the different temperature settings. It has been recorded that the mean intra-canal temperature ranged 40.21˚C–57.24˚C. In addition, the mean root surface temperatures ranged from 37.22˚C to 41.90˚C for all three temperatures tested. The results of this study indicate that the temperature on the root surface was below the critical level; therefore, it should not cause damage to the periodontal ligament and surrounding bone (Weller and Koch, 1995).

Sweatman *et al*. (2001) measured the temperature changes *in vitro* within the root canal and on the root surface at different radicular levels using three different thermoplasticised gutta-percha techniques. Three human maxillary central incisors were obturated with three different thermoplasticised gutta-percha techniques, namely Obtura-II, system B, and ultrasonic lateral condensation. The Obtura-II system was set on a temperature of 185˚C, with the tip of 23-gauge needle placed 4–5 mm from the working length. Sealer was used with the three different techniques. The split-tooth temperature measurement system and a computer to record the thermocouple temperature were used similar to that used by Weller and Koch (1995) due to the high accuracy of the technique in detecting the change in temperature. Investigators recorded the temperature two minutes before and following the obturation at 0.5 seconds intervals at each thermocouple for the three different techniques. They concluded that, through the use of any of the three thermoplasticised gutta-percha techniques, the rise in temperature in the root canal and on the root surface was within safe limits (Sweatman et al., 2001).

Lipski (2006) conducted an *in vitro* infrared thermographic assessment of the root surface temperature generated by Obtura-II technique. Thirty extracted human teeth (15 maxillary incisors and 15 mandibular incisors) were used. The teeth were obturated using Obtura-II technique that was set on 160˚C; sealer was also used. The temperature changes on the outer surfaces of the roots were measured using an infrared thermal imaging camera. Investigators have found a raise in temperature of 8.5˚C in the maxillary central incisors, which was below the theoretical critical level and therefore did not cause any damage to the supporting tissue structures (Lipski, 2006). Similar findings were obtained when Obtura-II was set on 160˚C to 200˚C and tested *in vitro* on maxillary central incisors and premolars (Lipski, 2003). On the other hand, when Obtura-II was used in the case of mandibular central incisor, an elevation of the root surface temperature by more than 10˚C was reported. Due to the fact that mandibular incisors have relatively thin dentinal walls compared with central incisors and premolars, investigators suggested that the heat transfer was dependent on the remaining radicular dentine. Finally, caution should be experienced when using Obtura-II technique to fill teeth with thin remaining dentine walls (Lipski, 2006).

Various factors that can affect the temperature change on the external root surfaces have been highlighted in the literature. The amount of the remaining dentine thickness is one of the most important factors. It has been reported that dentine is considered a good insulator, and that the thicker the dentine, the less heat is transferred to the external root surface. Moreover, the diameter of the root canal is another vital factor. Studies have shown that a higher temperature was recorded at the root surface in the areas of largest root canal diameter (Weller and Koch, 1995). Finally, Hardie (1986) and Barkhordar *et al*. (1990) stated that the root canal sealer acts as an insulator and lowers the external surface temperature changes by 1˚C–2˚C compared with the use of thermoplasticised gutta-percha without sealer (Hardie, 1986, Barkhordar et al., 1990).

1.9.2 Apical Sealing Ability of Obtura-II TPG Technique

Root canal obturation is intended to prevent the microorganisms and toxins in the canal from passing along the root canal space into the periapical tissues (Nguyen, 1994). An adequate complete obturation is an important key to achieving a successful root canal treatment. In addition, it has been stated in the literature that most of the reported endodontic failure cases are secondary to incomplete obturation of the root canal system (Ingle and Bakland, 2002). Due to the variation in the anatomy of the root canal system, obturation is not always a straight-forward step to conduct. In order to facilitate this step, advances in technology have led to the investigation and the implementation of several obturation techniques. Yee *et al*. (1977) was the first to introduce injectable thermoplasticised gutta-percha. In their study, the sealing ability of this technique has been evaluated *in vitro* with the use of the dye-penetration method. They concluded that the thermoplasticised gutta-percha obturation technique adapted well to the root canal walls and has a good sealing ability (Yee et al., 1977).

Bradshaw *et al*. (1989) conducted an *in vitro* study in order to compare the sealing ability of the traditionally used obturation technique lateral condensation to the Obtura technique. The root canals of 120 single rooted teeth were divided randomly into 12 subgroups. Four operators each filled three of these subgroups; one group with lateral condensation, one with thermoplasticised gutta-percha with sealer, and one with thermoplasticised gutta-percha without sealer. The root canal fillings were assessed both radiographically and with the dye-penetration test to investigate the leakage. The results showed that lateral condensation had a better sealing ability compared with thermoplasticised gutta-percha, which was associated with many voids; however, the sealing ability was significantly higher when the sealer was used. In addition, it was clear from the results that there was great variation between operators in those groups where thermoplasticised gutta-percha was used. The lowest sealing results were associated with the less-experienced operator.

This study suggested that, when thermoplasticised gutta-percha was to be used in endodontic treatment, it should be combined with sealer to achieve better sealing results. In addition, the operator should practice the Obtura technique well before employing it clinically (Bradshaw et al., 1989). The results confirm the opinion of Gutmann and Rakusin (1987), who stated that clinicians should take time to master the Obtura technique before employing it in the treatment of their patients as it is a highly sensitive technique (Gutmann and Rakusin, 1987).

In their *in vitro* study, Veis *et al*. (1994) evaluated the apical leakage of root canal filling material after *in situ* obturation with thermoplasticised gutta-percha and lateral condensation. Thirty single-rooted teeth, which were due to be extracted for orthodontic or periodontal reasons, were divided randomly into two groups: Group A were obturated with thermoplasticised gutta-percha; Group B with lateral condensation. These teeth were extracted 15 days following obturation and were immersed in India ink for three days, with the leakage determined using the area-metric analysis. The roots were sectioned transversely, with each section photographed with a stereoscopic microscope under the same magnification. After obtaining a non-parametric analysis, researchers found no significant differences in the sealing ability between the two obturation techniques. However, thermoplasticised gutta-percha technique showed superior results in most of the obturated root canals (Veis et al., 1994).

Hate *et al*. (1995) evaluated the sealing ability of different thermoplasticised gutta-percha techniques through the application of a new method by comparing the adaptation between the canal wall and the gutta-percha at different levels from the apex. Gaps between the gutta-percha and the prepared canal walls were filled with resorcinol-formaldehyde resin, with the ratio of resin to filling used as the basis for statistical comparison. Notably, 159 extracted single-rooted maxillary human teeth were instrumented and randomly divided into nine groups of 17 teeth each and six control teeth. Experimental groups were obturated with thermafil, Obtura-II, ultrafil regular set, and ultrafil firm set gutta-percha, each with and without root canal sealer.

Moreover, the control group was obturated with lateral condensation technique with sealer. These teeth were sectioned horizontally and examined under stereomicroscope with uniform magnification. The results revealed no significant difference in the mean leakage area at the same level for the different obturation techniques. However, the leakage was significantly less when the sealer was used (Hata et al., 1995).

Johnson and Bond (1999) carried out an *in vitro* study with the objective to compare the dye leakage between canals backfilled in a single increment and canals filled in multiple increments using Obtura-II system with two different sealers. Sixty extracted single canal teeth were divided into 4 groups in which they were obturated either with single increment or with 4–5 mm increments. Roth 801 and AH26 sealers were used. Following obturation, the teeth were immersed in Perlikan ink for 5 days and the dye penetration was measured on four surfaces of each root. All groups showed excellent sealing ability, without any presence of statistically significant differences in the dye leakage between the four groups. Investigators concluded that it may be clinically acceptable to backfill canals up to 10 mm in a single increment using sealer and Obtura-II gutta-percha technique (Johnson and Bond, 1999).

In order to evaluate the apical sealing abilities of three different root canal obturation techniques, Vizgirda *et al*. (2004) conducted an *in vitro* study using 60 bovine incisors with single canals. The teeth were prepared and divided randomly into 3 groups of 20 teeth obturated with lateral condensation, thermoplasticised gutta-percha or mineral trioxide aggregate. The teeth were immersed in 1% methylene blue dye for 3 days. Under stereomicroscopy, the linear extent of the dye penetration was measured. It was found that teeth obturated with lateral condensation or Obtura-II technique showed significantly less apical dye penetration compared with those obturated with MTA. Therefore, lateral condensation and Obtura-II system provided an apical seal superior to MTA (Vizgirda et al., 2004).

1.9.3 Coronal Sealing Ability of Obtura-II TPG Technique

Coronal leakage has been recognised as an important cause of failure of root canal treatment (Saunders and Saunders, 1994). Torabinejad *et al*. (1990) found that, when endodontically treated teeth are exposed to bacteria coronally, they become contaminated apically (Torabinejad et al., 1990). Furthermore, it has been shown that the coronal seal is critical in terms of achieving a successful endodontic treatment, and may be as important as the obturation itself to prevent the leakage (Ray and Trope, 1995). Few studies in the literature have centred on the evaluation of the coronal sealing ability of Obtura-II technique; most of these were conducted *in vitro*. However, the results showed a considerable sealing ability—either similar or superior to other obturation techniques.

McRobert and Lumley (1997) assessed the coronal leakage with three gutta-percha backfilling techniques. After chemo-mechanical preparation, 46 mandibular premolars were assigned to 4 experimental and two control groups. Ten teeth were obturated using lateral condensation technique and 30 were obturated apically using system B. The latter 30 teeth were backfilled using either Obtura-II, system B or alphaseal. The remaining six teeth served as controls. Teeth were examined radiographically with the aim of evaluating the presence of voids. Later, teeth were placed in India ink for 65 hours, and the coronal leakage was quantified by linear measurement of ink penetration. Results revealed no statistically significant differences between the four groups radiographically. On the other hand, Obtura-II and system B showed significantly less dye leakage compared with Alphaseal and lateral condensation techniques (McRobert and Lumley, 1997).

Similarly, Jacobson *et al*. (2002) conducted an *in vitro* study in order to compare the coronal bacterial leakage between lateral condensation and system B continuous wave with Obtura-II backfilled obturation technique. An anaerobic bacterial leakage model was used.

The findings garnered suggested that microbial coronal leakage occurred more quickly when using lateral condensation than with system B continuous wave of condensation and Obtura-II backfill (Jacobson et al., 2002).

1.9.4 Adaptation Ability of Obtura-II TGP Technique

One of the main reasons for investigating thermoplasticised gutta-percha was to develop an obturation technique that can adapt well to the three-dimensional configuration of the root canal system and replicate its intricacies. Several studies have shown the excellent adaptation of thermoplasticised gutta-percha and its ability to replicate the irregularities of the root canal system (Marlin et al., 1981, Budd et al., 1991, Gutmann, 1993). Researchers have also shown that the adaptation of this technique is either equal or superior to other traditional obturation techniques, mainly when the root canal sealer is used. Sealer has become considered a vital factor in improving the adaptation and sealing ability of thermoplasticised gutta-percha Obtura-II technique (Gutmann, 1993).

Weller *et al*. (1997) conducted an *in vitro* study with the aim of comparing the ability of three types of Thermafil obturators, Obtura-II thermoplasticised gutta-percha and lateral condensation technique to obturate a standardised root canal. A split-tooth model was constructed, with the root canal obturated 20 times with each technique. Special criteria were set to grade the adaptation of each technique to the root canal system. Analysis revealed variations in the adaptation between different techniques. Moreover, Obtura-II technique demonstrated the best adaptation to the prepared root canal (Weller et al., 1997).

In a study to evaluate the ability of gutta-percha and resilon to fill simulated lateral canals by using the Obtura-II system, Tanomaru-Filho *et al*. (2012) used 45 extracted human single-rooted teeth. Teeth were prepared, and simulated lateral canals were made at three different levels of the length of the root. Following obturation and decalcification, the specimens were analysed with the use of digital radiography and photographs. Researchers concluded that gutta-percha and resilon were solid core materials with lateral canal filling abilities when used alongside the Obtura-II system (Tanomaru-Filho et al., 2012).

1.9.5 Clinical and Radiographic Evaluation of Obtura-II TPG Technique

Obtura-II thermoplasticised gutta-percha has been developed and available as an alternative obturation technique to the traditional ones for several years. It has been evaluated *in vivo* and *in vitro*, and results have supported its superiority over other obturation techniques. However, very few studies have been found in the literature evaluating the clinical and radiographic healing of teeth obturated using this technique.

Marlin *et al*. (1981) conducted the first clinical study in order to evaluate the outcome of root canal treatment using Obtura thermoplasticised gutta-percha technique. The healing of 125 cases was evaluated on the basis of clinical and radiographic findings 6 and 12 months post-operatively. All patients were reported as being comfortable clinically. This preliminary report suggested that the Obtura technique success rate was comparable with the rate achieved with conventional techniques. Moreover, it has been found that there was an obvious reduction of chair time when utilising this technique, which therefore could lead to a reduction in the cost of endodontic treatment (Marlin et al., 1981).

In a clinical study, Sobardo-Navarro (1991) evaluated the success of endodontic treatment of 41 human teeth with 71 closed apices root canals that were obturated with Obtura technique. The patients were recalled 6 and 36 months postoperatively. All obturated teeth were evaluated both clinically and radiographically. The investigator reported a success rate of 93% when the Obtura technique was used. In addition, the author stated that clinicians should be well-trained and familiar with the Obtura technique in order to achieve good outcomes (Sobarzo-Navarro, 1991).

Tani-Ishii and Teranaka (2003) evaluated the clinical and radiographic healing of 236 endodontically treated teeth (82 molars, 97 premolars, and 57 anteriors) in 131 cases obturated with Obtura-II system. One operator performed all canal preparation and obturation.

The root canal sealer was used in all cases. The clinical symptoms, periodontal conditions and radiographic findings were evaluated at 3, 6 and 12 months. A comparison was carried out between the radiographs taken immediately post-obturation and the recall radiographs. Furthermore, the final root filings have been classified, based on their length, into three groups, namely short (more than 2 mm short of the apex), flush (within 2 mm), and long (beyond the apex). Results have shown that 12.7% of obturated cases were short, 81.4% were flushed and 5.9% were long. The reported success rate of treatment utilising Obtura-II system was 96% with no statistically significant differences between the three groups (Tani-Ishii and Teranaka, 2003).

It was concluded from this study that Obtura-II was an excellent obturation technique that accounted for a high clinical success rate. In addition, the root-filling excess when using Obtura-II system had no impact on the healing process of the periapical lesions. There was a significant reduction in the size of the preoperative periapical lesions in the over-filled cases after 12 months. Therefore, the treatment outcome for cases with apical periodontitis was not dependent on the level of root filling in relation to the root apex.

The above summarised studies were preliminary clinical studies evaluating the outcome of Obtura-II thermoplasticised gutta-percha technique. Two studies were carried out early when the technique was newly introduced (Marlin et al., 1981, Sobarzo-Navarro, 1991). Although both studies reported a high clinical success rate, the clinical success criteria were not very clear. Moreover, these studies included different types of adult teeth of wide range of pre-operative diagnoses. As a consequence, it was not possible to compare the results of these studies. In addition, none of these studies evaluated Obtura-II technique in premature non-vital children's teeth. Finally, all the clinical studies did not comment on the Obtura-II outcomes in the long-term as the follow-up period ranged from between 6 and 12 months post-operatively.

1.10 Factors Affecting the Endodontic Treatment Success

For a long period of time, several studies have been carried out with the objective to determine the success and/or failure of endodontic treatment. In addition, some of these studies have investigated the factors that could affect the outcome of the endodontic treatment. Strindberg (1956) conducted the first scientific evaluation of endodontic treatment, and emphasised the importance of establishing criteria to determine the success of these treatment. This work was the foundation based upon which several studies had set their endodontic success criteria (Strindberg, 1956). Different studies used different obturation techniques, set relatively different criteria and study designs to determine the success, thus making the comparison between these studies not always possible (Smith et al., 1993). Histologically, endodontic success has been defined as a complete repair of the periapical tissues without the presence of inflammatory cells (Abbott, 1991). However, endodontic success is evaluated mostly through analysing the radiographic findings and the presence or absence of clinical signs, and the symptoms of the treated tooth at the recall visit (Benenati and Khajotia, 2002). In their systematic review, Ng *et al*. (2010) reported an endodontic treatment success rate ranging between 31% and 100%, reflecting the differences in the criteria set by different researchers (Ng et al., 2010).

Several factors have been shown to affect the outcome of the endodontic treatment; however, some factors have shown controversial effect on the outcome when compared with different studies. For the sake of simplicity, these factors can be categorised as pre-operative and intra-operative factors. In addition, some other factors that can affect the endodontic treatment outcomes could fall outside of these two categories (Chandra, 2009).

1.10.1 Pre-operative Factors

It has been reported by some investigators that general patient factors could affect the success rate of endodontic treatment. Most of the studies in this field have reported no gender preferences when evaluating the endodontic success rate; however, Swartz *et al*. (1983) reported a higher success rate in females (Swartz et al., 1983). On the contrary, Smith *et al*. (1993) have stated that males presented 6% higher success rates when compared with females; however, none of these two studies provided any justifications for their findings (Smith et al., 1993).

The age of the patient was not considered a strong factor affecting the endodontic success rate; however, few studies have reported a lower success rates in older patients. The definitive reason behind this finding is not clear, although some investigators relate that to the higher prevalence of systemic conditions and the reduced healing abilities in older patients (Ng et al., 2010).

Although the tooth type seems to be an important factor potentially affecting the success rates, taking into consideration the complex anatomy of multi-rooted to single-rooted teeth, studies thus far have not demonstrated any significant differences between different types of teeth (Ng et al., 2010).

The pre-operative pulpal and periodontal diagnoses of the endodontic treated teeth have been shown to affect the endodontic success rates significantly. Ng *et al*. (2010) in their systematic review reported a 5–9% higher success rate in vital teeth compared with necrotic ones; however, other studies have highlighted that the periodontal status is more vital in determining the endodontic success than the pulpal status. They noticed that necrotic teeth with no periapical infection have a high success rates. It has been suggested that the necrotic debris can be well-eliminated using root canal irrigation facilitating the endodontic treatment (Strindberg, 1956, Grahnen and Hansson, 1961).

Several studies have reported that the presence of periapical radiolucency indicates the presence of anaerobic bacteria in infected canals, therefore lowering the success rate. However, researchers did not report significant differences in the success rate between different sizes of the periapical radiolucency lesion. Nevertheless, it has been highlighted that, the larger the lesion, the longer period of time required for healing to occur (Ng et al., 2010).

1.10.2 Intra-operative Factors

It is essential to ensure an adequate root canal access, bacterial debridement and isolation during the endodontic treatment to achieve desirable outcomes; however, the use of rubber dam, the amount of mechanical preparation, and the use of different irrigants and intra-canal medicaments showed no significant differences in the success rate (Basmadjian-Charles et al., 2002).

As using gutta-percha with endodontic sealer utilising different techniques is the most common obturation method, several studies have examined the effects of the root-filling length on the success rate. Most endodontic studies have categorised the length of the root-filling material as being flush (0–2 mm within the radiographic apex), short (more than 2 mm above the radiographic apex) and long (beyond the radiographic apex). Ng *et al*. (2010) have also indicated from their review of the literature that flush root canal fillings have been associated with the highest success rates compared with long and short. Despite the fact that long root-filing beyond the apex is considered unnecessary invasion to the surrounding tissues, researchers have stated that these tissues have shown high tolerance towards the root filling materials. It has been shown that excess sealer can be absorbed by the teeth, supporting tissues in three months, and that the prognosis is generally good (Nguyen, 1994).

In addition, Tani-Ishii and Tarenaka (2003) in their clinical evaluation of Obtura-II thermoplasticised gutta-percha reported a high success rate of the technique with all three categories of root-filing length (Tani-Ishii and Teranaka, 2003).

The quality of the root filling is considered an important factor influencing the success rate of endodontic treatment. Ng *et al*. (2010) have reported a 25.9% lesser chance of healing in root canals, showing inadequate endodontic filling radiographically. Moreover, it has been reported that radiographs showing the evidence of voids have a significantly lower success rates than those not presenting any radiographic signs of heterogeneous root canal filling.

1.10.3 Other Factors

The effect of the number of treatment visits on the outcomes seems to be a controversial issue when comparing different opinions highlighted in the literature; however, in their systematic review, Figini *et al*. (2008) reported no significant differences when evaluating the radiographic treatment outcomes of a single- or multiple-visit root canal treatment (Figini et al., 2008).

The follow-up period seems to affect the success rate—especially in the sense that any radiographic changes, whether healing or pathology, will not be evident radiographically before 6 months post-obturation. Jokinen *et al*. (1978) have also reported that the vast majority of failure cases were noticed mainly radiographically two years post-operatively. Accordingly, they suggested that an observational period of less than one year is not acceptable in terms of evaluating the outcome of endodontic treatment (Jokinen et al., 1978).

The quality of coronal restoration has been reported as an important factor affecting the rate of success of endodontic treatment. Some studies have emphasised the belief that the adequacy of the root canal filling itself is more important than the coronal restoration (Tronstad et al., 2000). However, Ray and Trope (1995) have reported that the absence of peri-radicular inflammation following root canal treatment was 11 times greater in teeth when adequate coronal restorations were placed. The significant differences in this study emphasised the importance of coronal seal as a vital factor affecting the endodontic success rate (Ray and Trope, 1995).

All of the studies evaluating the factors affecting the success rate of endodontic treatment were carried out on an adult population. Most of the teeth involved in these studies were diagnosed with pulpitis or apical periodontitis, and no reports carried out thus far evaluated the endodontic success rate following trauma in children.

Furthermore, one of the obvious drawbacks in several epidemiological studies evaluating the factors affecting the success rate had short follow-up periods post-operatively, ranging mainly between 6 months and 2 years.

Due to the fact that the gold standard of treatment following TDI is to maintain the vitality of the traumatised teeth, most of the trauma studies have considered the factors affecting the healing outcomes. Although these studies are several, their findings cannot be applied directly when evaluating the success rate of endodontic treatment of a traumatised tooth.

1.11 Teeth Auto-transplantation in Children

Missing anterior teeth in children secondary to TDIs is not an uncommon phenomenon. In their cross-sectional epidemiological study it was reported that 12 in 1,000 children in the United Kingdom had missing anterior teeth due to TDIs (Chadwick and Pendry, 2004). Managing a growing child with missing anterior teeth is a challenging task facing clinicians; therefore, such cases should be managed with a multidisciplinary approach. In addition, it is necessary to identify these cases early, assess the prognosis of the anterior teeth, and accordingly explain the situation to patients and carers. Several treatment options are available for the replacement of missing teeth in children. Tooth auto-transplantation is considered one of the best treatment options in motivated, compliant children when there is an indication of extraction of healthy teeth for orthodontic reasons (Roden Jr and Yanosky, 2013).

Tooth auto-transplantation is defined as the movement of a tooth from one site (donor site) to another site (recipient site) within the same person (Andreasen et al., 1990). In early-1950, auto-transplantation was first described in the literature in which the third molars were used to replace extracted first molars (Miller, 1950). Due to the poor case selection and the traumatic extraction of the third molars, many of these studies reported low success rates (Tsukiboshi, 2002). Later, however, several studies reported high success rate when premolars were transplanted due to hypodontia (Kristerson, 1985, Jonsson and Sigurdsson, 2004).

Although there is a limited body of literature concerning premolar auto-transplantation within the maxillary anterior region, high success rates have been reported nevertheless (Czochrowska et al., 2002). This is mainly due to the increased understanding of the biology of periodontal ligament and factors influencing the healing of auto-transplanted teeth (Czochrowska et al., 2002).

Auto-transplantation is considered the only treatment option providing a vital replacement of the missing anterior teeth in growing children. This treatment option has several advantages over the other available options when approaching missing anterior teeth in children secondary to trauma. The alveolar development at a site is dependent upon the presence of a functioning tooth. Consequently, alveolar bone loss and insufficient bone quality and quantity result following a loss of these teeth after TDIs. Auto-transplantation allows for continued alveolar stimulation, maintaining the height and width of alveolar process. In addition, unlike implants, transplanted teeth can be moved orthodontically as and when required. Furthermore, this treatment option provides an aesthetic replacement during development without altering the adjacent teeth (Day et al., 2008, Roden Jr and Yanosky, 2013). Czochrowska *et al*. (2002) compared the aesthetic outcome of 22 auto-transplanted premolars to their contralateral natural maxillary incisors. They reported that only 14% of the sample was considered to be mismatched when contrasted alongside contralateral teeth. In addition, the majority of patients were satisfied with the appearance of auto-transplanted teeth. On the other hand, this procedure continues to carry various disadvantages. It is an invasive surgical procedure in which general anaesthetic is required in most cases. In addition, possible complications, such as pulp necrosis and external root resorption, could occur. Finally, auto-transplantation is indicated only for those patients requiring extraction as part of their orthodontic treatment (Day et al., 2008).

In order to achieve successful results when undertaking auto-transplantation, a clear treatment plan should be formulated following the evaluation of cases from multidisciplinary points of view. In their paper, Roden and Yanosky (2013) illustrated the keys for auto-transplanted teeth which are summarised in Table 1.1.

Table 1.1: Summarises the key factors for a successful auto-transplantation.

	Keys for Auto-transplant Success
1	Donor tooth 1/2 to 2/3 root development, with > 1 mm open apex
2	Atraumatic extraction, maintain periodontal ligament cells
3	Brief extra-oral time of donor tooth
4	Best result if recipient site is fresh extraction site
5	Over-prepared recipient site
6	Functional fixation
7	Follicle cells and Hertwig's root sheath intact
8	Keep donor tooth out of occlusion

Planning endodontic treatment 7–14 days following the auto-transplantation of a closed apex donor is a vital element of the treatment plan (Day et al., 2008). In addition, it is necessary to monitor cases with open apices in order to diagnose any pulpal infection prior to the occurrence of destructive inflammatory resorption. Tsukiboshi (2001) recommended post-surgery review intervals of 1, 2, 3, 6 and 12 months, and then annually. This is important in order to assess the clinical and radiographic pulpal and periodontal healing (Tsukiboshi et al., 2001).

It has been reported that the survival rate of premolar auto-transplantation ranges from between 74% and 100% (Mensink and Van Merkesteyn, 2010); this could be due to the effect of different prognostic factors assessed between different studies.

Several prognostic factors have been highlighted in the literature as potentially affecting the survival rates of auto-transplantation. The stage of root development and the stage of eruption of the donor teeth have been significantly associated with the pulpal healing, and therefore the survival rate. Other factors, such as the age of the patient and the skills of operators, can also impact outcomes. Finally, the surgical steps undertaken during this procedure can significantly influence the survival rates of auto-transplanted teeth.

Chapter Two

A Study of the Clinical and Radiographic Outcomes of Root Canal Obturation with Obtura-II System using Thermoplasticised Gutta-percha in Traumatised Teeth

Abstract

Background: Obtura-II injectable thermoplasticised gutta-percha technique has been available for several years. However, there are no published studies that have evaluated its clinical and radiographic success in non-vital young traumatised permanent incisors in children where teeth are expected to survive for the life-span of the patient.

Aim: Evaluating the clinical and radiographic success of Obtura-II system in root canals of non-vital young traumatised permanent incisors in children; and studying the effect of different demographic and prognostic factors on the success rate of the technique.

Method: A retrospective study assessing the Obtura-II treatment outcomes. Clinical dental records and periapical radiographs of 667 patients who attended the trauma clinic at the Paediatric Dentistry Department at Leeds Dental Institute in the period during the years 2003 and 2011 were screened. The obturated teeth were classified as successful or failure according to criteria developed for this study. Various prognostic factors that could influence the outcome of the technique were recorded using a special data extraction proforma. The data were entered into SPSS, with

subsequent analyses carried out in the forms of simple descriptive analysis and bivariate analyses. Furthermore, a logistic regression analysis was carried out in order to obtain the relation between different prognostic factors and the treatment outcomes.

Results: According to the study criteria, 235 cases with 275 teeth with various stages of root development were included. The mean age of patients at the time of trauma was 10.2 years. The clinically successful cases accounted for 92.7% whilst radiographically successful cases accounted for 85.4% over a mean follow-up period of 51 months. The logistic regression analysis showed a significant association between some of the prognostic factors, such as the type of trauma, the duration of $Ca(OH)_2$ dressing, and the quality of obturation and the Obtura-II technique treatment outcomes.

Conclusion: Through the use of the Obtura-II technique, root canal treatment was considered clinically successful in 92.7% and radiographically in 85.4% of non-vital young traumatised teeth cases over a long follow-up period. Furthermore, several factors were found to be significantly associated with the treatment outcomes of this technique.

Section One

Introduction

It became obvious, after reviewing the literature, that the Obtura-II thermoplasticised gutta-percha technique has been investigated both *in vitro* and *in vivo*. Researchers have looked at several different aspects of this technique, such as its sealing ability and adaptation to the root canal system, with the heat produced by this technique and its effect on the teeth and supporting structures also investigated. However, it was evident that there are few studies evaluating the clinical and radiographic success of the technique. In addition, these few studies have short follow-up periods ranging between 6 months and 2 years following the root canal treatment utilising Obtura-II technique. Furthermore, this technique has never been evaluated in growing children with immature non-vital permanent teeth that require root canal treatment secondary to trauma.

The literature review also confirmed that, although there were several studies commenting on the prognostic factors affecting the endodontic success rate, all of these studies had nevertheless been conducted on adult populations. Most of these studies were epidemiological studies with a short follow-up period and different criteria evaluating the success of endodontic treatment. As a consequence, it was difficult to compare the outcomes of these different studies. Furthermore, none of these studies had evaluated the factors affecting the outcomes of endodontic treatment in children with immature non-vital teeth.

In conclusion, when such a treatment is carried out at a very young age, it is expected that the tooth will survive for the lifetime of the patient, making it important to evaluate this technique in a comprehensive manner and to evaluate its long term outcomes.

Section Two

Research Aims, Questions, and Hypothesis

2.2.1 Aims

- To evaluate the clinical and the radiographic success of Obtura-II injectable thermoplasticised gutta-percha technique for the treatment of non-vital young traumatised permanent incisors.
- To study the effect of several prognostic factors on both the clinical and radiographic success rates of this technique when used in the treatment of non-vital young traumatised permanent incisors in children.

2.2.2 Research Questions

The study has two defined questions that should be answered on completion. The questions are:

- What are the clinical and the radiographic success rates of Obtura-II technique when used for root canal obturation of non-vital young traumatised permanent incisors in children?

- What are the different prognostic factors, if any, that influence the clinical and radiographic success of Obtura-II technique when used in the endodontic treatment of non-vital young traumatised teeth?

2.2.3 Research Hypothesis – Null Hypothesis

There is no association between any of the prognostic factors and the clinical and radiographic success of Obtura-II injectable thermoplasticised gutta-percha in the endodontic treatment of non-vital young traumatised permanent incisors in children.

Section Three

Materials and Methods

2.3.1 Obtaining Ethical Approval

Experts' methodological opinion from the study's supervisors was obtained and ensured that the study was based on solid scientific principles. Subsequently, the study methodology and protocol were designed. Both the study protocol and ethics application form were submitted to the local Dental Research Ethics Committee (DREC) at Leeds Dental Institute. Based on (DREC) recommendations, few amendments were incorporated within the study's protocol, and subsequently ethical approval from (DREC) was obtained (see Appendix 1). The National Research Ethics Service (NRES) was contacted and advised us that (DREC) ethical approval was sufficiently enough for this study and the study could proceed (see Appendix 2).

2.3.2 Methodology for Sample Selection

2.3.2.1 Identification of the Sample

The study sample was identified from the clinical dental records of paediatric patients who attended the trauma or the casual clinics at the Paediatric Dentistry Department at Leeds Dental Institute during the period 2003–2011. These patients experienced dental trauma that had resulted in the loss of vitality of at least one permanent incisor, which was treated endodontically with thermoplasticised gutta-percha (Obtura-II system). Figure 2.3.1 shows the Obtura-II system. The clinical dental records were evaluated in December 2012 in order to ensure a minimum of a one-year follow-up post-obturation of the traumatised teeth.

Figure 2.3.1: A photograph showing the Obtura II system.

2.3.2.2.1 Inclusion Criteria

The followings were the inclusion criteria:

- Clinical dental records of patients who attended the trauma or the casual clinic at the Paediatric Dentistry Department at Leeds Dental Institute after experiencing a dental trauma which had led to the loss of vitality of at least one permanent incisor.
- Clinical dental records of patients who had calcium hydroxide apexification prior to the final obturation.
- Clinical dental records of patients who had MTA apical plug prior to the final obturation.
- Clinical dental records of patients who had their traumatised permanent incisors endodontically treated with thermoplasticied gutta-percha (Obtura-II system).

- Follow-up period following the final obturation with the Obtura-II system of at least one year at the Paediatric Dentistry Department at Leeds Dental Institutes.

2.3.2.2.2 Exclusion Criteria

The exclusion criteria for this study were as follows:

- Clinical dental records of patients who had one or more non-vital permanent incisors secondary to dental caries.
- Subjects with follow-up periods of less than one year following the final obturation using Obtura-II system.

2.3.3 Methodology for Data Collection

Data was collected retrospectively from the clinical dental records of the paediatric patients from Leeds Dental Institute who were included in the study with the use of a data-extraction proforma (see Appendix 3), which was designed especially for this study.

2.3.3.1 Data-Recording Methods

The data were extracted from the clinical dental records written by the clinicians who treated the patients. The trauma details, diagnosis and treatment plan were obtained from the trauma sheet available in the clinical dental records. In addition, the obturation details of the traumatised teeth and the clinical findings in each visit were evaluated. Furthermore, the pre-operative and the post-operative periapical radiographs available at the clinical dental records were evaluated.

These periapical radiographs were made through the use of an x-ray radiation machine (Focus by Instrumentarium Dental, Nahkelanti, Finland) and Kodak E-speed dental films size 2 (INSIGHT, Kodak, Rochester,NY) with a paralleling technique. All films were processed in an x-ray automatic processor machine (Velopex Extra, Velopex International) using Velopex dental developer and fixer.

In addition, radiographs were laminated for protection. Finally, the viewing conditions were standardised by using a light box with fixed light intensity.

The findings that were identified from the clinical dental records were as follows:

1. Patient details, which include
   - Date of birth
   - Gender
2. Type of referral
   - General dental practitioner
   - Community dental services
   - Other specialist
   - Self-referral / emergency
3. Level of patient's cooperation, based on Frankl score. (Frankl et al., 1962)
   - Definitely positive (++)
   - Positive (+)
   - Negative (-)
   - Definitely negative (--)
4. Trauma details, which include the following:
   - Type of trauma
   - Age at trauma
   - Affected tooth
5. Treatment details, which include the following:
   - Start date of treatment

- Date of pulp extirpation
- The duration of calcium hydroxide intra-canal dressing prior to final obturation in weeks
- Type of apical stop
    - Calcium hydroxide $Ca(OH)_2$
    - Mineral trioxide aggregate MTA
- Date of obturation
- Total treatment period in months
- Total review period in months
- Final permanent coronal restoration
    - Date of placement
    - Type of materials used

6. The clinical examination details during the last review visit, which include:
    - Pain associated with the endodontic treated tooth following the final obturation
    - The use of analgesics
    - Tenderness to percussion or interference with normal function
    - Tenderness to palpation
7. The clinical evaluation of periodontal healing details during the last review visit, which include:
    - The presence of abscess
    - Tooth mobility
    - The tooth sound on percussion

8. The findings that were identified from comparing the pre-operative and post-operative radiographs were as follows:
   - The stage of root development of the traumatised tooth at the time of trauma
   - The length of the thermoplasticised gutta-percha obturation
   - The quality of the obturation
   - The periodontal ligament space
   - The periapical lesion
   - Root resorption
   - Root fracture

2.3.3.2 Data Variables

The data variables were categorised into demographic factors, prognostic factors, clinical outcomes, and radiographic outcomes, as can be seen in the data extraction proforma. Furthermore, the data variables were divided into independent and dependent variables: the former were the data already existing in the clinical dental records, including the demographic factors, prognostic factors, clinical outcomes, and radiographic outcomes; on the contrary, the latter were those formed after judging the independent variables. The clinical and the radiographic success were considered dependent variables.

2.3.4 Methodology for the Assessment of Variables

2.3.4.1 Types of Trauma

The types of trauma were recorded from the clinical dental records. The clinicians who assessed the patients in their first visits clearly stated the types of trauma in the trauma sheets, which were available in the clinical dental records.

2.3.4.2 Stage of Root Development at Trauma

The stages of root development of the traumatised teeth at the time of trauma were assessed radiographically based on a previously described scale by (Dominguez Reyes et al., 2005). This scale was developed in relation to premature incisor teeth that underwent apexification using $Ca(OH)_2$. It classifies the root development of the premature incisors at the time of apexification into three categories based on the inclination of the apical walls and the shape of the apex. The three categories are divergent apical walls, parallel apical walls, and convergent apical walls. Moreover, a fourth category, which is complete root development, was added by Kafourou *et al*. (2010) in an attempt to distinguish the teeth that had closed apices. In this study, the aforementioned four categories were used, and were defined as following:

1. Divergent apical walls (DAW): the walls of the apical foramen have a divergent inclination before the tooth its final root length.
2. Parallel apical walls (PAW): the walls of the apical foramen are parallel and the tooth has nearly reached its final root length, but still has incomplete root formation.
3. Convergent apical walls (CAW): the walls of the apical foramen have got a convergent inclination, but before complete apical closure, and the tooth has reached its full length.
4. Complete root development: it is the most mature phase of the root development when the tooth has reached its full root development and the apex is constricted.

The periapical radiographs were taken when the patient initially presented with the trauma were evaluated to determine the stages of root development.

2.3.4.3 Duration of $Ca(OH)_2$ Intra-canal Dressing

The duration of the non-setting calcium hydroxide placed in the canals of the traumatised teeth were calculated from the clinical dental records.

This was calculated from the initial date of placing calcium hydroxide until the date of obturation of the traumatised teeth in weeks.

2.3.5 Methodology for the Assessment of Outcomes

The outcome measures of obturation using thermoplasticised gutta-percha were assessed in accordance to the following detailed criteria.

2.3.5.1 Pain Following Root Canal Obturation

The post-operative pain following the obturation was extracted from the clinical dental records. The clinicians who treated the traumatised teeth stated whether the patients had any pain or discomfort associated with the traumatised obturated teeth at each review visit following obturation. In addition, the severity of the pain (ranging mild, moderate, severe) was mentioned. In the cases where no details relating to the pain had been mentioned in the clinical dental records, it was considered that the patient was free of pain following obturation.

2.3.5.2 The Use of Analgesics for the Relief of Pain

The clinical dental records were reviewed in order to check whether or not the patients used analgesics to control any pain associated with the obturated teeth after the final obturation. This information was documented in the clinical dental records by clinicians who examined the patients during the review visits. In the cases where no information regarding the use of analgesics was documented, the obturated teeth were considered pain-free, and it was assumed that no analgesics had been prescribed and/or used.

2.3.5.3 Tenderness to Percussion or Normal Function

Gentle percussion of the obturated teeth, using the end of a metallic mirror, was part of the clinical examination the patients underwent following the final obturation. The obturated teeth, in addition to control teeth, were percussed. Moreover, the patients were asked whether or not they experienced any pain with normal masticatory function associated with the oburated teeth. The responses of the patients documented in the clinical dental records by the clinicians were transferred to the data extraction proforma.

2.3.5.4 Tenderness to Palpation

Similar to the percussion examination, assessing the response of patients to palpation is a mandatory aspect of the clinical examination during the review visits. The clinicians applied gentle finger pressure, palpating the area overlaying the obturated roots, both labially and palatally. The responses of patients were documented in the clinical dental records. Following the evaluation of clinical dental records, this information was transferred to the data extraction proforma.

2.3.5.5 Periodontal Healing

The periodontal healing was assessed from both a clinical and a radiographic point of view. The clinical dental records were evaluated to establish what had been documented regarding the mobility (physiological normal mobility, increase pathological mobility, absence of mobility or ankylosis). In addition, the information regarding the presence of abscess and the presence of metallic sound associated with the obturated teeth during the review visits were noted from the clinical dental records. Furthermore, the radiographs were used to evaluate the periodontal healing. The pre- and post-operative periapical radiographs of the obturated teeth were evaluated, checking the size of the periodontal ligament space and the width of the lamina dura. Finally, the size of the associated periapical radiolucency was assessed pre- and post-operatively.

2.3.5.6 Quality of the Coronal Seal

The quality of the coronal seal was classified as being adequate or inadequate. The seal was considered adequate if two or more restorative materials were used in the final coronal restoration. From the clinical dental records, the types of material used and documented by the treating clinicians were abstracted. The information was then transferred to the data extraction profoma, and accordingly categorised as being either adequate or inadequate.

2.3.5.7 Quality of the Root Canal Obturation

The quality of the root canal obturation was assessed radiographically by evaluating the periapical radiographs, which had been taken following the final obturation. The quality of obturation was classified as being either adequate or inadequate based on the following criteria.

The quality of the obturation was recorded as being adequate if:

- There was no space between the thermoplasticised gutta-percha and the root canal walls.
- There was no canal space visible beyond the end of the thermoplasticised gutta-percha.

On the contrary, the quality of obturation was considered inadequate if:

- There was a space evident between the thermoplasticised gutta-percha and the root canal walls.
- The thermoplasticised gutta-percha over extended through the apex.
- The thermoplasticised gutta-percha was under-filled by more than 2 mm from the apex.

2.3.5.8 Resorption

The post-operative radiographs, which were taken during the final review visit, after at least one year following the final obturation, were evaluated. Any signs of external root resorption were documented in the data extraction proforma.

2.3.5.9 Periapical Pathosis

The healing of the periapical pathosis was evaluated radiographically through comparing the pre-operative periapical radiographs with the periapical radiographs taken at the last review visit at least one year following the final obturation. Cases were considered successful when there was a decrease in the size or diminished periapical lesions compared with the pre-operative periapical radiographs. In addition, in cases where the periapical lesion was healing but had left a local widening of the periodontal ligament space, the defect was considered to be scar tissue; the case was also categorised as being successful. On the other hand, cases with a periapical lesion that remained the same size as the initial lesion were considered to have an uncertain obturation outcome. Finally, an outcome of failure of obturation was recorded when there was an increase in the size of the periapical lesion.

2.3.5.10 Definition of Success and Failure

Criteria for the clinical success:

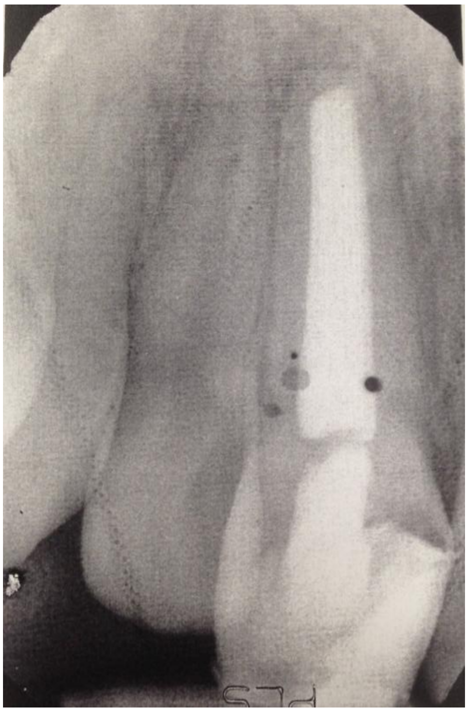
- The tooth was free of pain and the patient did not use analgesics
- The tooth was not tender to percussion and there was no interference with normal functions
- There was no evidence of an abscess associated with the obturated tooth at the last review visit
- Normal physiological tooth mobility.

In regard to the criteria for radiographic success, the periapical radiographs were assessed based on the criteria set by the European Society of Endodontology (2006):

- There was a radiographic evidence of normal periodontal space width
- There was a decrease in the size of the periapical lesion compared with its size in the pre-operative radiograph
- There was no evidence of external root resorption.

An example of a radiographically successful case is demonstrated in Figure 2.3.2.

Figure 2.3.2: Shows a periapical radiograph demonstrating an example of a case of radiographic success.



Criteria for clinical failure:

- There was pain associated with the obturated tooth, and the patient required the use of analgesics to control the pain
- The tooth was tender to percussion, and there was interference with normal function

- There was an evidence of an abscess associated with the obturated tooth at the last review visit
- An increase of pathological mobility or the absence of the physiological mobility (ankylosis).

Criteria for radiographic failure:

- Increase in the size of the periapical lesion in the periapical radiograph that was taken at the last review visit compared to its size at the pre-operative periapical radiograph
- Evidence of a new periapical lesion that developed following the root canal obturation of the traumatised tooth and which was not there originally
- Signs of continuing root resorption or hypercementosis.

An example of a radiographically failure case is demonstrated in Figure 2.3.3.

Figure 2.3.3: Shows a periapical radiograph of a case considered to be a radiographic failure.

2.3.6 Inter-examiner Reliability

The clinical dental records were coded and then randomised utilising the 'RANDOM' feature of the Microsoft Excel 2010 software. From the generated randomised list, 15% of the sample was selected. This equated to the first 36 clinical dental records. Both investigators (AF and MSD) reviewed all periapcal radiographs for these cases. For each case, the two investigator agreed on how the data was classified. This step took place also in an attempt to check that the indices were accurately and consistently used. Subsequently, the rest of the 85% of the cases were reviewed by the main investigator (AF). In the cases of uncertainty or any query in the clinical dental records or the periapical radiographs reviewed, the opinion of the second investigator (MSD) was sought and a common agreement reached.

2.3.7 Intra-examiner Reliability

Following the main investigator being trained by reviewing the first 15% of the cases with the second investigator (MSD), the rest of the 85% of the cases were reviewed by the main investigator (AF). The outcomes documented in the data extraction proforma were subjected to tests for intra-examiner reliability. Notably, 15% of the clinical dental records and periapical radiographs were re-evaluated against the indices of the study. These cases were randomly selected utilising the 'RANDOM' feature of Microsoft Excel in the same manner as explained in the previous section. This random sample was different to that the notes selected in 2.3.6.

2.3.8 Sample Size Calculation

Due to the fact that there were no similar studies published in the literature, no estimate could be used to determine the sample size. Thus, it was agreed after consulting the biostatistician (JK) at Leeds Dental Institute that it would be sensible to aim for a sample size of between 150 and 250 cases.

2.3.9 Data Handling and Analysis

Following data collection, data were entered immediately into password-protected documents in the university computer. The data was analysed statistically using SPSS Version 19 (SPSS Inc. Chicago, IL) program.

2.3.10 Statistical Tests used in the Study to Analyse the Data

Statistical advice was obtained with regard to the statistical tools, and tests were required to analyse the data of the study.

Demographic and prognostic factors were displayed using graphic descriptive statistics, such as tables, bar and pie charts. Qualitative variables were summarised using numerical descriptive statistics, such as means and standard deviations. On the other hand, categorical variables were summarised using frequencies and percentage proportions. In addition, bivariate analysis took place to explore the primary association between the predictors of interest and the treatment outcomes. These tests included Chi-square, Fisher's exact test and t-test.

In an attempt to establish the association between the different demographic and prognostic factors with the clinical and the radiographic success, a logistic regression analysis took place. The level of statistical significance was set on $p < 0.05$. The logistic regression models were formulated based on the results of the bivariate analysis.

Further detailed descriptions of the statistical tests utilised are discussed in the following chapter.

Section Four

Results

2.4.0 Statistical Tests

All collected data were entered into SPSS (Statistical Package for Social Science, Version 19) for Windows (SPSS Inc. Chicago, IL) software to analyse the data.

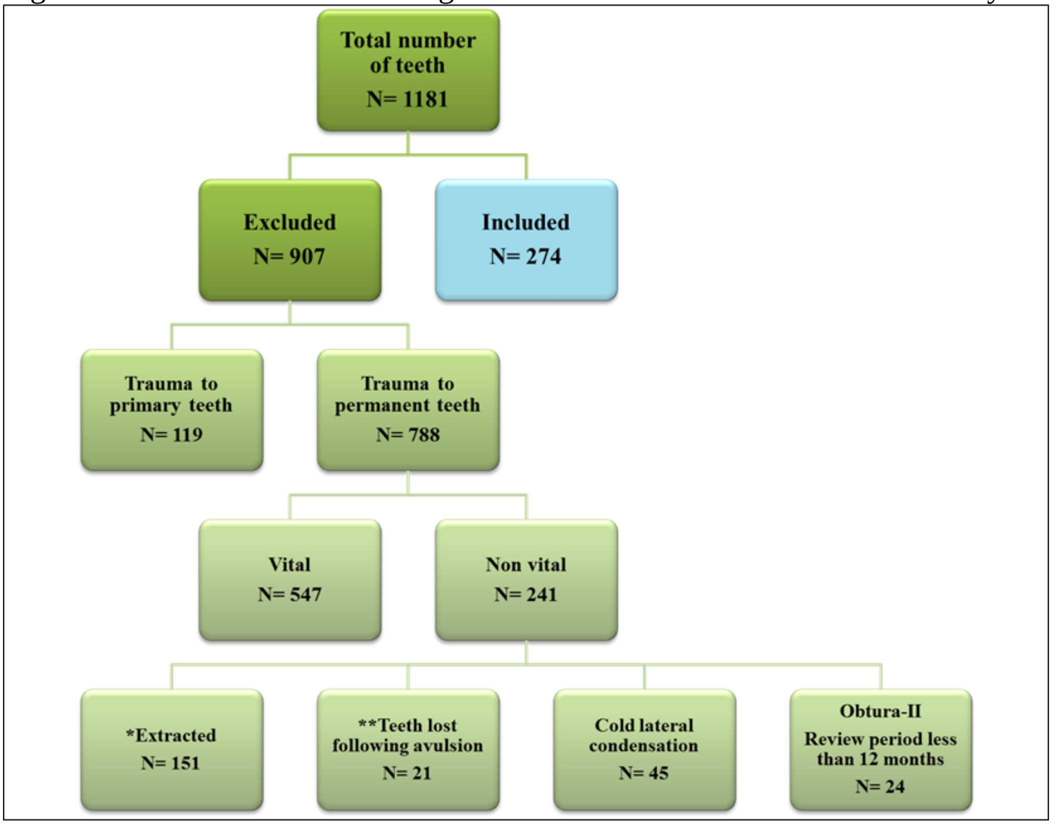
Initially, a series of descriptive statistics were performed on the data including percentages, means, and standard deviations (SD). In addition, the maximum and the minimum values were determined for all the numerical variables. Furthermore, Chi-square test, Fishers' exact test and independent t-test were applied in order to study the effect of different demographic and prognostic factors on the clinical and radiographic outcomes. Finally, a series of logistic regressions were conducted.

This chapter discusses in details all statistical methods employed and the results obtained.

2.4.1 Study Sample

Initially 667 clinical dental records with 1,181 traumatised teeth of children who attended the trauma clinic at the Paediatric Dentistry Department at Leeds Dental Institute in the period between 2003 and 2011 were screened. A total of 235 clinical dental records of children with 274 traumatised teeth met the inclusion criteria. The following flowchart (Figure 2.4.1) shows the distribution of the sample.

Figure 2.4.1: A flow chart showing the distribution of the excluded cases only.

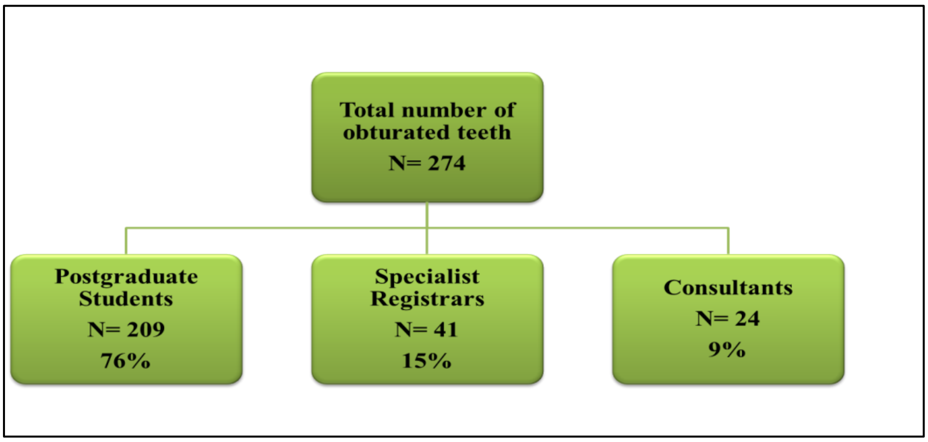


*Extracted: Teeth which ultimately require extraction and did not meet the inclusion

** Avulsion injury where teeth were not replanted

It was found that out of the total 274 included teeth, 209 teeth were obturated by postgraduate students, 41 teeth by specialist registrars, and 24 teeth by consultants. The following flow chart (Figure 2.4.2) summarises these findings.

Figure 2.4.2: A flow chart showing distribution of sample based on treating clinician.



2.4.2 Demographic Factors – Descriptive Statistics

2.4.2.1 Gender

From the 235 patients included in our study 138 (58.7%) were males. On the other hand, 97 (41.3%) were females.

2.4.2.2 Age at Trauma

The mean age of the patients was 10.2 years with a standard deviation of 2.5 years. The youngest patient was 6 years old and the oldest patient was 21 years old.

2.4.3 Prognostic Factors – Descriptive Statistics

2.4.3.1 Teeth Involved in Trauma

The maxillary central incisor was shown to be the most common tooth involved in trauma. The upper right central incisor accounted for 44.9% and the upper left central incisor accounted for 44.5% of the traumatised teeth.

The rest of the traumatised teeth accounted individually for less than 6%. Table 2.4.1 summarises the frequency of the teeth involved in trauma.

Table 2.4.1: Illustrating the frequency of teeth involved in trauma.

Tooth	Number	Percentage
UR1	123	44.9%
UR2	9	3.3%
UR3	1	0.4%
UL1	122	44.5%
UL2	16	5.8%
LL2	1	0.4%
LR1	2	0.7%
Total	274	100.0%

2.4.3.2 Type of Trauma

With regard to the type of trauma, it was found that complicated crown fracture was the most common type of trauma among this population and accounted for 46.7%. The second most common type of trauma was the uncomplicated crown fracture with a frequency of 27.4%. In addition, avulsion accounted for 10.2% of the cases. Finally, the remaining types of trauma individually composed less than 6% of this sample. The frequency of the types of trauma are summarised in Table 2.4.2.

Table 2.4.2: Showing the frequency of different types of trauma.

Type of Trauma	Number	Percentage
Complicated Crown Fracture	128	46.7%
Uncomplicated Crown Fracture	75	27.4%
Avulsion	28	10.2%
Luxation	12	4.4%
Subluxation	5	1.8%
Intrusion	15	5.5%
Extrusion	7	2.6%
Root Fracture	2	0.7%
Crown/Root Fracture	2	0.7%
Total	274	100.0%

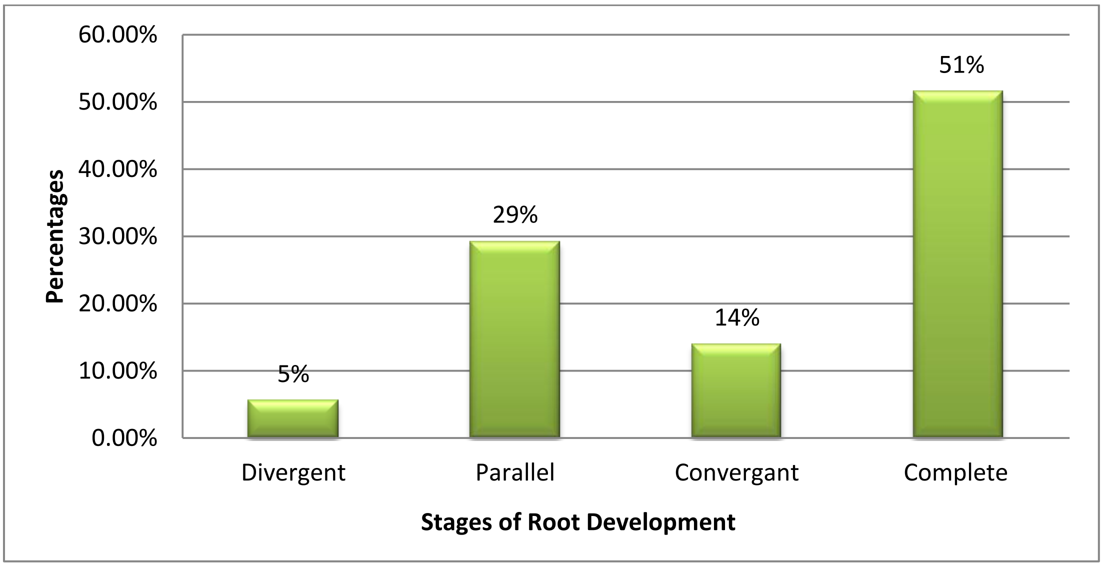
2.4.3.3 Associated Trauma

It was observed that most of the teeth (N=253, 92.3%) were affected by only one type of trauma. On the contrary, 7.7% (N=21) of the teeth were affected by an associated trauma in addition to the original trauma type. Most of the associated traumas were luxation and subluxation injuries.

2.4.3.4 Stages of Root Development

With respect to stage of root development of the traumatised teeth at time of trauma, over 51% (N=141) of cases were found to have complete root development. Parallel roots accounted for around 29% (N=80) of the cases. Close to 14% (N=38) of the cases were found to have convergent roots. Finally, slightly over 5% (N=15) of the cases had divergent roots. Figure 2.4.3 summarise in a bar chart the frequencies of the stages of root development of the traumatised teeth.

Figure 2.4.3: Bar chart showing the frequencies of the stages of root development of traumatised teeth.



2.4.3.5 Duration of Calcium Hydroxide Intra-canal Dressing

All traumatised teeth included in this study were dressed with calcium hydroxide intra-canal medicament. The descriptive statistics on this continuous measure found that the mean duration of $Ca(OH)_2$ placed in the root canals was 45 weeks with a standard deviation close to 45 weeks. This measure was found to have a minimum duration of 0 week and a maximum of 332 weeks.

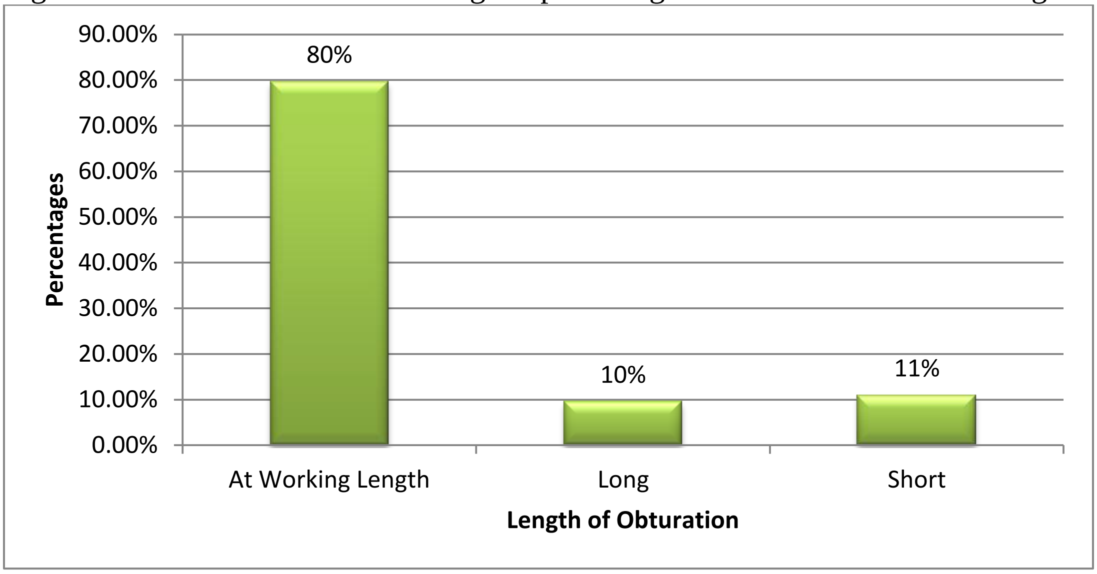
2.4.3.6 Use of MTA as an Apical Barrier

Descriptive statistics were conducted on whether or not MTA was used as an apical barrier prior to obturation of the traumatised premature incisors. MTA was found to be used in 9.5% (N=26) of the cases.

2.4.3.7 Length of Gutta-percha Obturation

Regarding the obturation length, it was found that almost 80% (N=218) of the cases had an obturation at the working length. Obturation extending beyond the apex was found in nearly 10% (N=26) of the cases. Finally, around 11% (N=30) of the cases had obturation shorter than the working length. The percentages of different obturation lengths is summarised in Figure 2.4.4.

Figure 2.4.4: Bar chart demonstrating the percentages of different obturation lengths.



2.4.3.8 Quality of Obturation

The descriptive statistics conducted on the quality of obturation found that it was adequate in almost 95% (N=260) of the cases. On the other hand, the quality of obturation was found to be inadequate in 5% (N=14) of the cases due to the presence of voids and spaces between the root canal walls and the obturation material.

2.4.3.9 Treatment Period

The mean treatment period was 13 months with a standard deviation slightly above 12 months. In addition, the minimum treatment period was found to be 1 month with a maximum treatment period of 84 months in total.

2.4.3.10 Post-Obturation Review Period

With regard to the total post-obturation review period, this was found to have a mean of slightly above 51 months with a standard deviation slightly above 36 months. The minimum total period of review following the obturation of the traumatised teeth was found to be 12 months. Finally, the maximum period of review was found to be 120 months.

2.4.4 Treatment Outcome – Descriptive Statistics

2.4.4.1 Clinical Outcomes

Based on the criteria mentioned previously in section three (Materials and Methods) the treatment outcomes were classified as being either clinically successful or a clinical failure, and radiographically successful or radiographic failure.

It was found that 92.7% of the cases were considered as clinically successful, whereas 7.3% were considered as failures. The clinical outcomes of the obturated traumatised teeth are summarised in Table 2.4.3.

Table 2.4.3: Presenting the percentages of the clinical outcomes.

Clinical Outcome	Number	Percentage
Clinical Success	254	92.7%
Clinical Failure	20	7.3%
Total	274	100.0

2.4.4.2 Radiographic Outcomes

Descriptive statistics were conducted on the radiographic outcomes. It was found that 85.4% of the cases were considered as radiographically successful. On the other hand, 14.6% of the cases were categorised as failures. Table 2.4.4 summarises the radiographic outcomes of the obturated traumatised teeth.

Table 2.4.4: Shows the percentages of radiographic outcomes.

Radiographic Outcomes	Number	Percentage
Radiographic Success	234	85.4%
Radiographic Failure	40	14.6%
Total	274	100.0

Furthermore, Table 2.4.5 illustrates the main causes of radiographic failure and their percentages. Some teeth presented more than one sign of radiographic failure.

Table 2.4.5: Demonstrates the main causes of radiographic failure.

Causes of Radiographic Failure	Number	Percentage
Absent PDL Space	14	35%
External Root Resorption	25	62.5%
Increased Size PA Radiolucency	25	62.5%

2.4.4.3 External Root Resorption

It was observed that 25 cases accounting for 8.8% from the whole sample suffered external root resorption while 91.25% of the cases did not show evidence of root resorption.

2.4.4.4 Root Fracture

Eight cases representing only 2.9% of the whole sample had root fracture.

2.4.4.5 Tooth Extraction

Nineteen teeth accounting for 6.9% were extracted following endodontic treatment with obtura-II thermoplasticised gutta-percha technique.

2.4.5 Association between the Outcomes and Demographic and Prognostic Factors

The following set of results focus upon the association between the predictors of interest which are the demographic and prognostic factors and the outcomes which are the clinical success, radiographic success, root resorption, root fracture, and extraction. In order to analyse this association Chi-square test was conducted along with Fisher's exact.

2.4.5.1 Clinical Success

2.4.5.1.1 Factors with No Significant Associations

It was found that some of the tested prognostic factors did not have a significant association with the clinical success. These factors are summarised in Table 2.4.6.

Table 2.4.6: Illustrates the factors with no significant associations with clinical success and their *p* values.

Factors	*p* Value
Gender	0.15
Traumatised Tooth	0.91
Associated Trauma	0.06
MTA Apical Barrier	0.11
Treatment Period	0.07
Obturation Length	0.16

2.4.5.1.2 Factors with Significant Associations

Type of Trauma

With regard to the type of trauma, a significant association was found between this measure and clinical success (χ^2, $p = 0.001$). As shown in Table 2.4.7 the cross tabulation table, teeth that had been avulsed or intruded had higher chances of clinical failure as compared to other types of trauma (35.7% and 6.7%) respectively.

Table 2.4.7: Cross-tabulation table showing percentages of different types of trauma associated with clinical success and failure.

Type of Trauma	Clinical Success	
	Yes	No
Complicated crown	94.5%	5.5%
Uncomplicated crown	97.3%	2.7%
* Avulsion	64.3%	35.7%
Luxation	100.0%	0.0%
Subluxation	100.0%	0.0%
* Intrusion	93.3%	6.7%
Extrusion	100.0%	0.0%
Root fracture	100.0%	0.0%
Root/crown fracture	100.0%	0.0%
Total	92.7%	7.3%

* Indicates higher chances of clinical failure.

Age at Trauma

The descriptive statistics conducted with respect to age at the time of trauma found that among the 254 cases in which clinical success was indicated, the mean age of the sample was 10.3 years (*SD* = 2.4).

Among the remaining 20 clinical failure cases there was a lower mean age of 9.0 years (*SD* = 1.8). Independent-samples *t*-test showed that this difference was statistically significant ($p = 0.021$). This result indicated that clinical successful cases were associated with significantly older patients.

Stages of Root Development

The analyses conducted between the stage of root development and clinical success were found to be statistical significant (χ^2, $p = 0.005$). The results presented in the following cross tabulation table (Table 2.4.8) indicate that clinical success was more likely to occur in cases of convergent root and complete root development compared to cases with parallel and divergent roots.

Table 2.4.8: Cross tabulation table showing the percentages of stages of root development in association to clinical success and failure.

Stage of Root Development	**Clinical Success**	
	Yes	No
Divergent root	93.3%	6.7%
Parallel root	83.8%	16.3%
*Convergent root	97.4%	2.6%
*Complete root	96.5%	3.5%
Total	92.7%	7.3%

* Indicates higher chances of clinical success.

Duration of $Ca(OH)_2$ Intra-canal Dressing

With respect to the duration of $Ca(OH)_2$ application among the 254 cases in which clinical success was achieved, the mean duration of 41.8 weeks was found (*SD* = 36.1). Among the 20 cases deemed to be clinical failures the mean duration of $Ca(OH)_2$ application was found to be 88.2 weeks (*SD* = 96.6). This was found to be statistically significance (p <0.001).

Post-Obturation Review Period

The descriptive statistics conducted on the period of review found that among the 254 cases in which clinical success was achieved, a mean of 50.1 months was found (*SD* = 36.4), while among the remaining 20 cases, a mean of 69.0 months was found (*SD* = 29.7).

Independent-samples *t*-test showed that this was statistically significant ($p = 0.025$). This result indicates that the longer the review period the higher the possibilities to detect cases with clinical failure.

Quality of Obturation

A significant association was found between the clinical success and the quality of obturation ($\chi 2$, $p = 0.013$). As shown in Table 2.4.9, the clinical success was significantly more likely to occur in cases where the quality of obturation was adequate compared to inadequate obturation.

Table 2.4.9: Cross tabulation table showing the percentages of the obturation quality in association to clinical success.

Quality of Condensation	**Clinical Success**	
	Yes	No
*Adequate	93.8%	6.2%
Inadequate	71.4%	28.6%
Total	92.7%	7.3%

* Indicates higher percentages of clinical success.

2.4.5.2 Radiographic Success

2.4.5.2.1 Factors with No Significant Associations

It was observed that some factors were non-significantly associated with radiographic success. These factors and their *p* values are summarised in Table 2.4.10.

Table 2.4.10: Shows the factors that are non-significantly associated with the radiographic success.

Factors	*p* Value
Gender	0.38
Traumatised Tooth	0.74
Associated Trauma	0.36
MTA Apical Barrier	0.23

2.4.5.2.2 Factors with Significant Association

Type of Trauma

A significant association was found between radiographic success and type of trauma (χ^2, $p < 0.001$). The following cross tabulation table (Table 2.4.11) indicates that the radiographic success was less likely to occur in cases of avulsion and intrusion.

Table 2.4.11: Cross tabulation showing the percentages of different types of trauma in relation to radiographic success.

Type of Trauma	**Radiographic Success**	
	Yes	No
Complicated crown	89.8%	10.2%
Uncomplicated crown	93.3%	6.7%
*Avulsion	39.3%	60.7%
Luxation	91.7%	8.3%
Subluxation	100.0%	0.0%
*Intrusion	80.0%	20.0%
Extrusion	100.0%	0.0%
Root fracture	100.0%	0.0%
Crown/root fracture	50.0%	50.0%
Total	85.4%	14.6%

* Indicates types of trauma associated with higher percentages of radiographic failure.

Further analysis was conducted to calculate the percentage of radiographic success after excluding avulsion injuries, and the success rate increased to 90.7%. On the other hand, the percentage of the radiographic success did not show any change after excluding the intrusion from the analysis. Finally, the success rate was calculated after excluding both avulsion and intrusion and the percentage radiographic success increased to 91.3%. The following three tables (Table 2.4.12, 2.4.13, 2.4.14) summarise these findings.

Table 2.4.12: Cross tabulation showing the percentage of different types of trauma excluding avulsion in relation to radiographic success and failure.

Type of Trauma	**Radiographic Success**	
	Yes	No
Complicated crown	89.8%	10.2%
Uncomplicated crown	93.3%	6.7%
Luxation	91.7%	8.3%
Subluxation	100.0%	0.0%
*Intrusion	80.0%	20.0%
Extrusion	100.0%	0.0%
Root fracture	100.0%	0.0%
Crown/root fracture	50.0%	50.0%
Total	90.7%	9.3%

* Indicates types of trauma associated with higher percentages of radiographic failure.

Table 2.4.13: Cross tabulation showing the percentage of different types of trauma excluding intrusion in relation to radiographic success and failure.

Type of Trauma	**Radiographic Success**	
	Yes	No
Complicated crown	89.8%	10.2%
Uncomplicated crown	93.3%	6.7%
*Avulsion	39.3%	60.7%
Luxation	91.7%	8.3%
Subluxation	100.0%	0.0%
Extrusion	100.0%	0.0%
Root fracture	100.0%	0.0%
Crown/root fracture	50.0%	50.0%
Total	85.7%	14.3%

* Indicates types of trauma associated with higher percentages of radiographic failure.

Table 2.4.14: Cross tabulation showing the percentage of different types of trauma excluding avulsion and intrusion in relation to radiographic success and failure.

Type of Trauma	**Radiographic Success**	
	Yes	No
Complicated crown	89.8%	10.2%
Uncomplicated crown	93.3%	6.7%
Luxation	91.7%	8.3%
Subluxation	100.0%	0.0%
Extrusion	100.0%	0.0%
Root fracture	100.0%	0.0%
Crown/root fracture	50.0%	50.0%
Total	91.3%	8.7%

* Indicates types of trauma associated with higher percentages of radiographic failure.

Age at Trauma

With respect to the age at the time of trauma, in the 234 cases in which radiographic success was obtained the mean age was 10.3 years (*SD* = 2.4). Among the remaining 40 radiographic failure cases, the mean age was 9.4 years (*SD* = 1.9). Independent-samples *t*-test was found to achieve significance, ($p = 0.028$). This result indicates that radiographic success was associated with significantly older patients.

Stages of Root Development

A significant association was found between radiographic success and the stage of root development (χ^2, p = 0.009). As shown in the following cross tabulation table (Table 2.4.15), radiographic success was substantially more likely to be achieved in cases with convergent root or complete root development.

Table 2.4.15: Cross tabulation table showing the percentages of stages of root development in association to radiographic success.

Stage of Root Development	**Radiographic Success**	
	Yes	No
Divergent root	80.0%	20.0%
Parallel root	75.0%	25.0%
*Convergent root	94.7%	5.3%
*Complete root	89.4%	10.6%
Total	85.4%	14.6%

* Indicates stages of root development with higher percentages of radiographic success.

Duration of $Ca(OH)_2$ Intra-canal Dressing

The descriptive statistics conducted on the duration of intra-canal $Ca(OH)_2$ dressing found that among the 234 radiographic success cases, the mean duration was 39.9 weeks (SD = 33.9).

On the other hand, among the remaining 40 radiographic failure cases, the mean duration was found to be significantly higher at 76.2 weeks (*SD* = 77.5), (p <0.001). This result indicates that the duration of $Ca(OH)_2$ was significantly longer in cases deemed to be radiographic failures.

Treatment Period

The mean treatment period for the 234 radiographic success cases was found to be 11.5 months (*SD* = 9.9). On the contrary, for the 40 radiographic failure cases, the mean treatment period was found to be 19.1 months (*SD* = 19.4). This difference was statistically significant. (p = 0.019). The results of this analysis indicated that the mean treatment period was significantly longer in cases where radiographic failure was detected.

Post-Obturation Review Period

The mean review period for the 234 radiographic success cases was found to be 49.3 months (*SD* = 36.5). However, among the remaining 40 radiographic failure cases, this was found to be 63.7 months (*SD* = 32.5). Independent-samples *t*-test showed statistical significance (p = 0.021). This result indicates that a significantly longer period of review was associated with cases in which radiographic failure was indicated.

Length of Gutta-percha Obturation

The analyses conducted on gutta-percha obturation length were found to achieve statistical significance (χ^2, p = 0.001). These results indicate that a significant association existed between this measure and radiographic success.

As shown in the following cross tabulation table (Table 2.4.16), radiographic success was more likely in cases where the gutta-percha obturation was at the working length as compared with it being long or short.

Table 2.4.16: Cross tabulation table showing the percentages of different obturation length in relation to radiographic success.

Obturation Length	**Radiographic Success**	
	Yes	No
*At the working length	89.4%	10.6%
Long	61.5%	38.5%
Short	76.7%	23.3%
Total	85.4%	14.6%

* Indicates higher percentages of radiographic success.

Quality of Obturation

The quality of obturation was significantly related to radiographic success (χ^2, *p* <0.001). As shown in Table 2.4.17, the radiographic success was substantially more likely in cases where the quality of obturation was adequate.

Table 2.4.17: Cross tabulation table showing the percentages of different categories of obturation quality in relation to radiographic success.

Quality of Condensation	**Radiographic Success**	
	Yes	No
*Adequate	87.7%	12.3%
Inadequate	42.9%	57.1%
Total	85.4%	14.6%

* Indicates higher percentages of radiographic success.

2.4.5.3 External Root Resorption

As 25 cases were shown to have external root resorption, the associations between the different prognostic factors and this outcome were studied. Table 2.4.18 summarises the factors that showed a significant association with the occurrence of external root resorption.

Table 2.4.18: Shows the factors significantly associated with external root resorption.

Factors	*p* Value	Comments
Type of Trauma	0.001	Avulsion, intrusion, and crown/root fracture were more significantly associated with root resorption
Stage of Root Development	0.043	Divergent and parallel roots were more significantly associated with root resorption
Quality of Obturation	0 .001	Inadequate obturation cases were more significantly associated with root resorption

2.4.5.4 Root Fracture

Eight teeth were found to have root fractures in our sample. The association between the prognostic factors have been studied. Table 2.4.19 summarises the factors which were found to have significant associations with root fracture.

Table 2.4.19: Summarises the factors significantly associated with root fracture.

Factors	*p* Value	Comments
Type of Trauma	0.032	There was a significant association between cases with luxation and crown/root fracture with the occurrence of fracture
Associated Trauma	0.001	Cases with associated luxation injuries were more significantly associated with root fracture compared to cases with single type of trauma
Duration of $Ca(OH)_2$	0.005	The longer the $Ca(OH)_2$ was placed in the canal the more significantly the case was associated with root fracture

2.4.5.5 Tooth Extraction

In the study sample, 19 teeth were extracted following the completion of endodontic treatment so it was necessary to evaluate the association between the extraction and the different prognostic factors. Table 2.4.20 summarises the factors that were found to have significant associations with tooth extraction.

Table 2.4.20: Summarises factors significantly associated with tooth extraction.

Factors	*p* Value	Comments
Type of Trauma	0.001	Cases with avulsion, luxation, and crown/root fracture were more significantly associated with extraction compared to the rest types of trauma
Quality of Obturation	0.011	Cases with inadequate obturation were more significantly associated with extraction compared to adequate obturation

2.4.6 Logistic Regression Analysis

A regression model was constructed based on the factors that were shown to have significant associations with the treatment outcomes in the initial bivariate analysis.

2.4.6.1 Clinical Success

In this analysis, the type of trauma, the duration of intra-canal $Ca(OH)_2$ dressing, as well as quality of obturation were found to achieve statistical significance. First, avulsion was associated with a significantly reduced likelihood of clinical success as compared with uncomplicated crown fracture cases. Next, a longer $Ca(OH)_2$ duration was also associated with a significantly reduced likelihood of clinical success. Finally, an adequate quality of obturation was associated with a significantly increased likelihood of success.

The results of the regression analysis, focusing upon clinical success, are summarised in Table 2.4.21.

Table 2.4.21: Logistic regression analysis table showing the association between the clinical success and the prognostic factors.

Category	*B*	*S.E.*	*Wald*	*df*	*Sig*	*Odds Ratio*
Trauma: Uncomplicated	1.020	0.87	1.365	1	0.243	2.774
Trauma: Avulsion	-2.821	0.71	15.848	1	*0.000	0.060
Trauma: Other	0.766	1.415	0.29	1	0.588	2.152
Age at Trauma	0.247	0.20	1.461	1	0.227	1.280
Stage of R.D Parallel	-1.166	1.159	1.012	1	0.314	0.312
Stage of R.D Convergent	-0.233	1.578	0.02	1	0.883	0.79
Stage of R.D Complete	-0.605	1.353	0.20	1	0.655	0.55
$Ca(OH)_2$ Duration	-0.012	0.005	6.689	1	*0.010	0.99
Period of Review	-0.010	0.009	1.251	1	0.263	0.99
Quality of Obturation	2.081	0.773	7.256	1	*0.007	8.012
Constant	0.96	2.225	0.18	1	0.670	2.615

B: Unstandardised coefficient, S.E: Standard error, Wald: Value for the Wald Chi-square, df: Degree of freedom, Sig: Statistic significance level.

* Indicates significance.

2.4.6.2 Radiographic Success

- When conducting the logistic regression analysis on the radiographic success, it was found that the type of trauma, the age at trauma, the duration of $Ca(OH)_2$ dressing, the length of gutta-percha obturation, as well as the quality of obturation had a significant influence on the radiographic success. In summary:
- Avulsion was associated with a significantly reduced likelihood of radiographic success compared with cases of uncomplicated crown fracture.
- Older patients had better chances for radiographic success.
- A longer $Ca(OH)_2$ duration was associated with a significantly reduced likelihood of radiographic success.
- Long gutta-percha obturation length was associated with significantly reduced success as compared to those at the working length.
- An adequate quality of obturation was associated with a significantly increased likelihood of radiographic success.

Table 2.4.22 summarises the results of the logistic regression analysis conducted on radiographic success.

Table 2.4.22: Logistic regression analysis table showing the associations between radiographic success and the prognostic factors.

Category	*B*	*S.E.*	*Wald*	*df*	*Sig.*	*Odds Ratio*
Trauma: Uncomplicated	0.672	0.685	0.964	1	0.326	1.958
Trauma: Avulsion	-3.827	0.712	28.889	1	*0.000	0.022
Trauma: Other	-1.221	0.730	2.796	1	0.094	0.295
Age at Trauma	0.311	0.157	3.940	1	*0.047	1.365
Stage of R.D.: Parallel	-0.878	0.929	0.893	1	0.345	0.416
Stage of R.D.: Converg.	-0.170	1.165	0.021	1	0.884	0.844
Stage of R.D.: Complete	-1.131	1.033	1.199	1	0.274	0.323
$Ca(OH)_2$ Duration	-0.050	0.019	6.925	1	*0.009	0.951
Treatment Period	0.128	0.072	3.142	1	0.076	1.137
Period of Review	-0.004	0.007	0.331	1	0.565	0.996
Obturation Length: Long	-2.364	0.696	11.548	1	*0.001	0.094
Obturation Length: At WL	-0.572	0.719	0.635	1	0.426	0.564
Quality of Obturation	2.595	0.857	9.178	1	*0.002	13.396
Constant	-0.396	1.884	0.044	1	0.834	0.673

B: Unstandardised coefficient, S.E: Standard error, Wald: Value for the Wald Chi-square, df: Degree of freedom, Sig: Statistic significance level.

* Indicates significance.

2.4.6.3 External Root Resorption

When conducting logistic regression analysis on root resorption, it was found that the type of trauma and the quality of obturation were significantly associated with this outcome. Avulsion was associated with a significantly increased likelihood of root resorption as compared with uncomplicated crown fracture. On the other hand, an adequate quality of obturation was associated with a significantly reduced likelihood of root resorption. Table 2.4.23 summarises the results of the logistic regression conducted on root resorption.

Table 2.4.23: Logistic regression analysis table showing the association between the external root resorption and the prognostic factors.

Category	*B*	*S.E.*	*Wald*	*df*	*Sig.*	*Odds Ratio*
Trauma: Uncomplicated	-2.119	1.423	2.219	1	0.136	0.120
Trauma: Avulsion	5.079	1.085	21.919	1	*0.000	160.691
Trauma: Other	2.222	1.208	3.385	1	0.066	9.227
Stage of R.D. Parallel	-0.279	1.065	0.069	1	0.793	0.756
Stage of R.D. Convergent	-18.475	5514.02	0.000	1	0.997	0.000
Stage of R.D. Complete	-0.044	1.041	0.002	1	0.966	0.957
$Ca(OH)_2$ Duration	0.045	0.030	2.192	1	0.139	1.046
Treatment Period	-0.105	0.118	0.799	1	0.371	0.900
Period of Review	0.006	0.009	0.447	1	0.504	1.006
Quality of Obturation	-4.619	1.237	13.954	1	*0.000	0.010
Constant	-1.225	1.294	0.897	1	0.344	0.294

B: Unstandardised coefficient, S.E: Standard error, Wald: Value for the Wald Chi-square, df: Degree of freedom, Sig: Statistic significance level.

2.4.6.4 Root Fracture

Table 2.4.24 presents the results of the logistic regression analysis conducted on root fracture. In this analysis, none of these predictors were found to achieve statistical significance.

Table 2.4.24: Logistic regression analysis table showing the association between root fracture and the prognostic factors.

Category	*B*	*S.E.*	*Wald*	*df*	*Sig.*	*Odds Ratio*
Trauma:Uncomplicated	-17.126	4487.23	0.000	1	0.997	0.000
Trauma: Avulsion	0.766	1.234	0.386	1	0.535	2.152
Trauma: Other	1.353	0.910	2.213	1	0.137	3.870
Associated Trauma	-1.317	0.950	1.923	1	0.165	0.268
$Ca(OH)_2$ Duration	0.070	0.038	3.472	1	0.062	1.073
Treatment Period	-0.245	0.148	2.752	1	0.097	0.782
Constant	-1.844	1.843	1.001	1	0.317	0.158

B: Unstandardised coefficient, S.E: Standard error, Wald: Value for the Wald Chi-square, df: Degree of freedom, Sig: Statistic significance level.

2.4.6.5 Tooth Extraction

When the logistic regression analysis was conducted on tooth extraction, only the type of trauma and the quality of obturation were found to achieve statistical significance. Avulsion was associated with a significantly increased likelihood of tooth extraction as compared with uncomplicated crown fracture. On the other hand, an adequate quality of obturation was found to be associated with a significantly reduced likelihood of tooth extraction. Finally, Table 2.4.25 summarises the results of the logistic regression analysis conducted on tooth extraction.

Table 2.4.25: Logistic regression analysis table showing the association between tooth extraction and the prognostic factors.

Category	*B*	*S.E.*	*Wald*	*df*	*Sig.*	*Odds Ratio*
Trauma: Uncomplicated	-1.099	1.127	0.950	1	0.330	0.333
Trauma: Avulsion	2.714	0.677	16.068	1	*0.000	15.095
Trauma: Other	1.370	0.758	3.263	1	0.071	3.935
Quality of Obturation	-2.516	0.823	9.349	1	*0.002	0.081
Constant	-1.131	0.726	2.425	1	0.119	0.323

B: Unstandardised coefficient, S.E: Standard error, Wald: Value for the Wald Chi-square, df: Degree of freedom, Sig: Statistic significance level

* Indicates significance.

Section Five

Discussion

2.5.1 Introduction

The current study has provided the opportunity to evaluate the long-term clinical and radiographic success of Obtura-II injectable thermoplasticised gutta-percha technique in children. This medium- to long-term outcome of this technique has seldom been reported before, especially in the case of traumatised young incisors, including those with incomplete root development as in the case of young children. In addition, it allowed us to study the effect of several demographic and prognostic factors on the treatment outcomes.

A comprehensive discussion of the methodology and the results of the current study and their comparison to studies published previously in the literature are detailed in this chapter.

2.5.2 Study Aims Appraisal

The aim of conducting this research was centred on evaluating the clinical and radiographic success of Obtura-II system injectable thermoplasticised gutta-percha in traumatised non-vital young incisors in children. In addition, the research had a secondary aim of analysing the effect of different prognostic factors on the long-term outcome of Obtura-II in this situation. Although three studies were found in which the clinical and the radiographic success of the Obtura technique were evaluated (Marlin et al., 1981, Sobarzo-Navarro, 1991, Tani-Ishii and Teranaka, 2003), all of these studies were carried out on an adult population. These studies evaluated the outcomes of the Obtura technique in incisors, premolars and molar teeth. Furthermore, Tani-Ishii and Teranaka (2003) evaluated the effect of the obturation length on the success rate. However, none of the aforementioned studies examined the effects of any other prognostic factors on the success rate of the Obtura technique. Finally, the post-obturation follow-up period was relatively short, as the longest period reported in these studies was 12 months (Tani-Ishii and Teranaka, 2003).

Traumatic dental injuries are very common in children. According to Glendor (2008), 25% of school children had experienced TDIs at some stage prior to leaving school (Glendor, 2008). In addition, TDIs are associated with serious complications when they occur at early age in a growing child. It has been highlighted that TDIs are the most common cause of loss of pulp vitality in immature teeth (Sarris et al., 2008). As it is important to preserve these teeth, endodontic and restorative treatments are required. Obtura-II technique has been commonly used in endodontic treatment in children for several years; however, this technique has never been evaluated in children. Following the completion of an in-depth literature review, no studies with the same aims as the present study were found to be published; therefore, it was recognised as important to conduct a study evaluating the medium- and long-term outcomes of Obtura-II in traumatised non-vital immature teeth in children.

2.5.3 Appraisal of the Methodology

2.5.3.1 Obtaining Ethical Approval

When conducting a study dealing with data derived from humans, it is essential to maintain high scientific standards of accuracy and evidence. In addition, it is equally important to ensure that the study is acceptable morally by maintaining ethical standards. The World Medical Association's Declaration of Helsinki states clearly the importance of obtaining ethical approval prior to conducting studies involving human participants or otherwise acquiring data extracted from humans.

Accordingly, prior to conducting the current study, ethical approval was obtained from the Dental Research Ethics Committee (DREC) at Leeds Dental Institute. In addition, the National Research Ethics Service (NRES) was contacted, which advised that the DREC ethical approval was sufficient in order for us to proceed with this study.

2.5.3.2 Study Design

The Obtura-II technique has been used for several years in the endodontic treatment of traumatised non-vital immature teeth in children at the Paediatric Dentistry Department at Leeds Dental Institute. However, this technique, along with its outcomes, has never been evaluated previously. The clinical dental records, including existing data recorded by clinicians who treated such patients using the Obtura-II technique, in addition to the periapical radiographs, are available as from the year 2003. After obtaining experts' opinions, it was considered important that a study be conducted evaluating the outcomes of Obtura-II and the various factors that could influence the clinical and radiographic outcomes. It has been shown that carrying out a retrospective study in the field of dental trauma is valuable. Most of the studies available in the literature concerning the prevalence, causes and treatment outcomes of TDIs are of a retrospective design (Andreasen, 2013). With this noted, this study was designed as a retrospective study to evaluate the clinical and radiographic success of obtura-II system; therefore, the clinical dental records and the periapical radiographs of paediatric patients from 2003 up to 2011 were evaluated.

2.5.3.3 Classifications and Evaluation Criteria

2.5.3.3.1 Stages of Root Development

In this study, the pre-operative periapical radiographs were evaluated with the objective to determine the stage of root development of traumatised tooth at time of trauma. The scale described by Dominguez Reyes *et al*. (2005) in their study of $Ca(OH)_2$ apexification in young permanent incisors was adopted for this study. This scale classified the stages of root development according to the shape of the apex into three distinct categories (Dominguez Reyes et al., 2005). After evaluating several scales, this particular scale was selected as it is easy to use and provided reproducible measures when used by the investigator to determine the stage of root development radiographically. In present study, all periapical radiographs were taken at the same Radiography Department. Furthermore, it is important to highlight that, although these radiographs were taken by several radiographers over a period of time, the Leeds Dental Institute follows a standardised technique for film positioning and exposure for all patients. Finally, the periapical radiographs were initially evaluated by two investigators of the study (AF and MSD), ensuring that the scale was used accurately and consistently.

2.5.3.3.2 Criteria for Success and Failure

Strindberg (1956) conducted the first scientific evaluation of endodontic treatment, and emphasised the importance of establishing criteria to determine the success of these treatments (Strindberg, 1956). Over the years, several studies have followed different criteria for evaluating the endodontic treatment outcomes; however, the outcomes are commonly evaluated through analysing the radiographic findings and the presence or absence of clinical signs and symptoms (Ng et al., 2010).

In order to study accurately the endodontic treatment outcomes of the Obtura-II technique, validated and tested criteria set by the European Society of Endodontology (2006) were followed for our study (Loest, 2006). It was important to use a wide range of parameters in order to evaluate the clinical success as one parameter cannot describe comprehensively the clinical picture. In addition, radiographic evaluation took place in order to confirm the clinical findings as the clinical evaluation, by itself, in children could lead to inconsistent findings. Finally, in order to ensure the accuracy and reliability of radiographic evaluation of the outcomes, 15% of the cases were evaluated by two investigators of the study. Radiographically, cases were assessed based on the aforementioned criteria in section three (Materials and Methods). Root resorption is common sequelae following traumatic dental injuries mainly with those associated with injuries to the periodontal ligament. As a consequence, the periapical radiographs were carefully assessed for signs of resorption. Cases with radiographic signs of non-progressive surface resorption up to one year following TDIs were considered successful. On the other hand, cases with clear radiographic signs of progressive replacement resorption in a year following TDI were considered a radiographical failure.

2.5.3.4 Statistical Analysis of the Data

2.5.3.4.1 Study Sample

In a retrospective study, the population characteristics and the method of sampling are vital in minimising the uncontrolled variables. There were no similar published studies in the literature; therefore, no estimate could be used to determine the sample size. Initially, 667 clinical dental records with 1,181 traumatised teeth of children who attended the trauma clinic at the Paediatric Dentistry Department at Leeds Dental Institute were screened. A total of 235 clinical dental records of children with 274 traumatised teeth met the inclusion criteria. The sample size of our study (235 cases) was within the range (150–250 cases) recommended by the biostatistician (JK).

2.5.2.4.2 Statistical Tests

Statistical advice was obtained with regard to the statistical tools and tests required to analyse the data of the current study. In order to fulfil the aims of the study, several tests were implemented. Initially, a series of descriptive statistics were conducted on the data, including percentages, tables, and bar and pie charts. Secondly, a series of bivariate analyses were conducted in order to determine whether or not significant associations exist between the predictor of interest (demographic and prognostic factors) and the outcomes (clinical and radiographic success). Chi-square analysis was conducted, along with Fisher's exact test and phi coefficient. The level of significant was set at 95% confidence interval and p value < 0.05. Finally, a series of logistic regression analyses were conducted. The regression models were constructed based on the variables found to be significant in the initial bivariate analysis.

2.5.4 Results

2.5.4.1 Demographic Factors

Discussion is presented on the demographic characteristics of the sample in the study.

2.5.4.1.1 Gender

Gender has been reported by several studies to be a well-recognised risk variable of TDIs (Andreasen, 2013). Boys have been reported to suffer more TDIs than girls with a ratio of 2:1 (Glendor, 2008). This is explained mainly by the higher participation of boys in leisure activities and contact sports. In this study, boys were found to suffer more TDIs with a percentage of 58.7% compared with girls, although the ratio was not equal to 2:1. The changes in gender prevalence and higher TDIs in girl is due to the fact that girls are more involved in sports that were traditionally considered boys' sports (Glendor, 2008, Andreasen, 2013), which could go some way to explaining the small gender difference reported in this study. Moreover, as this study was retrospective and inclusion criteria were adhered to strictly, it might well be that the sample was not representative of the true gender distribution of trauma that is otherwise found in the population.

Furthermore, gender was not found to be a significant factor affecting the clinical or radiographic success of Obtura-II technique. This finding is similar to that reported by most of the epidemiological studies evaluating the factors influencing the endodontic success rate.

2.5.3.1.2 Age at Trauma

Age is a well-known risk variable of TDIs. It has been reported that the peak incidence of TDIs in permanent teeth varies between 7-10 years of age (Al-Jundi, 2002, Glendor, 2008, Andreasen, 2013). In addition, several epidemiological studies carried out in other countries have reported a peak TDIs age of 10-12 years (Hamdan and Rock, 1995, Al-Jundi, 2002). In this study, the mean age at the time of trauma was 10.2 years, which is similar to that reported by other studies. This may be due to the fact that children, at this age, are participating more in sports and physical activities, and are therefore more prone to TDIs. The minimum age in this study was six years whilst the maximum age was 21 years. Although the Paediatric Dentistry Department at Leeds Dental Institute treats children up to the age of 16 years, some of the older patients with leaning difficulties and developmental delay who suffered TDIs and required special care were also treated in the department.

Several studies have highlighted that the age of the patient was not considered a strong factor affecting the endodontic success rate; however, few studies have reported that the success rate might reduce with the increase of age as a result of a reduction in the healing ability of older patients (Ng et al., 2010). Importantly, none of these studies evaluated the effect of age on the endodontic success rate in children population. In this study, age was a significant factor affecting both the clinical and radiographic success of Obtura-II. It was found that the mean age of patients was 10.3 years in the successful cases whereas it was found to be 9.0 years in the clinical failure cases and 9.4 years in the radiographic failure cases. This indicates that the older the age of the child with a traumatised tooth, the higher the chances of obtaining successful root canal treatment utilising Obtura-II system. This can be explained as the older the child, the more developed the tooth with a smaller apical opening and thicker dentinal walls facilitating the root canal treatment.

2.5.4.2 Prognostic Factors

2.5.4.2.1 Teeth Involved in Trauma

In this study, the upper-right central incisor was the tooth most commonly involved in TDIs, accounting for 44.9% followed by the upper left central incisor. This finding is comparable to what is highlighted in the literature, where the maxillary central incisors are the teeth more susceptible to TDIs (Gassner et al., 1999). These teeth are more likely to sustain damage mainly owing to their vulnerable position. Due to the fact that only anterior teeth with similar anatomical configurations were included in this study, no statistical significant differences in the success rate were found between different teeth. Ng *el al*. (2010) reported that, although multi-rooted teeth have more complex root canal anatomy compared with single-rooted teeth, studies have not demonstrated any significant differences in the success of root canal treatment of these teeth (Ng et al., 2010).

2.5.4.2.2 Type of Trauma

Crown fracture was the most common type of trauma reported in this study. Our findings coincided with those reported by Andreasen (2013), who highlighted that fractures are the most common type of TDI to occur in permanent teeth. However, they also reported that enamel fractures, followed by uncomplicated crown fractures, are the types reported most commonly (Andreasen, 2013). On the contrary, we found that 46.7% of the cases suffered complicated crown fractures and 27.4% were uncomplicated crown fractures, which could be due to the fact that cases with enamel fracture and uncomplicated crown fractures can be easily treated by the general dental practitioners. However, challenging cases with complicated crown fractures that required root canal treatment of immature teeth are the type of cases mainly referred to specialists.

After analysing the data, it was found that avulsion and intrusion were significantly associated with higher chances of clinical and radiographic failures of Obtura-II technique. No previous study was found evaluating the effect of different types of trauma on the endodontic success rate in children compared to our findings. However, this finding is expected as avulsion and intrusion are more aggressive types of trauma resulting in the destruction of the periodontal ligament and therefore less chances of healing. However, it must be pointed out that the failure in this group cannot be attributed to the obturation technique under study, but due to a higher rate of external root resorption, as would be expected in cases of avulsed and replanted teeth, and also for teeth that have had surgical or orthodontic repositioning after severe intrusion injuries. This is supported by our findings that the radiographic success rate increased from 85.4% to 91.3% when excluding the avulsion and intrusion cases from the analysis.

2.5.4.2.3 Stages of Root Development

The findings of this study confirmed that the stage of root development was a significant factor affecting the success rate of Obtura-II technique in non-vital traumatised immature teeth. Complete root development and convergent roots were associated with more successful cases compared with divergent and parallel roots. Our findings could not be compared with other studies as the stages of root development have never been evaluated as a factor affecting the endodontic outcomes in children previously. However, such findings could be explained logically. The divergent and parallel roots have wider open apices compared with the complete and convergent roots. Moreover, the root canals of these teeth have less cementum and dentine, making them brittle and meaning they can fracture more easily under physiological forces. Finally, the crown root ratio in immature teeth with divergent and parallel roots could be compromised. As a consequence, the root canal treatment will be more difficult with lower success chances in these teeth.

2.5.4.2.4 Duration of $Ca(OH)_2$ Intra-Canal Dressing

The data analysis showed that the duration of $Ca(OH)_2$ intra-canal dressing was inversely associated with the success rate. The mean duration of $Ca(OH)_2$ in the clinical and radiographic failures was longer than that of the successful cases. To our knowledge, there are no studies in the literature that looked at the effect and length of intra-canal dressing with $Ca(OH)_2$ on the Obtura-II technique outcomes in traumatised teeth in children. However, several studies have confirmed the adverse effects of the long-term application of $Ca(OH)_2$ prior to final root canal obturation. The long-term exposure to $Ca(OH)_2$ weakens the dentine owing to its proteolytic action and its role in the desiccation of dentinal protein (Andreasen et al., 2006). Accordingly, fracture resistance will decrease, making these teeth more liable to cervical fracture—even under physiological forces (Cvek, 1992, Rosenberg et al., 2007, Twati et al., 2009).

Finally, the long period of $Ca(OH)_2$ dressing means that teeth will be maintained with temporary restorations for a long period of time, with such temporary restoration possibly fractured or not affording a good coronal seal in between visits, leading to the contamination of the root canal space and hence decreasing the chances of success.

2.5.4.2.5 Length of Gutta-Percha Obturation

In the present study, it was found that 80% of the cases had obturation at the working length. Long obturation, extending beyond the apex, was found in almost 10% of cases, where 11% of cases had short obturation. However, no statistical significance was found between the different obturation lengths and the clinical success rate. This finding is similar to that reported by Tani-Ishii and Teranaka (2003), who compared the success rate of Obtura-II in different teeth with different obturation lengths but in adults. They reported that, when the root canal fillings were flush, over or short, the success rates were 97%, 93% and 93%, respectively. Moreover, there were no significant differences between the different groups. Although the long root filling beyond the apex is considered an unnecessary invasion to the surrounding tissues, researchers have stated that these tissues have high tolerance toward most biocompatible root filling materials. In addition, it has been shown that an excess of endodontic sealer can be absorbed by the supporting tissues in three months and that the prognosis is generally good (Nguyen, 1994). However, in this study, the length of obturation was significantly associated with the radiographic success. Our analysis has shown that the radiographic success was more likely to occur in cases where the gutta-percha obturation was at the working length compared with long and short obturations. This finding is consistent with that reported by Ng *et al*. (2010) in their recent literature review regarding the factors affecting endodontic success. Although gutta-percha and endodontic sealers are biocompatible materials, when they extrude beyond the apex, however, irritation of the periapical tissue can arise. In addition, long obturation is commonly preceded by over instrumentation, which may push the pulp remnants and microorganisms beyond the apex, thus leading to higher failure rates (Basmadjian-Charles et al., 2002).

2.5.4.2.6 Quality of Obturation

In the present study, the quality of obturation had significantly affected the clinical and radiographic success. It has been found that the cases with adequate obturation accounted for almost 95% of the sample, and were more commonly associated with success compared with inadequate obturation. The quality of root canal filling is considered an important factor influencing the success rate of endodontic treatment. Ng *et al*. (2010) reported a 25.9% lesser chance of healing in root canals showing inadequate endodontic filling radiographically. Moreover, it has been reported that cases with radiographic evidence of voids had significantly lower success rates than those not presenting any radiographic signs of heterogeneous root canal filling. In our study it was noted that most of the obturations were carried out by postgraduate students. However, it is accepted that postgraduate students may have required considerable supervision and help during the patient treatment sessions. This is especially true for the postgraduate students in the early years of their education. Senior postgraduate students can usually carry out this treatment to completion with limited supervision only.

2.5.4.2.7 Treatment Period

The effect of the number of treatment visits on the outcomes seems to be a controversial issue when comparing different opinions highlighted in the literature. However, in their systematic review, Figini *et al*. (2008) reported no significant differences when evaluating the radiographic treatment outcomes of a single- or multiple-visit root canal treatment. Similarly, our analysis revealed that the treatment period was not significantly associated with the clinical success rate of Obtura-II system. On the other hand, this study showed that the radiographic success was significantly affected by the treatment period. It was shown that the mean treatment period of the successful cases (11.5 months) was less than that of the failure cases (19.1 months). Longer treatment period means a delay in both the final root canal treatment and the coronal restoration. In addition, the temporary coronal restoration could be lost at any point of the long treatment period, subsequently elevating the risk of bacterial contamination of the root canal system and decrease the healing susceptibility.

2.5.4.2.8 Post-Obturation Review Period

The follow-up period, after commencing root canal treatment, is a critical factor affecting the success rate—especially in the sense of radiographic changes. Radiographic changes—whether healing or pathology—will not be evident before six months post-operatively. Accordingly, several studies suggested a follow-up period of at least one year (Ng et al., 2010). In the present study, the clinical dental records and the periapical radiographs of patients who had their treatment in the period between 2003 and 2011 were evaluated in 2012, ensuring at least a one-year follow-up period, as recommended by the European Society of Endodontology (2006) (Loest, 2006).

Furthermore, cases with severe traumatic dental injuries that could be associated with complications are usually followed up for a longer period of time compared to the stable cases that could be discharged earlier. This is the likely explanation as to why those cases classified as a failure were followed up for a longer period.

2.5.4.3 Clinical Success

Endodontic treatment success rates range widely between 31% and 100% between different studies (Ng et al., 2010). Studies that have followed strict evaluation criteria reported success rates of up to 96%. On the contrary, most of the studies that followed loose criteria reported success rates up to 100% (Ng et al., 2008). In addition, different obturation techniques have been evaluated in different studies. However, the Obtura-II technique has never been evaluated previously in regard to children. In the present study, the clinical success rate of Obtura-II was 92.7%; this percentage is within the range reported by studies following strict evaluation criteria. Tani-Ishii and Teranaka (2003) reported a success rate of 96% when Obtura-II was used in adult patients. However, the results of this study cannot be directly compared to our study. Notably, the lower success rate reported by the present study could be due to the fact that the sample comprised traumatised immature teeth in children. These teeth have an insufficient amount of cementum and dentine in addition to the wide open apex that render obturation a challenging task compared with fully developed teeth. Furthermore, the post-operative follow-up period in the study by Tani-Ishii and Teranaka (2003) was of 12 months, whereas the mean follow-up period in the present study was 51 months.

2.5.4.4 Radiographic Success

Conveniently chosen, 15% of the periapical radiographs of the study sample were assessed by two investigators at the same time in order to assure that the radiographic evaluation criteria were followed accurately and consistently. The periapical radiographs in the present study were evaluated strictly in adherence to the radiographic evaluation criteria set by the European Society of Endodontology (2006). Several studies have evaluated the radiographic features of thermoplasticised gutta-percha Obtura technique. Upon first introducing this technique, Yee *et al*. (1977) reported that it had a good adaptation and sealing ability when evaluated radiographically. Later, many studies had confirmed this finding when the technique had been evaluated radiographically both *in vivo and in vitro*. Radiographically, the Obtura technique showed an excellent adaptation into the root canal system and replicated its irregularities (Marlin et al., 1981, Budd et al., 1991, Gutmann, 1993). When the radiographic success of this technique has been evaluated in adult teeth after the 12 months' post-operative follow-up period, Tani-Ishii and Teranaka (2003) reported a success rate of 96%.

In the present study, it was observed that 85.4% of the cases were considered radiographically successful; however, owing to the lack of studies of a similar nature in the literature, it was difficult to compare these findings with those published previously. More than half of the failure cases in this sample (62.5% of the radiographic failures) were due to the increase in the size of the periapical radiolucency following root canal treatment. Several studies reported that the presence of periapical radiolucency, which indicates the presence of anaerobic bacteria in the infected canals, thus lowering the success rate. Owing to the complex anatomy of the immature non-vital permanent incisors and their wide-open apices, the removal of the necrotic debris is extremely difficult. Furthermore, such root canals are difficult to be instrumented and irrigated, thus reducing the chances of thorough bacterial debridement and consequently the radiographic success rates. Although the presence of preoperative periapical radiolucency can lower the chances of success rate, researchers did not report significant differences in the success rate between different sizes of these lesions preoperatively. However, it has been highlighted that, the larger the lesion, the longer the period of time required for healing (Ng et al., 2010). In addition, most of the studies reported higher radiographic success rates had a maximum follow-up period of 12 months, whereas the mean follow-up period in the present study was 51 months with a maximum follow-up period of 120 months. According to Jokinen *et al.* (1978), the vast majority of failure cases were noticed mainly radiographically two years post-operatively.

2.5.5 Study Limitations and Challenges Encountered

Obtura-II injectable thermoplasticised gutta-percha has been used for several years in endodontics to treat immature non-vital teeth in children; however, the outcomes of this technique have never been evaluated before. Therefore, a retrospective study was designed to evaluate this technique and to assess the various prognostic factors that may determine its outcome. One of the main problems encountered which the present study depended on was the details recorded in the clinical dental records for clinical reasons rather than for the aim of the research. Although there is a specially designed trauma sheet available in the clinical dental record, some of these records were not completed, and specific research information was difficult to extract. It is inevitable that clinical records would be completed to varying degrees of accuracy and conscientiousness by various clinicians. In addition, it is important to highlight that these records were documented by different clinicians with a range of clinical experience, ranging from postgraduate students to consultants.

It was also difficult to decide on a reasonable and scientifically valid sample size as there were no similar studies carried out previously and published in the literature that could be used as a guide.

2.5.6 Future Research

Our study is the first study of its kind and therefore provides an original investigation into this subject. Although we feel that the study findings are valid, a larger prospective research will be necessary in order to confirm the validity and superiority of using Obtura-II system injectable thermoplasticised gutta-percha in non-vital immature traumatised teeth. It has been confirmed in the present study that using the Obtura-II system in treating non-vital immature traumatised teeth can result in high success rates in the long-term. However, no similar data against which these findings could be compared has been published previously.

Furthermore, it would be beneficial to design a clinical prospective study in which the patients who received endodontic treatment using the Obtura-II system can be reviewed and evaluated clinically, and accordingly compared with alternative methods of obturation as employed generally by most clinicians. Several studies have, from different clinical aspects, compared Obtura-II with other commonly used obturation techniques in the adult population. Many studies highlighted the superiority of Obtura-II in comparison with other techniques. However, such types of comparison study have never been conducted on a child population. Various endodontic techniques are used to accomplish the obturation of the root canal space in children, such as the lateral condensation, using MTA, and the thermoplasticised injectable gutta-percha. Accordingly, a comparative prospective study in traumatised immature teeth would allow this evaluation to be carried out.

In the present study, the teeth that had $Ca(OH)_2$ apexification and those with MTA apical plug followed by a final obturation using Obtura-II were included. Such techniques have different characteristics and effects on the teeth; therefore, it would be prudent to conduct two distinct studies evaluating the Obtura-II system in children: one with $Ca(OH)_2$ apexification and one with MTA apical plug. However, it should also be considered that apexification with calcium hydroxide is now seldom used and the prolonged use of calcium hydroxide in root canals of immature teeth is now discouraged.

Section Six

Conclusion

The following conclusions can be drawn from the reported findings of the current study:

1. Root canal obturation with the use of Obtura-II technique utilising thermoplasticised gutta-percha was considered to be clinically successful in 92.7% of the cases in young non-vital traumatised teeth in children.

2. Root canal obturation with Obtura-II technique was considered to be radiographically successful in 85.4% of the cases in immature young non-vital traumatised teeth in children.

3. The mean post-operative follow-up period for which the success rates were evaluated was 51 months.

4. The quality of the root canal treatment was considered to be adequate in 95% of the cases. In addition, 80% were judged to be obturated to the working length, 10% were-overfilled and 11% were under-filled.

5. Several demographic and prognostic factors individually were deemed to have significant effects on the clinical and radiographic success of Obtura-II technique when used in children. Accordingly, the null hypothesis was rejected.

    - The factors significantly affecting both the clinical and the radiographic success were: age at trauma, stage of root development, type of trauma, duration of $Ca(OH)_2$ dressing, quality of obturation, and the review period.

- The factors significantly affecting the radiographic success were: the length of obturation and the treatment period.

6. Based on the regression analysis findings some factors were found to significantly influence the treatment outcomes:

    - The factors significantly affecting the clinical success rate were: type of trauma, duration of $Ca(OH)_2$ dressing, and the quality of obturation.

    - The factors significantly affecting the radiographic success were: type of trauma, age at trauma, duration of $Ca(OH)_2$ dressing, length and quality of obturation.

Chapter Three

A Pilot Study of the Clinical and Radiographic Outcomes of Root Canal Obturation with Obtura-II System using Thermoplasticised Gutta-percha in Auto-transplanted Teeth

Abstract

Background: Obtura-II injectable thermoplasticised gutta-percha has been available for several years; however, the success of this approach has never been assessed in auto-transplanted teeth that have replaced non-restorable traumatised teeth in children.

Aim: Evaluating the clinical and radiographic success of Obtura-II as a root canal technique in the endodontic treatment of the auto-transplanted teeth in children; and determining the effect of different demographic and prognostic factors on success rates.

Method: The study was designed as a retrospective pilot study, evaluating the clinical and radiographic outcomes of the Obtura-II injectable thermoplasticised gutta-percha technique. A convenience sample of 41 clinical dental records and periapical radiographs of patients who had undergone auto-transplantation at the Paediatric Dentistry Department at Leeds Dental Institute in the period 2003–2011 were evaluated. The obturated teeth were classified as successful or failure according to criteria developed for this study. Various prognostic factors that could influence the outcome of the technique were recorded using a special data extraction proforma. The data were entered into SPSS, with simple descriptive analysis and bivariate analyses conducted.

Results: Forty-nine (49) premolar auto-transplanted teeth met the inclusion criteria. All teeth were considered clinically successful with the exception of one tooth. Radiographically, 45 were deemed successful and four as failures. The Chi-square test revealed that clinical success was not significantly affected by any of the factors tested. However, the radiographic success was significantly associated with the post-obturation review period ($p < 0.05$).

Conclusion: Using the Obtura-II system in the root canal, the treatment of auto-transplanted teeth was considered clinically successful in 97.9% of cases and radiographically successful in 93.8% of cases. Clinical success was not affected by any of the prognostic factors, whilst radiographic success was significantly affected by the review period.

Section One

Introduction

After reviewing the literature, it has been concluded that several studies have evaluated the auto-transplantation procedure, its advantages and disadvantages. In addition, the success and survival rate of the procedure, and the prognostic factors affecting the outcome have been highlighted. Although it is recommended that the auto-transplanted teeth should be endodontically treated 7–14 days following the surgery, no studies have been found in the literature to centre on evaluating the endodontic treatment in these transplanted teeth in children; therefore, it was considered necessary to evaluate the endodontic treatment outcomes in the teeth that had been auto-transplanted in children in the Department of Paediatric Dentistry at the Leeds Dental Institute. In addition, we wanted to evaluate the influence of the different prognostic factors on the success rates of endodontically treated auto-transplanted teeth.

Section Two

Research Aims, Questions, and Hypothesis

3.2.1 Aims

- To evaluate the clinical and radiographic success of root canal obturation carried out with the use of thermoplasticised gutta-percha Obtura-II system in auto-transplanted teeth in children.
- To study the effect of several prognostic factors on the success rate of this technique in auto-transplanted teeth.

3.2.2 Research Questions

The study defined two questions that should be answered upon completion. The questions are:

1. What are the clinical and the radiographic success rates for endodontic treatment of auto-transplanted teeth which have root canal obturation with the Obtura-II technique?
2. What are the different prognostic factors, if any; influencing the clinical and radiographic success of these teeth treated using Obtura-II technique?

3.2.3 Research Hypothesis – Null Hypothesis

There is no association between any of the prognostic factors and the clinical and radiographic success of Obtura-II injectable thermoplasticised gutta-percha in the endodontic treatment of auto-transplanted teeth in children.

Section Three

Materials and Methods

The same methodology, as presented in detail in chapter two section three, was followed in order to conduct this part of the study; however, as this part focuses on evaluating the success of thermoplasticised gutta-percha (Obtura-II system) in auto-transplanted teeth, special inclusion and exclusion criteria were set. Furthermore, additional prognostic factors were evaluated in this part of the study. A special data-extraction proforma was designed for this part of the research (see Appendix 4).

3.3.1 Prognostic Factors

- Age at premolar transplant (PMT) procedure
- Transplanted teeth
- Stages of root development of transplanted teeth.

3.3.2 Inclusion Criteria

- Clinical dental records of patients who attended the trauma clinic at the Paediatric Dentistry Department at Leeds Dental Institute after experiencing dental trauma which led to loss of vitality of at least one permanent incisor.
- Clinical dental records of patients who had auto-transplant replacing traumatised non-restorable permanent incisors.
- Clinical dental records of patients who had their auto-transplanted teeth endodontically treated with thermoplasticised gutta-percha (Obtura-II system).
- Follow-up period following final obturation with Obtura-II system of at least one year at the Paediatric Dentistry Department at Leeds Dental Institute.

3.3.3 Exclusion Criteria

- Clinical dental records of patients who had teeth auto-transplantation after losing maxillary permanent incisors due to any reasons other than trauma.
- Clinical dental records of patients who had auto-transplantation and the transplanted teeth remained vital.
- Subjects with follow-up periods of less than one year following the final obturation using Obtura-II system.

3.3.4 Sample Size Calculation

Due to the fact that there were no similar studies in the literature, there were no estimates that could be used for the sample size calculation. Therefore, it was agreed that, following statistical consultation, this study should be considered an exploratory pilot study, which can be used in future to determine the sample size of similar studies.

Section Four

Results

3.4.1 Statistical Tests

All data gathered were entered into SPSS (Statistical Package for Social Science, Version 19) for Windows (SPSS Inc. Chicago, IL) software for analysis.

A series of descriptive statistics were performed on the data, including percentages, mean, standard deviation (SD). For numerical variables, the maximum and minimum values were calculated. Finally, Chi-square test, Fishers' exact test and independent t-test were applied with the aim of studying the association between the demographic and prognostic factors with the clinical and radiographic outcomes.

3.4.2 Study Sample

Eighty-one (81) clinical dental records with 103 auto-transplanted teeth of children patients who attended the trauma clinic at the Paediatric Dentistry Department at Leeds Dental Institute in the period between 2003 and 2011 were screened. A total of 41 cases with 49 root-treated auto-transplanted teeth met the inclusion criteria.

3.4.3 Demographic Factors—Descriptive Statistics

3.4.3.1 Gender

From the 41 cases, 30 (73.2%) were males whilst 11 (26.8%) were females.

3.4.3.2 Age at Trauma

The mean age of the patients at the time of trauma was 10.5 years with a standard deviation of 1.7 years.

3.4.4 Prognostic Factors—Descriptive Statistics

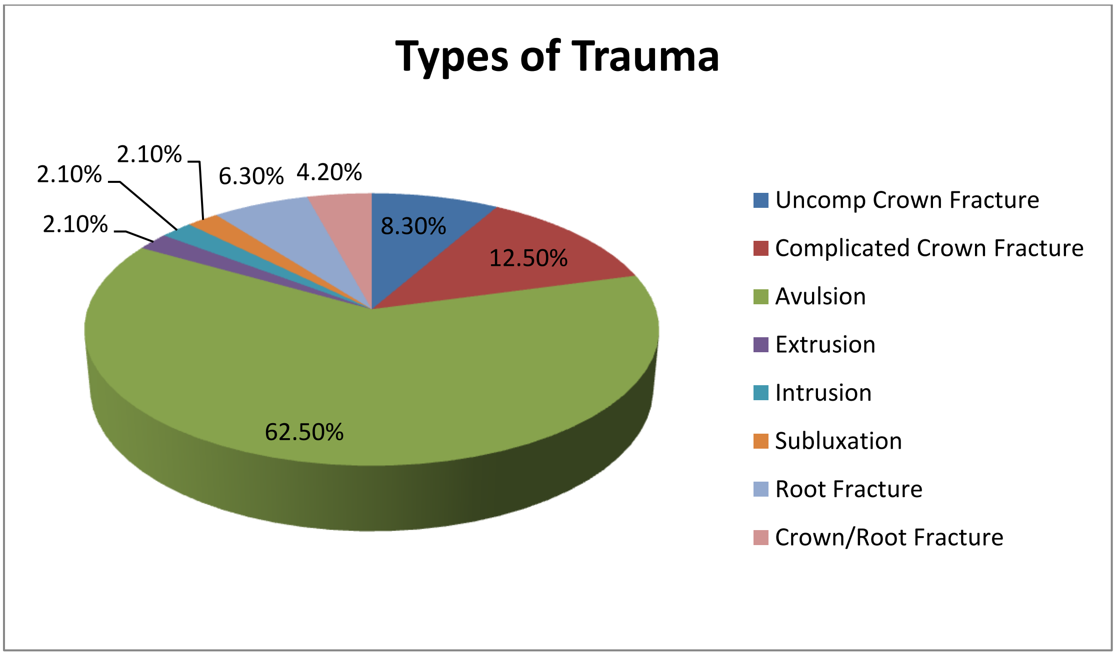
3.4.4.1 Teeth Involved in Trauma

It was found that 54% (N=26) of the sample transplantation had been carried out to replace traumatised maxillary left-central incisors. In addition, in 46% (N=22) of the cases, the maxillary right-central incisor had been replaced.

3.4.4.2 Type of Trauma

Regarding the types of trauma, it was found that, in more than 62% (N=30) of the cases, the anterior teeth were lost due to avulsion; accordingly, auto-transplants were considered indicated. Complicated crown fractures accounted for 12% (N=6) of the cases. On the contrary, all remaining types of trauma individually made up less than 9% of the sample. The different types of trauma and their percentages are summarised in Figure 3.4.1.

Figure 3.4.1: Pie chart illustrating the number of teeth affected by different types of trauma.



3.4.4.3 Age at PMT

The mean age of patients at the point of premolar transplant was 14.4 years, with a standard deviation of 2.3 years.

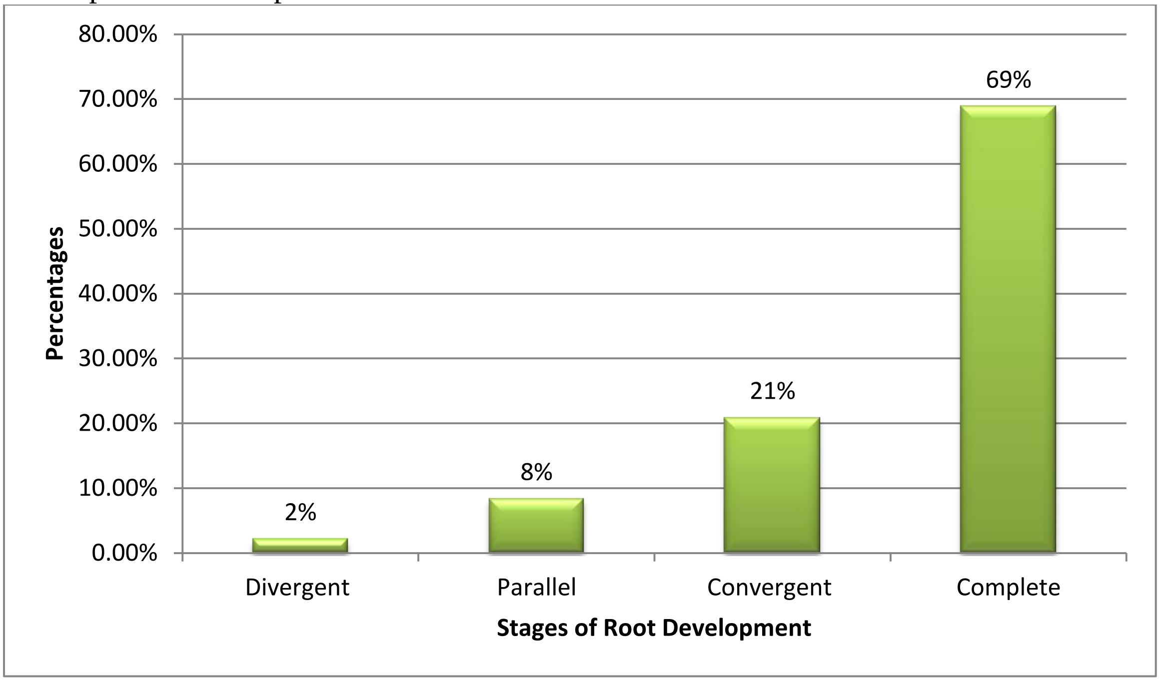
3.4.4.4 Transplanted Teeth

The descriptive statistics have shown that the maxillary right second premolar was the most common tooth (N=19, 40%) used in premolar transplant procedures to replace the traumatised non-restorable incisors. Next, the maxillary left second premolar accounted for 23% (N=11) of the cases. Similarly, the lower-right second premolar accounted for almost 23% (N=11) of the transplant cases. Finally, all remaining premolars made up less than 7% (N=8) of the sample.

3.4.4.5 Stages of Root Development of Transplanted Teeth

It was found that 69% (N=33) of premolar transplanted teeth were of complete root development. The convergent roots accounted for 21% (N=10) of the cases. Finally, the remaining categories—parallel (N=4) and divergent (N=1) roots—collectively made up less than 10% of cases. Figure 3.4.2 demonstrates the percentages of stages of root development of premolar transplanted teeth.

Figure 3.4.2: Bar chart illustrating the percentages of different stages of root development of transplanted teeth.



3.4.4.6 Duration of $Ca(OH)_2$ Intra-canal Dressing

The mean period of $Ca(OH)_2$ placed in the root canal systems of the premolar transplanted teeth was 18.29 weeks, with a standard deviation of 16.16 weeks.

3.4.4.7 Length of Obturation

It was found that slightly over 77% of cases had obturation to the working length. The rest of the cases were of either long or short obturation. Table 3.4.1 summarises the numbers and percentages of cases with different obturation lengths in the transplanted teeth.

Table 3.4.1: Summarises the numbers and percentages of different obturation lengths in transplanted teeth.

Obturation Length	Number	Percentage
At Working Length	37	77.1%
Long	6	12.5%
Short	5	10.4%

3.4.4.8 Quality of Obturation

It was found that 97.9% (N=47) of the obturated premolars following the auto-transplantation had adequate obturation. On the contrary, in 2.1% (N=1) of the cases, obturation were deemed inadequate.

3.4.4.9 Treatment Period

The mean treatment period was 6.9 months with a standard deviation of 6.4 months.

3.4.4.10 Post-Obturation Review Period

The mean review period following obturation of the premolar transplanted teeth was 37.2 months with a standard deviation of 24.9 months.

Finally, Table 3.4.2 summarises the descriptive statistics of the continuous measures of the study sample.

Table 3.4.2: Summary of descriptive statistics of continuous measures.

	Mean	Median	S.D	Range	Min.	Max.
Age at Trauma	10.5	10.6	1.7	7.5	7.0	14.5
Age at PMT	14.4	13.8	2.3	9.9	11.1	21.0
Duration of $Ca(OH)_2$	18.3	12.0	16.2	76	4	80
Treatment Period	6.9	4.0	6.4	24	1	25
Follow-up Period	37.3	31.0	24.9	93	12	105

3.4.5 Treatment Outcomes—Descriptive Statistics

3.4.5.1 Clinical Outcomes

Forty-seven (47) cases (97.9%) were deemed successful clinically. Only one case was considered a failure as the auto-transplanted tooth was infra-occluded when the patient attended the last review visit.

3.4.5.2 Radiographic Outcomes

It was found that 45 cases (93.8%) were considered successful radiographically. On the contrary, 4 cases (6.3%) were categorised as radiographic failures. External root resorption and the decrease in the periodontal ligament space were the most common causes of such failures.

3.4.6 Association between the Outcomes and the Demographic and Prognostic Factors

A series of bivariate analyses was carried out in order to determine whether or not significant associations exist between the predictors of interest (demographic and prognostic factors) and the clinical and radiographic success.

3.4.6.1 Clinical Success

It was found that none of the demographic or prognostic factors had a significant association with clinical success. Table 3.4.3 summarises these factors and their *p* values.

Table 3.4.3: Illustrates the different demographic factors and their *p* values in relation to Obtura II clinical success in the auto-transplanted teeth.

Factors	***p* Values**
Gender	0.37
Age at Trauma	0.82
Teeth Involved in Trauma	1.00
Type of Trauma	1.00
Age at PMT	0.85
Transplanted Teeth	0.60
Stage of PMT Root Development	1.00
Duration of $Ca(OH)_2$ Dressing	0.69
Length of Obturation	0.10
Quality of Obturation	1.00
Treatment Period	0.65
Post-Obturation Review Period	0.40

3.4.6.2 Radiographic Success

The analyses conducted between demographic and prognostic factors, and radiographic success failed to indicate significant association with the exception of the post-obturation follow-up period. The mean follow-up period of radiographic successful cases was 35.2 (SD 23.9) months whilst it was 69.0 months (SD 18.2) for the radiographic failure cases. The independent-samples *t*-test conducted on these mean differences was found to achieve statistical significance ($p = 0.02$).

The results indicated that a significantly longer follow-up period was associated with the cases that were evaluated as radiographic failures. Table 3.4.4 illustrates the demographic and prognostic factors with their *p* values in association with the radiographic success.

Table 3.4.4: Illustrates the different demographic and prognostic factors and their *p* values in relation to Obtura II radiographic success in the auto-transplanted teeth.

Factors	*p* Values
Gender	0.54
Age at Trauma	0.34
Teeth Involved in Trauma	0.58
Type of Trauma	0.11
Age at PMT	0.15
Transplanted Teeth	0.52
Stage of PMT Root Development	1.00
Duration of $Ca(OH)_2$ Dressing	0.13
Length of Obturation	0.32
Quality of Obturation	1.00
Treatment Period	0.62
***Post-Obturation Review Period**	0.02

*Indicates significance.

Section Five

Discussion

The current study has allowed us to evaluate the long-term clinical and radiographic outcomes of Obtura-II injectable thermoplasticised gutta-percha system in premolar auto-transplanted teeth in children following trauma. Furthermore, it has afforded the opportunity to evaluate the effect of different prognostic factors on treatment outcomes.

This section discusses the aims, methodology and the results of this study, and compares them, when and where possible, with studies published previously.

3.5.1 Appraisal of the Study Aims

The main aim of this study was to evaluate the long-term clinical and radiographic success of Obtura-II system when used in treating premolar auto-transplanted teeth in children following trauma. In addition, a secondary aim was concerned with evaluating the effect of several prognostic factors on long-term outcomes.

Several studies have shown that TDIs are very common in children. Glendor (2008) reported that more than 25% of school children suffered different types of TDI at any age prior to leaving school. Traumatic dental injuries are commonly associated with severe complications when occurring in a growing child. It has been reported that 12 out of 1,000 children lose their anterior teeth as a consequence of TDIs (Chadwick *et al*., 2003). There are various treatment options available to replace missing anterior teeth in children; however, auto-transplantation is considered the best option in a motivated compliant child when there is an indication of extraction of otherwise healthy teeth (Roden and Yanosky, 2013). Several studies have evaluated the survival and success of auto-transplanted teeth and accordingly have reported satisfactory results (Czochrowska *et al*., 2002).

It is recommended that the root canal treatment be initiated 7–14 days following the transplantation of a tooth with closed apex (Day *et al*., 2008). In addition, clinical and radiographic monitoring of open apex auto-transplanted teeth is essential in terms of planning for a root canal treatment when signs of infection occur prior to the destruction of these teeth (Tsukiboshi, 2001). Obtura-II technique injectable thermoplasticised gutta-percha technique is used widely nowadays in the endodontic treatment of auto-transplanted teeth, although such a technique has never before been evaluated in these cases. Therefore, it was recognised as important that a study be conducted evaluating the medium- and long-term outcomes of Obtura-II technique when used in auto-transplanted teeth in children following trauma.

3.5.2 Appraisal of the Methodology

3.5.2.1 Classification and Evaluation Criteria

Stages of Root Development

The stages of root development of the premolar auto-transplanted teeth were evaluated from the pre-operative periapical radiographs. After reviewing the literature, various scales evaluating the stages of immature teeth root development have been found. In this study, the scale described by Dominguez Reyes *et al*. (2005) was adopted as it was easy to use and gave reproducible measures. This scale classified the roots of immature teeth based on the shape of the apices into divergent, parallel and convergent roots. Furthermore, in order to ensure the accuracy and consistency of using this scale, the periapical radiographs were evaluated by two investigators of the study (AF and MSD).

Criteria for Success and Failure

The main aim of carrying out an endodontic treatment is to preserve the teeth and maintain them in functional status in the long-term. In order to fulfil this aim, a successful endodontic treatment is required. Over recent years, several studies have followed different criteria for the evaluation of endodontic success. The evaluation of endodontic outcomes is mainly based on evaluating the radiographic findings and the clinical signs and symptoms if present. In this study, the Obtura-II technique outcomes in auto-transplanted teeth were evaluated using the validated and tested criteria set out by the European Society of Endodontology (2006). In order to achieve an accurate evaluation reflecting the actual picture, a wide range of clinical parameters were evaluated. In addition, the post-operative periapical radiographs were evaluated by two investigators of the study (AF and MSD), thus ensuring the accuracy and the reliability of radiographic outcomes.

3.5.2.2 Statistical Analysis of the Data

Study Sample

In retrospective studies, population characteristics and methods of sampling are important in order to minimise the uncontrolled variables. As there were no similar studies published in the literature, no estimate could be used for the sample size determination. Following a biostatistician consultation, it was agreed that this study considered an exploratory pilot study, which could also be used in determining a suitable sample size for similar future studies. Initially, there was the screening of 81 clinical dental records with 103 premolar auto-transplanted teeth of children who attended the trauma clinic at Leeds Dental Institute during the period 2003–2011. Based on the inclusion criteria, 41 clinical dental records with 49 premolar auto-transplanted teeth were included in the current study. The remaining auto-transplanted teeth were diagnosed as having undergone revascularisation and were therefore excluded from the study.

Statistical Tests

Statistical advice was obtained with regard to the statistical tools and tests required to analyse the data of the current study. First, a series of descriptive statistics including percentages, tables and charts were conducted. Subsequently, a series of bivariate analyses—including Chi-square test—were carried out in order to evaluate the association between the prognostic factors and the outcomes of Obtura-II technique in auto-transplanted teeth. The level of significance was set at 95% confidence interval and p value < 0.05. Finally, it was not possible in this study to conduct a logistic regression analysis due to the fact that only a single analysis from the bivariate analysis was found to achieve significance.

3.5.3 Results

3.5.3.1 Clinical Success

Various studies have reported a wide range of endodontic success between 31% and 100%. This wide range is due to the fact that different studies followed different evaluation criteria and used different obturation techniques (Ng *et al*., 2010). Up to the present date, there have been no studies published evaluating the success of Obtura-II in endodontically treated auto-transplanted teeth in children. In this study, 97.9% of cases were deemed clinically successful. This percentage is considered at the high end of the spectrum of the endodontic success range reported by other studies. However, the results of this study cannot be compared directly with the findings of other studies. In the present sample, one case was considered a clinical failure; infra-occlusion was the distinct reason behind the failure in this premolar auto-transplanted tooth.

3.5.3.2 Radiographic Success

In order to ensure that the radiographic evaluation criteria are followed accurately and consistently, the post-operative periapical radiographs were evaluated by two investigators of the study at the same time. Several studies evaluated radiographically the different aspects of thermoplasticised gutta-percha (Marlin *et al*., 1981; Budd *et al*., 1991; Gutman, 1992; Tani-Ishii and Teranaka, 2003). However, there are no studies centred on evaluating the radiographic success of Obtura-II in premolar auto-transplanted teeth in children. Accordingly, the findings of the present study cannot be directly compared with the results of any study published previously. The results of the current study reveal that 93.8% of cases were successfully radiographically. Four (4) cases were deemed radiographic failures, the main reasons for which were the evidence of progressive external root resorption and the decrease in the width of the periodontal ligament space.

It is important to highlight that all cases deemed failures were where the donor tooth had a complete root development. Finally, the mean post-obturation follow-up period in the current study was 37.3 months. This is coincident with the recommendation of the European Society of Endodontology (2006) to have at least a one-year follow-up period. The follow-up period is important when considering the radiographic success as Jokinen *et al*. (1978) reported that the majority of endodontic failure cases can be detected radiographically at least two years after obturation.

3.5.3.3 Associations between the Outcomes and the Demographic and Prognostic Factors

For a long period of time, several studies have been carried out with the objective to determine the success and/or failure of endodontic treatment. In addition, some of these studies have investigated the factors potentially affecting the outcome of this treatment. Different studies used different obturation techniques, and set relatively different criteria and study designs to determine the success. However, endodontic success is evaluated mainly through analysing the radiographic findings and the presence or absence of clinical signs, and the symptoms (Benenati and Khajotia, 2002). Up until this point in time, no studies have been carried out with the aim of evaluating the treatment outcomes of Obtura-II technique in premolar auto-transplanted teeth in children. As a consequence, the findings of our study cannot be directly compared with the results of these studies.

The bivariate analysis of the data of the current study revealed that the clinical success rate of Obtura-II technique in treating premolar auto-transplanted teeth in children was not significantly affected by any of the demographic or the prognostic factors.

This finding could be due to the superiority of Obtura-II technique in treating the premolar auto-transplanted teeth as all the cases in the sample were considered clinically successful with the exception of one case. In addition, it is important to highlight that, although clinicians with a range of clinical experience conducted the endodontic treatment on these premolar auto-transplanted teeth, all the clinicians working at the Paediatric Dentistry Department at Leeds Dental Institute received a thorough training on using Obtura-II technique in auto-transplanted teeth. Finally, the last reason that could explain this finding is the small sample size of the current study, which could mask the effect of any prognostic factor if present when the bivariate analysis was conducted.

Similar to the clinical success, none of the factors were significantly associated with the radiographic success of Obtura-II technique when used in this situation. However, the only exception was the post-operative follow-up period. The bivariate analysis revealed that, the longer the post-obturation follow-up period, the less the chances of radiographic success of the Obtura-II technique in premolar auto-transplanted teeth in children. In the current study, it was found that the mean follow-up period of the radiographically successful cases was 35.2 months. On the other hand, the radiographic failure cases had a significantly longer follow-up period of 69.0 months. This can be explained logically as the radiographic changes, whether healing or pathology, cannot be evident unless six months post-operative. In addition, this finding is parallel to that reported by Jokinen *et al*. (1978) where the majority of endodontic failure cases could be detected mainly radiographically at least two years post-obturation. It is also important to point out that the radiographic failure was not due to the failure of endodontic treatment but a failure of the transplantation due to development of external resorption.

3.5.4 Study Limitations and Challenges Encountered

Auto-transplantation replacing missing anterior teeth in children during their period of growth and development has been advocated for a number of decades. However, there are a relatively limited number of studies discussing this topic in the literature. This was one of the major challenges encountered when conducting the current study.

In addition, there were no similar studies available in the literature based on which a scientific sample size calculation could be made.

3.5.5 Future Studies

The present study is the first study of its kind, and therefore is an original investigation into this subject. We believe from the findings of the current study that the Obtura-II technique is a superior endodontic obturation technique that can be used in treating auto-transplanted teeth in children. However, the present study did not find any significant association between the prognostic factors and the treatment outcomes. Therefore, it would be beneficial to conduct a study with a similar design but with a larger sample size. This future study can explore in-depth the association between the prognostic factors and the treatment outcomes by conducting a logistic regression analysis.

Furthermore, this study is considered an exploratory study, and therefore can be used in future as a guide in determining the sample size of similar studies.

Finally, it would be beneficial to design a clinical prospective study in which the patients who received endodontic treatment of auto-transplanted teeth using Obtura-II system can be reviewed and evaluated clinically. In addition, it is important to compare this technique with alternative methods of obturation, as employed generally by most clinicians.

Several studies have compared Obtura-II from various clinical aspects to other obturation techniques commonly used in adult populations. Moreover, many studies have highlighted the superiority of Obtura-II in comparison with other techniques; however, the Obtura-II technique has never been evaluated in auto-transplanted teeth in children or compared to other obturation techniques.

Section Six

Conclusion

The following conclusions can be drawn from the data presented through this study:

1. Root canal obturation, with the use of the Obtura-II technique utilising thermoplasticised gutta-percha, was considered clinically successful in 97.9% of the cases of auto-transplanted teeth in children.
2. Root canal obturation with Obtura-II technique was considered radiographically successful in 93.8% of the cases of auto-transplanted teeth in children.
3. The mean post-obturation follow-up period against which the success rate was determined was 37.3 months.
4. The clinical success rate of Obtura-II technique in the endodontic treatment of auto-transplanted teeth in children was not significantly affected by any of the demographic or the prognostic factors evaluated in this study.
5. The radiographic success rate of Obtura-II technique in auto-transplanted teeth was significantly affected by the post-obturation follow-up period. The longer the follow-up period, the higher the chances in detecting cases of failure.
6. As none of the prognostic factors had an effect on the clinical success, this part of the null hypothesis was accepted. However, the null hypothesis was rejected when considering the radiographic success.

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List of Appendices

APPENDIX 1: Email confirming DREC approval of the study.

```
----- Forwarded message from J.K.McDermott@leeds.ac.uk -----
    Date: Thu, 17 May 2012 10:39:20 +0100
    From: Julie McDermott <J.K.McDermott@leeds.ac.uk>
Reply-To: Julie McDermott <J.K.McDermott@leeds.ac.uk>
 Subject: Ethics application 'Retrospective analysis of
thermoplasticed gutta-pecha
technique'
      To: 'Anfal Faridoun' <dnaf@leeds.ac.uk>
      Cc: Gail Douglas <G.V.A.Douglas@leeds.ac.uk>, Monty Duggal
<M.S.Duggal@leeds.ac.uk>, Jack Toumba <K.J.Toumba@leeds.ac.uk>,
Medicine and Health
Research Governance <governance-ethics@leeds.ac.uk>
```

Dear Anfal,

Thank you for re-submitting the above Ethics application to the Dental Research Ethics Committee.

Your application has been re-reviewed and I am pleased to inform you that DREC are happy for you to proceed and apply for sponsorship review and NHS Research Ethics Committee approval.

Attached is a copy of the Faculty Standard Sponsorship Review Guidance. Please read this as it contains important information with regards to submitting your REC form for Faculty sponsorship sign-off.

If you need any further information, please do not hesitate to contact me.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, signed consent forms, participant information sheets and all other documents relating to the study. This should be kept in your study file, and may be subject to an audit inspection. If your project is to be audited, you will be given at least 2 weeks' notice.

It is our policy to remind everyone that it is your responsibility to comply with Health and Safety, Data Protection and any other legal and/or professional

guidelines there may
be.

With best wishes for the success of your project.

For and on behalf of#

Professor Gail Douglas

DREC Chairman

APPENDIX 2: Email from NRES confirming DREC approval and sponsorship.

```
----- Forwarded message from governance-ethics@leeds.ac.uk -----
    Date: Thu, 26 Jul 2012 13:23:52 +0100
    From: Medicine and Health Research Governance <governance-
ethics@leeds.ac.uk>
Reply-To: Medicine and Health Research Governance <governance-
ethics@leeds.ac.uk>
 Subject: RE: URGENT SPONSERSHIP REVIEW
      To: 'Anfal Faridoun' <dnaf@leeds.ac.uk>, Medicine and Health
Research Governance
<governance-ethics@leeds.ac.uk>
      Cc: Monty Duggal <M.S.Duggal@leeds.ac.uk>

Dear Anfal,

As this project will not require NRES approval you do not need
confirmation of
sponsorship, DREC approval is in place so you can proceed with your
study,

Yours Clare
Clare Skinner
Faculty Head of Research Support
0113 34 34897
Mobile 07713251855

PA   Debbie Cuthbert
Tel 011334 34361

Faculty of Medicine and Health
University of Leeds
Worsley Building
Leeds
LS2 9LN
```

APPENDEX 3: Data Extraction Proforma – Traumatised Teeth

Data Extraction Performa

Traumatised Teeth

Patient Details

Serial Number	
Date of Birth	dd/mm/yyyy
Gender	○ 1 Male ○ 2 Female
Referral	○ 1 General Dental practitioner ○ 2 Community Dental Services ○ 3 Specialist Paediatric Dentist ○ 4 Self-referral / Emergency
Degree of cooperation - Frankel score	○ 1 Definitely Positive ○ 2 Positive ○ 3 Negative ○ 4 Definitely Negative

Trauma Details

Type of Trauma	○ 1 Avulsion ○ 2 Intrusion ○ 3 Extrusion ○ 4 Luxation ○ 5 Subluxation ○ 6 Complicated Crown Fracture ○ 7 Uncomplicated Crown Fracture ○ 8 Root Fracture ○ 9 Crown / Root Fracture
Date of Trauma	dd/mm/yyyy
Age at Trauma	…………. Years
Affected Tooth (FDI)	
Stage of Root Development at trauma	○ 1 Divergent ○ 2 Parallel ○ 3 Convergent ○ 4 Complete

Treatment Details

Start Date	dd/mm/yyyy
Date of Pulp Extirpation	dd/mm/yyyy
Intracanal Medicament	○ 1 No ○ 2 Yes ○ Material used …………….. ○ Duration ……….. weeks
Apical Barrier	○ 1 $Ca(OH)_2$ ○ 2 MTA
Date of Obturation	dd/mm/yyyy
Total Treatment Time	…………. Months
Total follow-up period	…………. Months
Final Coronal Restoration	○ Date dd/mm/yyyy ○ Material used

Clinical Assessment during Review

Pain or Discomfort Since Obturation	○ 1 Yes
	    ○ Mild
	    ○ Moderate
	    ○ Severe
	    ○ When
	○ 2 NO

Use of Analgesics	○ 1 Yes
	    ○ When
	    ○ Type
	○ 2 No

Tenderness to Palpation	○ 1 Yes ○ When ○ 2 No
Tenderness to Percussion	○ 1 Yes ○ When ○ 2 No
Mobility	○ 1 Normal physiological mobility ○ 2 Absence of mobility ○ 3 Increased pathological mobility
Abscess	○ 1 Present ○ 2 Absent

Radiographic Examination

Periodontal ligament Space	○ 1 Normal ○ 2 Wide ○ 3 Absent
Length of Obturation	○ 1 At working length ○ 2 Long ○ 3 Short
Quality of Obturation	○ 1 Adequate ○ 2 Inadequate ○ Describe…………………………..
Quality of Coronal Seal	○ 1 Adequate ○ 2 Inadequate ○ Describe…………………………..
Periapical Radiolucency	○ 1 Absent ○ 2 Reduce in size ○ 3 The same size ○ 4 Increase in size
External Root Resorption	○ 1 Evident ○ 2 Not Evident
Root Fracture	○ 1 Evident ○ 2 Not Evident

APPENDEX 4: Data Extraction Proforma, Auto-transplanted Teeth

Data Extraction Proforma

Auto-Transplanted Teeth

Patient Details

Serial Number	
Date of Birth	dd/mm/yyyy
Gender	○ 1 Male ○ 2 Female
Referral	○ 1 General Dental practitioner ○ 2 Community Dental Services ○ 3 Specialist Paediatric Dentist ○ 4 Self-referral / Emergency
Degree of cooperation - Frankel score	○ 1 Definitely Positive ○ 2 Positive ○ 3 Negative ○ 4 Definitely Negative

Trauma Details

Type of Trauma	○ 1 Avulsion ○ 2 Intrusion ○ 3 Extrusion ○ 4 Luxation ○ 5 Subluxation ○ 6 Complicated Crown Fracture ○ 7 Uncomplicated Crown Fracture ○ 8 Root Fracture ○ 9 Crown / Root Fracture
Date of Trauma	dd/mm/yyyy
Age at Trauma	…………. Years
Affected Tooth (FDI)	
Stage of Root Development at Trauma	○ 1 Divergent ○ 2 Parallel ○ 3 Convergent ○ 4 Complete

Transplant Details

Reason for Transplant	
Date of Transplant	dd/mm/yyyy
Age at Transplant	…………….Years
Type of Anaesthesia	○ 1 Local Anaesthesia ○ 2 Relative Analgesia ○ 3 General Anaesthesia
Transplanted Tooth (FDI)	
Stage of Root Development at Transplant	○ 1 Divergent ○ 2 Parallel ○ 3 Convergent ○ 4 Complete

Treatment Details

Start Date	dd/mm/yyyy
Date of Pulp Extirpation	dd/mm/yyyy
Intracanal Medicament	○ 1 No ○ 2 Yes ○ Material used ……………. ○ Duration ……….. weeks
Date of Obturation	dd/mm/yyyy
Total Treatment Time	…………. Months
Total follow-up period	…………. Months
Final Coronal Restoration	○ Date dd/mm/yyyy ○ Material used

Clinical Assessment during Review

Pain or Discomfort Since Obturation	○ 1 Yes
	    ○ Mild
	    ○ Moderate
	    ○ Severe
	    ○ When
	○ 2 NO

Use of Analgesics	○ 1 Yes
	    ○ When
	    ○ Type
	○ 2 No

Tenderness to Palpation	○ 1 Yes ○ When ○ 2 No
Tenderness to Percussion	○ 1 Yes ○ When ○ 2 No
Mobility	○ 1 Normal physiological mobility ○ 2 Absence of mobility ○ 3 Increased pathological mobility
Abscess	○ 1 Present ○ 2 Absent

Radiographic Examination

Periodontal ligament Space	○ 1 Normal ○ 2 Wide ○ 3 Absent
Length of Obturation	○ 1 At working length ○ 2 Long ○ 3 Short
Quality of Obturation	○ 1 Adequate ○ 2 Inadequate ○ Describe…………………………..
Quality of Coronal Seal	○ 1 Adequate ○ 2 Inadequate ○ Describe…………………………..
Periapical Radiolucency	○ 1 Absent ○ 2 Reduce in size ○ 3 The same size ○ 4 Increase in size
External Root Resorption	○ 1 Evident ○ 2 Not Evident
Root Fracture	○ 1 Evident ○ 2 Not Evident

APPENDEX 5: Abstract of Oral Presentation at 24th IAPD Conference

Oral Session O06/Dental Trauma

O06-33

Retrospective pilot study of the clinical and radiographic success of thermoplasticised gutta-percha in non-vital immature permanent incisors

A. FARIDOUN, M. DUGGAL & J. TOUMBA
Department of Paediatric Dentistry, Leeds Dental Institute, University of Leeds, Leeds, UK

Background: Thermoplasticised injectable gutta-percha (TGP) (Obtura-II system) has been available for several years but few studies evaluated the clinical and radiographic success in young traumatised permanent incisors in growing children where teeth are expected to survive for the life-span of the patient.
Aim: Evaluate the clinical and radiographic success of TGP (Obura-II) in root canals of non-vital young, traumatised, permanent incisors.
Design: Retrospective pilot study evaluating clinical and radiographic outcomes of TGP system. A convenience sample of 50 clinical records and periapical radiographs for patients attending the trauma clinic at the paediatric dentistry department at Leeds Dental Institute between 2003 and 2011 were evaluated. The obturated teeth were classified as being successful, survived, or failure according to criteria developed for this study.
Results: Sixty-one teeth with different stages of root development met inclusion criteria, 29 had complete root development, 23 parallel, six convergent, and three divergent apical walls. The mean age of the patients was 10.7 years, and they were followed-up for a mean period of 96.7 months. One tooth was extracted due to root fracture. Four teeth showed evidence of replacement resorption, in addition three developed pathological mobility and pain. Five cases had a wider periapical radioluency compared to baseline. In 58 teeth treatment was deemed to be successful clinically.
Conclusion: Using Obtura-II system for TGP, root canal treatment was considered to be clinically successful in 95% and radiographically successful in 85% of young traumatised non-vital permanent incisors over the mean follow-up period of 8 years.
Keywords: Thermoplasticised gutta-percha, Trauma, Immature, Permanent incisors.

O06-34

Evaluation of adverse events following surgical extrusion of crown-root fractures using cone beam computed tomography (CBCT) & Periotest: a non-randomized controlled trial

A. ELKHADEM[1], M. RASHED[1], A. MORTADA[1], S. BAHGAT[1] & M. DAHABA[2]
[1]*Pediatric Dentistry, Faculty of Oral & Dental Medicine, Cairo University, Cairo, Egypt;* [2]*Oral Radiology, Faculty of Oral & Dental Medicine, Cairo University, Cairo, Egypt*

Background: Crown-root fracture constitutes a restorative challenge due to the sub-gingival location of the fracture margin. Surgical tooth extrusion is one of the treatment options. Adverse events following surgical extrusion have not been investigated previously in a controlled clinical trial.
Aim: To determine possible adverse events following surgical tooth extrusion using cone beam computed tomography and Periotest. Adverse events that were investigated are; ankylosis, increased tooth mobility, root resorption and tooth loss.
Design: Twenty patients with crown-root fracture in maxillary incisors were selected from outpatient clinic in pediatric dentistry department- Cairo University. Twelve males and eight females with age from 10 to 14 years participated in this study. Surgical extrusion was performed combined with endodontic treatment. Patients were evaluated using CBCT and Periotest. Contra-lateral teeth were served as controls.
Results: The mean age of participants was 131 months. Only 17 patients completed -follow-ups longer than 1 year period. Mean follow-up period was 16 months. No ankylosis occurred in any of the extruded teeth. Four teeth showed root resorption; one showed progressive inflammatory root resorption with subsequent tooth loss, while the other three teeth showed non-progressive surface resorption. Periotest values of surgical extruded teeth showed significant increase than control teeth by mean of 3.5(±5.3) PTV in the horizontal directions and a mean of 2.5(±3.8) PTV in the vertical directions. Two out of twenty (10%) teeth were lost (95% CI 3–30%) in study population.
Conclusion: Surgical tooth extrusion is a reliable method in management of crown-root fractures. Surface root resorption is the most common side-effect associated with the procedure. Although surgical extruded teeth possess increased tooth mobility in comparison to their counterparts, this increase is considered of minimal clinical importance.
Keywords: Surgical extrusion, Crown-root fracture, Adverse events, Cone beam computed tomography, Periotest.

O06-35

Apexogenesis in an early stage of tooth development: MTA *vs* Biodentine

R. CAUWELS & L. MARTENS
Dept Paediatric Dentistry & Special Care, PaeCaMeD research, Ghent University, Ghent, Belgium

Introduction: The treatment of pulpal injury of immature incisors provides a significant challenge for the clinician. Depending upon the vitality of the affected pulp, apexogenesis is the optimal approach. Apexogenesis is defined as a vital pulp therapy procedure performed to encourage continued physiological development and formation of the root end. Nowadays, calcium silicate cements are reported to succeed in tissue regeneration if the appropriate treatment guidelines are respected.
Case reports: Two 6 year old patients presented suffering from dental trauma on erupting permanent incisors. Root formation at that moment was in a premature stage. In both cases, a painful abscess developed a few weeks after traumatic injury. No pulp exposure however was seen at the time of injury. In the first case, after a pulp conditioning, the remaining vital pulp was covered by mineral trioxide aggregate (MTA: ProRoot® MTA). A follow-up of 42 months revealed a perfect maturation of the root. In the second case, a comparable situation is given in which, after two conditioning sessions of the apical tissue, Biodentine™ (Septodont-France) was used. After 30 months an optimal healing including full root formation was seen.
Comments: Biocompatible and bioactive properties of calcium silicate cements have been demonstrated in several studies. In contrast to MTA, the material properties of Biodentine™ are similar to those of human dentine. Moreover, coronal discoloration is well-known for MTA. Taking into account the excellent

APPENDEX 6: Certificate of Presenting at 24th IAPD Conference


IAPD 2013

24th Congress of the International Association of Paediatric Dentistry

Certificate of Presentation

On behalf of the Local Organizing Committee of the 24th Congress of International Association of Paediatric Dentistry (IAPD), we hereby certify that

Anfal Faridoun

was given the opportunity to present at the oral/poster session during the 24th Congress of the International Association of Paediatric Dentistry (IAPD) which took place from 12 to 15 June 2013 in Seoul, Korea.

Eduardo Alcaino
President of IAPD

Sangho Lee
Chair,
Organizing Committee of IAPD 2013

Kitae Park
Scientific Committee Chair,
Organizing Committee of IAPD 2013

APPENDEX 7: Abstract of Oral Presentation at the LDI Research Day 2013

Anfal Faridoun

A retrospective pilot study of the success of thermoplasticised gutta-percha in non-vital immature permanent incisors and auto-transplanted teeth

Dr Anfal Faridoun, Professor KJ Toumba, Professor MS Duggal

Department of Paediatric Dentistry, Leeds Dental Institute, University of Leeds, UK

Background: Thermoplasticised injectable gutta-percha (TGP) (Obtura-II system) has been available for several years but it has never been evaluated clinically and radiographically in young traumatised permanent incisors in growing children where teeth are expected to survive for the life-span of the patient. Furthermore, the success of this technique was not assessed in auto-transplanted teeth replacing non-restorable traumatised teeth in children.

Aim: Evaluate the clinical and radiographic success of TGP (Obura-II) in root canals of non-vital young, traumatised, permanent incisors and auto-transplanted teeth.

Design: A retrospective pilot study evaluating clinical and radiographic outcomes of TGP system. A convenience sample of 50 clinical records for patients who had trauma, 61 records of patients who had auto-transplants, and their periapical radiographs were evaluated. The patients attended trauma clinic at the paediatric dentistry department at Leeds Dental Institute between 2003 and 2011. The obturated teeth were classified as being successful, survived, or failed according to criteria developed for this study. Various prognostic factors that could have influenced the outcome of the technique were also recorded.

Results: Sixty-one traumatised anterior, and 34 auto-transplanted teeth met the inclusion criteria. The mean ages of the patients were 10.7 at trauma, and 13.1 years at transplant. Teeth were of different stages of root development. Cases were followed-up for a mean period of 96.7 months. In 58 traumatised and 33 transplanted teeth treatment was deemed to be successful clinically. Radiographically, 52 traumatised and 30 transplanted teeth were considered successful. A logistic regression analysis was done and showed no significant association between the prognostic factors and the success rate ($P>0.05$).

Conclusion: Using Obtura-II system for TGP, root canal treatment was considered to be clinically successful in 95% and radiographically successful in 85% of young traumatised non-vital permanent incisors over the mean follow-up period of 8 years. In addition, 97% and 88% radiographic and clinical success respectively was found in transplanted teeth. In this pilot study none of the prognostic factors that were evaluated influenced the outcome of this method.

17