DEVELOPMENT AND APPLICATION OF A METHOD FOR ESTIMATING DAILY CASE-MIX ADJUSTED COSTS OF ADULT CRITICAL CARE UNITS

BY

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PHD THESIS

VOLUME I

SCHOOL OF HEALTH & RELATED RESEARCH,
UNIVERSITY OF SHEFFIELD

2007

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A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

SCHOOL OF HEALTH & RELATED RESEARCH,
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VOLUME I

AUGUST 2007

ABSTRACT

Patients referred for treatment in an adult critical care unit are in, or at imminent risk of developing single or multiple organ failure. Despite the high treatment costs, knowledge of the costs of care is limited. The aims of this thesis were to synthesise current knowledge about the different methods used to estimate costs and to develop and apply a method for estimating daily case-mix adjusted costs for developing a set of Healthcare Resource Groups (HRGs) and for use in a trial-based economic evaluation. HRGs were required to support the Department of Health's new policy on reimbursing adult critical care called '*Reforming NHS Financial Flows: Introducing Payment By Results*'.

A systematic review of 20 published studies provided the background to, and justification for the methods employed in two empirical studies. The first empirical study was performed in a single critical care unit and using very detailed data on individual patients evaluated factors that had the potential to correlate with daily costs of critical care. Univariate and multivariate statistical analyses were undertaken using two different data sets. Patients' daily organ supports were identified as the key '*cost generating events*'. A prospective, observational, longitudinal multi-centre study involving a volunteer sample of 70 critical care units followed, where organ support data on 7,243 consecutive admissions and monthly data on critical care unit expenditure were collected. Different ways of modelling the organ support and expenditure data were explored. The overall R^2 for the chosen model – the daily number of organs supported was 0.52. Daily organ support weights for the average daily costs of critical care were 0.577 for 0 or 1 organ supported, 1.137 for 2 organs supported and 1.156 for 3 or more organs supported. These weights were then applied to average daily costs estimated for patients recruited to a clinical trial of Extracorporeal Membrane Oxygenation (ECMO) vs. conventional therapy for severe, but potentially reversible, respiratory failure.

DECLARATION

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any University; and that to the best of my knowledge and belief, it does not contain any material previously published or written by another person where due reference is not made in the text.

TABLE OF CONTENTS

"The wise man doesn't give the right answers, he poses the right questions."

Claude Levi-Strauss, Anthropolist (1908)

CHAPTER 1: INTRODUCTION

1.1 Background

There is widespread evidence to suggest that expenditure on health care is rising in the Developed World, in line with increases in life expectancy and improved living standards; both greatly enhanced by advances in technology and better access to medical treatment (Maniadakis *et al.*, 1999). As a result, health care providers are confronted with the unenviable challenge of reconciling limited resources with an increased demand and an aging population (Andersen *et al.*, 1976; Cullen *et al.*, 1976; Malek, 1996; Hoppe, 1996; Ely *et al.*, 1999).

The costs of health care need to be better understood in order to achieve much needed budgetary equilibrium, assess hospital efficiency and perform economic evaluations of different health care interventions (Adam *et al.*, 2003[1]). This understanding is important if the goals of resource allocation; that of the achievement of both efficiency and equity are to be met. The aim of any public health care system is to maximise the health and welfare of the population for a given budget (Robinson, 1993), yet whilst therapeutic interventions have the potential to improve health, they pose a major problem to society, since the allocation of resources [to these interventions] is constrained by the availability of funds, for which all areas of health care must compete.

According to Department of Health statistics, NHS expenditure in England was £76.4 billion in 2006, of which an estimated £1 billion was spent on adult critical care. Patients referred for treatment to an adult critical care unit are in, or at imminent risk of developing, single or multiple organ system failure. Once admitted, a multidisciplinary team of clinical specialists, operating at a ratio of one nurse to one

patient, provides 24-hour specialised care that involves close monitoring and stabilisation and support of vital functions. Costly drugs and investigations together with the use of highly sophisticated monitoring and organ support technology explain why a day of stay costs four times more than a day of care received on a general hospital ward (Wagner *et al.*, 1983; Royal College of Anaesthetists and Royal College of Surgeons, 1996). Mortality at discharge from the critical care unit is however high, with 20% to 25% of patients not surviving beyond their admission (Bennett & Bion, 1999).

Despite the high levels of expenditure and poor patient outcomes, very little is known about *how* critical care resources are distributed, *to whom* and *with what effect* (Bone *et al.*, 1993 & Shmueli & Sprung 2005). There is also some indication of an insufficient supply, with costs cited as a critical barrier to the opening of new beds (Audit Commission, 1999).

1.2 Rationale for the thesis

The impetus behind this PhD thesis arose as a direct result of encountering problems of a practical nature when attempting to cost the care of individual patients to identify iso-cost groups that would form the basis of Healthcare Resource Groups (HRGs) to support a proposed reimbursement system and to perform an economic evaluation of a multi-centre randomised controlled trial (RCT) of Extra-Corporeal Membrane Oxygenation (ECMO) versus conventional therapy for critically ill patients with severe, but potentially reversible, respiratory failure.

There were three specific problems; firstly, the absence of a reliable method for estimating the costs of individual patients for use in multi-centre costing evaluations, limited knowledge of both how costs of care related to the characteristics of patients and what constituted the key

'*cost generating events*' of critical care treatment[1] (Johnston *et al.*, 1999). These made the tasks of identifying the best way of classifying patients into homogeneous resource groupsand deciding what clinical and economic data to collect alongside the CESAR Trial fraught with difficulty.

1.2.1 *Development of Healthcare Resource Groups*

Healthcare Resource Groups, analogous to the American Diagnosis-Related Group (DRG) system[2], have been used for costing non-critical care patients by National Health Service (NHS) Hospital Trusts in England and Wales since the early 1990s (Appleby & Thomas, 2000). HRGs classify patients who exhibit similar clinical and resource use characteristics on the basis of ICD-10 (International Classification of Diseases Diagnostic Codes Version 10) and OPCS-4 (Office of Population Censuses and Survey Tabular List of Classification of Surgical Operations and Procedures Fourth Revision) procedure codes as the basis of grouping, together with information on age and discharge status.

Critically ill patients are a heterogeneous group with respect to their clinical and cost characteristics (Stevens *et al.*, 1998). The link between the case-mix of these types of patients and their costs of care has not been adequately explored because of difficulties with both a) the measurement and quantification of case-mix in adult critical care patients and b) the estimation of patient costs within and across critical care units. Previous research has found that for a significant number of critical care patients, a diagnosis, even retrospectively, cannot always be made (Stevens *et al.*, 1998) which is at odds with the structural foundations of an HRG-based system. A standard method for comparing the amount spent on critical care in different hospitals has

1 The term 'cost' is defined within the context of this thesis as the amount paid by an NHS hospital trust for their critical care resources (Finker, 1982).

2 Diagnosis-Related Groups are a system for describing the types of patients discharged from acute care hospitals that aim to promote efficiency in the production of hospital care by encouraging hospitals to produce targeted health outcomes with the least costly inputs (Fetter, 1987; Grimaldi & Micheletti, 1983).

been developed (Edbrooke *et al.*, 1999) but no work has been undertaken, to date, that studies the relationship between the expenditure on critical care units and the case-mix of patients treated in those units so as to develop a set of HRGs that accurately reflect both the expenditure and the case-mix in this patient population.

In order to support the implementation of a case-mix adjusted funding system that arose as a result of the Department of Health's policy '*Reforming NHS Financial Flows: Introducing Payment By Results*' (Department of Health, 2002), HRGs for adult critical care patients were needed. With the proposed HRGs being used to reimburse a proportion of the critical care unit funds, it was felt important that the HRGs captured both the key patient characteristics and *cost-generating events*' and were capable of reflecting the variation in costs between individual patients. A key output from this thesis was thus to identify these events and develop a costing method to reflect these, which then could be used to propose a set of suitable HRGs.

1.2.2 *Costing methods for economic evaluation*

Economic evaluations of new and existing interventions are used increasingly to inform health technology appraisal in the UK and the number conducted alongside clinical trials continues to grow (Coyle & Drummond, 2001).

Graves *et al.*, (2002) argue that '*appropriate and transparent costing methods are a pre-requisite for any statistical analysis of cost data*' [for the purposes of economic evaluation] yet despite considerable progress made with respect to estimating costs in the areas of neonatal intensive care, most notably with the Trial of Indomethacin Prophylaxis in Preterms (TIPP) (Zupancic *et al.*, 2003 & Schmidt *et al.*, 2001), the INNOVO (Neonatal Ventilation With Inhaled Nitric Oxide Versus Ventilatory Support Without Inhaled Nitric Oxide for Preterm Infants With Severe Respiratory Failure) and neonatal ECMO trials both reporting concurrent economic evaluations (see Field *et al.*,

2005 for the INNOVO trial and Tubman *et al.*, 1990; Field & Pearson 1994; Howard *et al.*, 1995, 1996; UK Collaborative ECMO Trial Group 1996; Hallam 1996; Roberts and the ECMO Economics Working Group 1998; Elbourne *et al.*, 1999; Petrou *et al.*, 2004, 2006) for the work performed on neonatal ECMO), there has not been one multi-centre clinical trial in adult critical care that has successfully estimated the costs of individual patients. Only one multi-centre trial-based economic evaluation on the use of pulmonary artery catheters has been performed in the UK to date (Harvey *et al.*, 2006 & Stevens *et al.*, 2005). This latter trial however did not attempt to estimate costs at the patient level but instead relied on the use of (average) NHS reference costs for the critical care received by patients. Coyle *et al.*, (1998) state that '*ideally unit costs should be calculated specifically for the centres participating in the clinical and economic study...with the resource use for each centre multiplied by its own unit cost, rather than adopting an average unit cost and then applying this to pooled resource data*' (p.140). This is why it is so important to develop a standard method of estimating costs that can be applied in different critical care units.

The absence of high quality economic evaluations in adult critical care is due in the most part to the heterogeneous case-mix that plague the design of clinical and observational studies of effectiveness, the expense of collecting detailed resource use data (Zupancic *et al.*, 2003) and finally, difficulties in estimating the unit costs of such resource use. Performing these evaluations in adult critical care face three main challenges:

1) The absence of a clinically meaningful, reproducible proxy measure of resource use, capable of discriminating between individual patients;

2) Uncertainty as to whether an appropriate costing method, even if identified, would be sufficiently acceptable to users in order to generate unit costs of critical care. Existing methods of costing are pitched at two extremes; either capable of detecting variation between patients

and not the variation between centres (generally referred to as '*micro-costing*' or '*bottom-up*' costing), or detecting the variation between centres and not patients ('*gross-costing*' or '*top-down*' costing). Given that methods used to estimate costs in different studies can vary considerably (Balas *et al.*, 1998; Drummond, 1985; Ganiats & Wong 1991; Gerard 1992; Gerard *et al.*, 1999; Graham *et al.*, 1998; Hornberger *et al.*, 1992; Jacobs & Fassbender 1998), a standardised approach would be advantageous to reduce methologic bias which would in turn facilitate valid comparisons between studies and ensure that policy makers are provided with consistent evidence (Adam *et al.*, 2003[2]; Stone *et al.*, 2000; Drummond *et al.*, 1997; Luce & Simpson 1995; O'Brien *et al.*, 1997; Gyldmark, 1995); and

3) Finally, the delicate trade-off between how one would ideally like to conduct an economic evaluation in adult critical care (in so ticking all of the check-list boxes that conform to theoretical '*best practice*') with what can be deemed a feasible and '*do-able*' evaluation.. This trade-off represents the biggest challenge of all.

As already stated, prerequisite to a proposed economic evaluation of ECMO versus conventional therapy for severe respiratory failure is knowledge of how costs of care relate to the characteristics of patients and what constitute the key 'cost generating' events of critical care treatment (Johnston *et al.*, 1999). Some assurance is required that observed differences in cost between the study arms can be attributed to the effect of the treatment(s) under evaluation and not as a result of other (unknown) factors skewing the cost estimates. For the above reasons, a standard methodology of estimating costs for use in economic evaluations was considered to be the second key output of the PhD.

1.3 Aims of the thesis

The aims of this thesis were thus to:

1) Synthesise current knowledge about the different methods used to estimate costs of care in critical care units; and

2) To develop and apply a suitable method for multi-centre costing evaluations. A systematic review of the literature served to provide the background to, and justification for, the costing methods employed in the empirical studies – particularly the multi-centre study, and played a key role in achieving the first aim of the thesis; that being to identify the intellectual origins of costing methods reported in the literature and evaluating any methods that could be used or adapted within the thesis.

The second aim of the thesis was informed by exploratory statistical analyses of data obtained from a single centre, described in Chapter 4 that evaluated different patient characteristics against the daily costs of care, and analyses of data on critical care unit expenditure and patients' organ support obtained from a multi-centre study of 46 critical care units described in Chapter 6. The multi-centre study set out to generate data to develop regression models to estimate patient costs. The regression models derived marginal per diem cost estimates. By summing together these per diem costs, total costs for individual cases could be determined. No attempt was made to relate these costs to intermediate or longer-term outcomes (i.e. survival from the critical care unit or from hospital).

A key requirement for the multi-centre study described in Chapter 5 was a standard method for estimating costs across different critical care units. This was important so as to avoid methodologic bias.

In this thesis, a method using 'activities of care' was considered for estimating patient costs (Edbrooke *et al.*, 1997). This method is capable of detecting variation in cost between patients, however the resultant estimates can suffer from a site selection bias (Jacobs & Baladi, 1996) thus affecting their generalisability to estimating patient costs in other critical care units. The method is not so good at estimating variation in costs due to differences in unit characteristics. Very detailed data collection at the patient-level needed to apply the 'activities of care'

method mean that widespread implementation of such a method would probably be both too costly and time consuming to consider in a multi-centre setting.

An alternative 'top-down' costing method, developed by the Critical Care National Working Group on Costs was also considered (Edbrooke *et al.*, 1999). This retrospective method estimates per diem costs for a critical care unit by apportioning the annual expenditure of a critical care unit by the annual number of patient days and is presently used as a benchmarking tool for the purposes of cost comparison. However, a case-mix bias occurs since the number of patient days is not sufficiently refined to take into account how patients vary in terms of their care requirements on a daily basis. Jacobs & Baladi (1996) thus recommend the use of case-mix weighted days over the use of per diem costs and so the development of a case-mix weighted day approach therefore formed the core objective of the thesis.

1.4 Outputs from the thesis

The purpose of this PhD was not only to enhance existing knowledge of the costs of adult critical care but to also perform two specific functions - the development of a set of proposed HRGs and the costing of patients recruited to the CESAR trial -, which would benefit the critical care and research community and merit peer-reviewed publication.

Scientific enquiry seeks to '*combine the power of rational thought and systematic investigation to produce new knowledge*' (Denscombe, 2002) and the originality of the academic contribution will be demonstrated by three endeavours that had not been achieved before in the United Kingdom, namely:

1) The development and application of a 'top-down' costing method for use in a multi-centre study (collecting precise and valid data) to support empirical investigation of the relationship between expenditure

on critical care and the case-mix of patients, from which generalisations can be made;

2) The production of a model using the resultant cost estimates for proposing a set of HRGs; and

3) The production of cost weights from the same model for estimating patient costs for the multi-centre RCT.

1.5 Structure of the thesis

Chapter 2 provides a background to subsequent chapters and sets out to pinpoint the issues that will form the substantive arguments of the thesis.

I will argue why:

1) The neoclassical theory of the firm does not readily apply to adult critical care units because of the complex nature of its inputs and lack of detailed information on the costs of such; and

2) Ambiguity exists as to what best constitutes an appropriate output measure (of case-mix) for adult critical care units.

In this Chapter, cost and production functions are explored in context of their application to hospitals and critical care units. The different types of costs that can be taken into account (dependent on the perspective and time horizon of the evaluation) are also described.

A systematic review of the literature is described in Chapter 3. The literature review serves to provide the background to, and justification for, the empirical studies and plays a key role in achieving one main objective that being, to identify existing methods used to estimate costs in adult critical care units and to critically appraise those methods. Findings from 26 identified studies meeting the inclusion criteria of the review are described. The quality of each study is assessed using criteria proposed by Burchardi *et al.*, (2001).

In Chapter 4, two exploratory studies involving patient-level data collected from the Critical Care Unit at the Royal Hallamshire Hospital are described using the '*activities of care*' costing methodology identified from the literature review (Edbrooke *et al.*, 1997). Here, the daily costs of care for individual patients are estimated so that the relationship between these costs and a set of case-mix related variables could be investigated. This study was important since it had the sole objective of identifying the key patient characteristics and '*cost generating events*' of critical care (Johnston *et al.*, 1999). Three different options are considered and discussed: using patients' TISS points; a multivariate analysis of all different types of case-mix variables, and finally, the use of patients' daily organ support data.

The design of a larger multi-centre study is described in Chapter 5 that sets out to perform a prospective period of data collection using a volunteer sample of 70 adult critical care units. Monthly expenditure data and daily data on patients' organ support are collected over a two to three month period. The monthly expenditure data is estimated using a 'top-down' method of costing (Edbrooke *et al.*, 1999). The results of this study are described in five sections in Chapter 6. Section I details how the patient data were collected and validated. Section II describes the characteristics of the volunteer sample of critical care units in terms of the geographical coverage of units, their teaching hospital status, the types of critical care units and the number of staffed beds and considers the representativeness of the sample. Section III considers the characteristics of patients studied, such as their length of stay, survival status at discharge from the critical care unit, the type of organ support that patients received during their stay and explores the relationship between patients' organ support and the type and size of the critical care unit. The collection and validation of expenditure data is reported in Section IV. Finally, preliminary analyses of the relationship between expenditure and the type and size of critical care unit are performed on a sub-sample of 46 critical care units in Section V.

Chapter 7 is concerned with the development of a set of proposed HRGs to support the Department of Health's funding policy. The aim is to identify, from the 46 critical care units who provided data on both expenditure and case-mix, an appropriate model from which estimates of daily case-mix adjusted costs of care can be determined. Nine models in total are described and a random-effects model based on the number of organs systems supported per day was the chosen model. This model was evaluated in two ways – by its ability to predict expenditure and by assessing through a small pilot study, its acceptability to users.

Chapter 8 considers the application of daily organ support weights, described in the previous chapter, to an ongoing economic evaluation alongside a clinical trial. The overall aim of this study is to estimate the incremental costs of ECMO, over and above the costs of conventional therapy for patients with severe, but potentially reversible, respiratory failure. A survey of the costs and characteristics of the participating critical care units is described and the application of the organ support weights to the obtained costs is illustrated.

Chapter 9 discusses the findings of work, its limitations and options for further research.

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"Although greater awareness of costs can create a better climate for increasing efficiency, the question is unfortunately often posed without a real understanding either of the nature of the cost or of the problem"

Gavin Mooney & Michael Drummond (1982)

CHAPTER 2: BACKGROUND TO COST FUNCTIONS

2.1 Introduction

The development of diagnosis-related groups (DRGs) initially began as an attempt to define operationally the products of a hospital in terms of groups of patients receiving similar sets of outputs or services (Fetter, 1987). Whilst a key component of the thesis is to estimate the costs of critical care patients for the purpose of developing a set of Healthcare Resource Groups (HRGs), the costs themselves are a function both of input prices and the rate of output (Shiell *et al.*, 1993). Chapter 2 thus sets out to provide some theoretical context to the importance of understanding this cost function when attempting to quantify (and understand) cost variation between different individual units (and patients). This is important because the resultant HRGs must respond to changes in the cost structure of critical care units and meet demand increases if the case-mix system is to maintain credibility and equity (Antioch & Walsh, 2000).

Cost functions describe the relationship between outputs and what is normally assumed to be the minimum cost of production (O'Neill & Largey, 1997). Scott & Parkin (1995) describe the two main approaches to the study of cost functions as the ad-hoc or behavioural cost function and that based on the theory of the firm. Based on the economic theory of the firm, cost functions can provide useful information to hospitals about economies of scale, optimal size, the degree of specialisation and mergers, and the marginal costs of services. The work of this thesis sets out to estimate the relationship between critical care costs per day of stay and factors thought to

influence such costs, where the focus is primarily on estimating the marginal costs as opposed to investigating economies of scale. Research looking at the effect of economies of scale (on the marginal costs) typically follows once reliable data on the costs have been obtained.

Many different regression models have been used for determining the association between patient characteristics and hospital costs (Austin *et al.*, 2003). Cost functions can be analysed econometrically using models that explain how total costs change in response to differences in service mix, inputs, input prices and scale of operations (Barnum & Kutzin 1993 & Adam *et al.*, 2003) or using non-statistical methods such as data envelopment analysis (DEA) (Jacobs, 2001). DEA is a linear programming method that estimates a deterministic frontier based on the observed data (Zuckerman *et al.*, 1994). Typically, applications of DEA in health economics however do not allow for a random error term and are likely to be sensitive to the influence of outliers (Jones, 2000).

There are a number of difficulties experienced when attempting to define cost functions. Hospitals do not adhere to maximising / minimising behaviour on the basis that most hospitals are non profit institutions (Hadley *et al.*, 1996). Cost functions can also be difficult to estimate as hospital use many inputs and produce a diversity of outputs (Breyer, 1987).

According to Berki (1972) '*there appears to be no agreement either on a conceptual or merely definitional level, among those who have most intensively studied the economics of hospitals, on what the appropriate measure of output is or should be*'. There is neither a uniformly agreed upon regression model with which to analyse cost data in order to define this (Glick & Polksy, 1999) nor is it known which method is best. From an econometric perspective, there are rarely sufficient degrees of freedom available to include all of the variables of interest and the interactive and squared terms required by a flexible

specification. This means that studies of cost functions often require very large samples with a reduced list of variables of interest (Barnett, 1997).

O'Neill & Largey (1997) and Folland *et al.*, (2004) (see also Richardson *et al.*, 2001) allude to the additional difficulties in the estimation of cost functions, namely the poor understanding of the underlying production relationship and the constraints under which production takes place.

The reasons that they give for this relate to;

- Variations in clinical practice (that include both the ways in which care is delivered e.g. constraints placed on prescribing / treatment choices; and
- The job functions (specialisation) of clinicians – some concentrating on more clinical tasks, others spending time doing research and administration etc (e.g. functions of clinicians).

They also highlight the case-mix response-to-treatment factor that can contribute to differences between both clinicians and critical care units, in terms of output. That is to say that even if critical care units treated a heterogeneous case-mix in the same way, it cannot be assumed that patients will respond *in the same way as one another* to their treatment.

2.2 Applications of production and cost theory to critical care units

2.2.1 Background to adult critical care

This thesis focuses specifically on adult patients (≥16 years of age) receiving treatment in critical care units in NHS Hospital Trusts. A critical care unit '*monitors and supports failing vital functions in acutely ill patients*' (Ferdinande, 1997 p.226) and is where patients '*with potentially recoverable diseases can benefit from more detailed*

observation and treatment than is generally available in the standard wards and departments' (King's Fund Panel, 1989 p.428).

Critical care developed in response to an epidemic of poliomyelitis in Copenhagen in 1952 (Lassen, 1953). The mortality associated with respiratory failure due to polio was 87% despite patients being treated with negative pressure ventilation with either cuirass or tank 'iron lung' ventilators. Using positive as opposed to negative pressure ventilation through a tracheostomy, the mortality rates fell to 26% (Intensive Care Society, 2003). In 1962, the Department of Health published "*Progressive Patient Care'* (MOH & PHLS, 1962) that resulted in funding to set up critical care units in the U.K, with a suggestion that between 2%-5% of a hospital's acute beds should be designated critical care beds. Research conducted during the 1970s and 1980s identified common features of sepsis and multi-organ failure and so the modern concept of critical care was founded (Intensive Care Society, 2003).

Over the last fifty years, critical care has developed into a rapidly changing and complex field of medicine, dealing with an enormous array of life-threatening conditions (Irwin & Rippe, 2003). As such, the case-mix of critical care units is very heterogeneous in terms of the clinical conditions treated and can include ventilator-associated pneumonia, systemic inflammatory response syndrome, chronic obstructive pulmonary disease, acute respiratory distress syndrome, severe community-acquired pneumonia, pancreatitis and acute renal failure (Marik, 2001). Patients typically require intensive monitoring, and most need some form of mechanical or pharmacological support such as mechanical ventilation, renal replacement therapy or vasoactive drugs (Bennett & Bion, 1999). As well as specific types of organ support, critical care patients require other interventions to maintain organ function and prevent further damage such as nutritional support, preserving skin integrity, psychological support and mobilisation (Adam & Forrest, 1999). Treating the sickest patients within the hospital, mortality rates at discharge from a critical care unit are high (between 20-30% of patients will not survive beyond their admission)

and a further 10% will die on the ward after discharge from the critical care unit (Bennett & Bion, 1999). The majority of patients are emergency admissions and their severity of illness is a major factor associated with patients' length of critical care unit and in-hospital stay, their morbidity, mortality and total costs of treatment (Shiell, 1991 & Stevens *et al.*, 1998). Epidemiological studies of critical care have found patients to be predominantly male, with a high proportion of elderly patients (greater than or equal to 70 years) constituting 25-30% of the total (Dragsted & Qvist, 1992). Characteristics of patients that influence admission to critical care are age, severity of illness and reason for admission (Sprung & Eidelmann, 1997 & Azoulay *et al.*, 2001). However, doctors' decisions to admit patients have also shown to be influenced by relatives' wishes and non-medical factors such as a patient's personality or availability of beds (Escher *et al.*, 2004).

Critical care forms part of a network that makes up an acute hospital, with patients presenting for admission from the Accident & Emergency (A&E) department, the operating theatres and the general hospital wards (Audit Commission, 1998). In the UK, patients receive critical care in an Intensive Care Unit (ICU) when requiring advanced respiratory support alone or combinations of two or more other acute organ systems, whereas the High Dependency Unit (HDU) is used to treat patients requiring support of a single acute organ, excluding advanced respiratory support (Department of Health, 1996). Critical care is the term used interchangeably to reflect both ICU and HDU care.

Critical care comprises 1-2% of total bed numbers in the UK, which is significantly less than the 20% reported in the United States (Bennett & Bion, 1997). Critical care patients are more expensive than other specialties because of their severity of illness and need for intensive care, which mean that the service is frequently scrutinised in terms of its growing expenditure (Cullen, 1977; Edbrooke *et al.*, 1999; Ridley *et al.*, 1993[1]; Slatyer *et al.*, 1986; Puig-Junoy, 1998). Nursing staff represent the largest component of cost due to the 1:1 nursing care,

with a lower ratio usually provided to those receiving high dependency care (Intensive Care Society, 2003).

A multidisciplinary team of nurses, doctors and professionals allied to medicine (clinical pharmacists, dieticians, physiotherapists, bacteriologists, speech therapists, clinical psychologists, occupational therapists, medical technical officers and clinical scientists) deliver critical care. Anaesthetists manage most of the critical care units in conjunction with the referring Clinicians (Bion, 1994). The Audit Commission reported the results of their survey of 193 critical care units in 1998 and found that the average six-bedded general critical care unit had 47 nurses (33.5 whole time equivalents), three consultants with fixed commitments to the unit with three more taking place in the on-call rota. There are two basic styles of medical management; closed (the unit's doctors take responsibility for clinical management with the patient's care formally transferred from the referring consultant) and open (patients remain under the care of the referring consultant with any unit doctors considered to be advisory) (Audit Commission, 1998). Twenty percent of ICUs and ICU/ HDUs operate open systems, however open systems are practiced in 80% of the separate high dependency units.

2.2.2 Costs of critical care

Bion *et al.*, (1999) state that '*it* [critical care] *is perceived as a service that consumes resources rather than one that generates desired outcomes...funded on the basis of political imperative rather than on the needs of the population*' and it is commonly thought that for some critical care patients, the high costs far outweigh any benefits of these treatments (Taylor, 1979 & Teres & Rapoport, 1991).

Reliable annual estimates of critical care expenditure are not readily available, although the Audit Commission quoted a figure of £700 million in 1998 for units residing in England and Wales. Since that

time, an injection of funds to increase bed provision has inflated this estimate to approximately £1 billion.

The costs of a critical care unit are influenced by the case-mix of patients (both the type of patients and the complexity of their clinical conditions), the quality of care, size of the critical care unit and the occupancy rates (Hibbert & Edbrooke, 2002). Daily costs range from £550 to £1,500 per day (Gilbertson *et al.*, 1991; Ridley *et al.*, 1993[2]) and are between four to six times more than care on a hospital ward (Wagner *et al.*, 1983 & Royal College of Anaesthetists and Royal College of Surgeons, 1996). As has been shown for many types of health care services, a relatively small number of patients in critical care units account for a disproportionately large proportion of the expenditure.

The costs for individual patients can vary not only within a single critical care unit but also between different critical care units. The reasons for the variation in cost between centres include clinical practice styles (Knaus *et al.*, 1982, 1986; Greenfield *et al.*, 1992; Stano 1993), unit size (Hibbert & Edbrooke, 2002 & Gyldmark, 1995), the ratio of emergency to elective admissions, the organisational structure of the critical care services (e.g. presence of a separate HDU or combined ICU) / HDU, whether the unit is located in a university or non-university hospital), the grade-mix of nurses and seniority of medical staff (Hibbert & Edbrooke, 2002), research, training activities and possibilities for treatment and care (Gyldmark, 1995). Added to this list is the quality of care (survival rates) and configuration (whether care is provided in specialist or generalist units, in separate or integrated ICU and HDUs, solely in critical care units or also in Accident & Emergency Departments, admission units, recovery and on the hospital wards) (Audit Commission, 1998).

There is an absence of information about the costs that makes the task of economic evaluation, more difficult and many hospitals do not know what the actual costs of their services are (Rizzo & Powe, 1999). Glick

et al., (2003) observe that whilst '*calculation of costs is an essential part of these [economic] evaluations...little, if any research has examined optimal strategies for such calculation*'. This view is further supported by Jacobs & Bachynsky (1996). More work is required therefore on the actual process of cost data collection (Raikou *et al.*, 2000) particularly in adult critical care. The current state of knowledge reflects Gyldmark's observation that '*it is difficult to relate the total cost [of running an ICU] to activity and/or patient characteristics and thus to optimise treatment activities and the use of limited capacity and resources*' (Gyldmark, 1995 p.964), which is really where the motivation for this thesis comes from.

There are many different ways in which costs can be defined, depending on whether an accountancy or economic standpoint is adopted.

2.2.3 Cost definitions

Accountants define costs in terms of the value of economic resources used as a result of producing or doing whatever is being costed. Such a cost can be broken down into cost elements; a cost element being, in effect, the cost of an individual resource (e.g. material) consumed by whatever is being costed. From an accountancy perspective, cost elements have two components: a quantity of the resource used and the price of that resource. The costs of all cost elements can thus be determined by the formula: cost = usage x price (Horngren *et al.*, 1999).

Economists' generally accepted definition of cost in a given period of time is '*a resource sacrificed or forgone to achieve a specific objective*' (Jegers *et al.*, 2001). This implies that the resource cannot be used for alternative applications. Therefore, the value of the best alternative sacrificed can be considered to be the value of the resources used. This value is defined as the **'opportunity'** cost and. refers to the benefit accrued from the alternative use of [the] resources (Johnston *et*

al., 1999). According to Mooney (2003) '*this concept of opportunity cost encourages us to place monetary values on 'costs' that might not normally be seen as having pound signs in front of them'* (p.6).

In this thesis, costs are considered as the monetary value expended by NHS providers on a given resource, which may or may not reflect the opportunity cost of its alternative use. The cost is also likely to reflect the price of the resource because of the way in which monies are allocated to NHS providers for meeting the costs of patient care on a not-for-profit basis. In the UK, NHS providers do not charge patients or insurance companies for their services so the term 'price' and 'cost' can be used interchangeably.

Resources are basic services used in the production process and include labour time, medical supplies and medicines, machining services, buildings and land (Schwartzbach & Vangermeesch, 1983 & Institute of Health Economics, 2000). Conversely, resource use can also be seen as a day in hospital (also referred to as a **cost-generating** event (Johnston *et al.*, 1999). Cost is the value of these resources (Institute of Health Economics, 2000) with a **unit cost** representing the value / price of a resource (Johnston *et al.*, 1999).

Direct costs represent the resources purchased directly as a result of an activity and can be subdivided into **fixed** and **variable** costs. Richardson *et al.*, (2001) define **direct costs** as those that can be linked to the care of a particular patient with **indirect costs** covering the overhead costs incurred for all patients; here an accountancy perspective is most evident.

The interpretation of **indirect costs** differs when an economic perspective is adopted. Here, indirect costs represent 'the element of indirect consumption of resources in the production process, for example the value of lost earnings by patients or carers of patients who are unable to work as a result of the health care activity' (Petrou & Mugford, 2000).

All direct and indirect costs have both fixed and variable components (Richardson *et al.*, 2001). **Fixed costs** are costs that do not vary with the quantity of output in the short run (about one year), e.g. rent, equipment lease payments, some wages and salaries – so costs that vary with time, rather than quantity (Drummond *et al.*, 1997). In the context of adult critical care, Mostafa (1995) in one of the first adult critical care cost studies describe the following resources as 'fixed':

- Construction;
- Maintenance of buildings;
- Purchase and maintenance of equipment and supporting services;
- Hotel costs (light, power, heat, laundry);
- General administration and finance;
- Admission department and records; and
- Portering

He categorised staff - the main elements being nursing and medical staff, technicians and clerks as being semi-fixed.

Variable costs vary with the level of output, e.g. supplies, food, fees for service (Drummond *et al.*, 1997). Taheri *et al.*, (2000) describe variable costs as those that can be identified directly with the care of individual patients on a particularly day, such as laboratory tests, radiographs and disposable equipment. Mostafa (1995) describe the following resources as 'variable':

- Respiratory therapy;
- Disposable equipment;
- Drugs and fluids and nutrition;
- Blood products and substitutes;
- Dialysis services.

Average costs (AC) include fixed costs, such as costs of hospital buildings and costs of overheads, as well as variable costs and the AC of a unit of service can be estimated from the total cost divided by the total number of units ((Johnston *et al.*, 1999).

Marginal costs (MC) cover the costs of producing one additional unit of output. For example, given an adult critical care unit is fully staffed and has an empty bed, the marginal cost of providing care to one additional critical care patient is limited to the incremental cost of supplies and other variable costs. However, a full critical care unit that needs to use agency staff to care for an additional patient would incur higher marginal costs for that patient (adapted from Richardson *et al.*, 2001).

A **total cost (TC)** is the cost of producing a particular quantity of output (Drummond *et al.*, 1997).

Intangible costs are those borne externally to the health sector, patients and their families (Drummond *et al.*, 1997) and refer to the element of pain or grief experienced by patients and their families and friends.

Charges are the prices set (asked) for a service. This may not equal the amount that is actually paid (Institute of Health Economics, 2000). Charges cannot be considered in the same way as costs because they do not reflect actual expenses; they are billing parameters between the health care providers and the payers (Jegers *et al.*, 2001). Charges for services often include capital and indirect costs such as medical education and are often used in reports of the "costs" of clinical programs because such data are readily available from patients' hospital bills (typically in the U.S.) (Douglas *et al.*, 1995). The relationship between costs and charges is the "cost-to-charge ratio".

Capital costs are the costs to purchase the major capital assets required by the programme; generally equipment, buildings, and land (Drummond *et al.*, 1997).

Overheads are an accounting term for those resources that serve many different departments and programmes, e.g. general hospital administration, central laundry, medical records, cleaning, porters, power, etc (Drummond *et al.*, 1997).

According to Robinson (1993), there are three main categories of cost that must be considered if a societal perspective is to be adopted:

- Health service costs;
- Costs borne by patients and their families; and
- External costs borne by the rest of society.

Under the heading of 'health service costs' suggested by Robinson (1993), these should include:

- Staff time;
- Medical supplies (including drugs);
- Hotel services;
- Use of capital equipment; and
- Overheads, such as lighting and heating.

These items may be divided into variable costs and fixed costs. In the long run, the vast majority of costs become variable because those that are fixed in the short run may be varied – for example, by opening and closing critical care beds. In economic evaluation, all health service costs – both fixed and variable are considered 'direct' costs. The scope of the PhD is focused on the measurement and estimation of these direct costs – specifically those that fall within the budgetary remit of the adult critical care unit. Costs borne by patients and their families and external costs borne by the rest of society are thus excluded.

Finally, an important source of cost variation that cannot be ignored is that of methodologic bias where differences in the methods used affect the estimates of such. Examples include differences in the time period, double-counting, exclusion of costs, method of resource measurement, method of cost allocation, source of unit cost data, inability to separate intensive care costs from the overall hospital costs, use of charges instead of costs, systematic errors and sampling variation (Gyldmark, 1995).

Whilst the issue of costs and the relationship between average per diem costs and the size of a critical care unit has featured heavily in the

neonatal critical care literature (John *et al.*, 1991; Fordham *et al.*, 1992; O'Neill & Largey, 1997; Richardson *et al.*, 2001), very little work has been undertaken in the adult critical care setting.

2.2.4 Costs and production functions In critical care

Fordham *et al.*, (1992) estimated the relative daily costs of two broad levels of care – intensive and non-intensive – in all neonatal intensive care units in the Trent region. In this study, total expenditure was apportioned by the total cot days at each level of care. Through a multiple regression analysis, the relative daily costs of each level of care were derived. Building on the preliminary findings of Fordham *et al.*, (1992), O'Neill *et al.*, (2000) collected cost and activity data from 49 neonatal units to determine the relationship between unit size, case-mix and cost, where case-mix was defined as the proportion of intensive care days to all care days provided. The authors' findings suggested the likely existence of economies of scale; that is, the cost per day of care provided decreased with the size of the neonatal unit, in terms of days of care it provided. On this basis, there are valid grounds for hypothesising similar findings could be observed in adult critical care, despite this being outside of the scope of this thesis to explore and test in the empirical sense beyond the exploratory analysis described in Chapter 6, Section V. As already mentioned and will be evident from subsequent chapters, the work of this thesis will not attempt to explore whether scale economies or allocative efficiency gains exist in the production of adult critical care activity. Study of such would have allowed one to determine whether larger sized critical care units are more 'efficient' than smaller sized units, which is without exception, a very important policy question. What work from the thesis will facilitate is empirical testing of the cost function since it will provide a means of costing some of the inputs into the critical care unit and offer a classification system of case-mix.

There is presently a lack of knowledge as to the nature of the cost function in adult critical care units because of first, difficulties in

defining and quantifying the output measure (the type of patients treated), lack of information about the most technically efficient way of treating patients and finally, lack of information on unit costs. Ways of identifying the most efficient means of treating critical care patients is complicated due to ethical concerns pervading the conduct of clinical trials where randomisation of one unproven treatment to another causes concern amongst the critical care staff. Added to this, is the absence of routinely collected cost data on both the running costs of the critical care unit and the treatment costs of individual patients and that makes the process of both identifying technically efficient and inefficient organisational methods of delivering care and identifying efficient and inefficient treatments, fraught with difficulty.

If a way in which input prices / costs could be determined, it would then be possible to estimate the cost of adopting different methods of production so that appropriate choices could be made as to the lowest-cost production method. The challenge then arises as to how the quality of the production method can be measured so as to determine the effect on this, as the costs of production decrease.

In the context of an adult critical care unit, inputs (of production) cover staff (e.g. nurses, doctors and professionals allied to medicine), consumables (e.g. drugs, fluids, disposable equipment and blood and blood products), capital equipment (e.g. beds, ventilators, computers, patient monitors and syringe drivers), clinical support services (e.g. radiology and laboratory tests), non-clinical support services (e.g. cleaners, porters, accountants, managers and administrators) and overheads such as heating and lighting. The critical care unit uses these so-called inputs to treat patients. The number of treated patient days can be considered an intermediate output with patients (and ideally successfully treated alive and healthy patients) as the final measure of output in a critical care unit.

An adequate description of case-mix does not exist for adult critical care patients. Whilst case-mix groups can be formed in a variety of

ways, Plomann & Shaffer (1983), Thompson *et al.*, (1975) and Lave & Lave (1970) identify the four most common approaches to case-mix grouping, where case-mix is:

- Measured in terms of the number of patients treated or the number of patient days of care rendered; or
- Standardised by controlling for differences in the types or numbers of services the hospital can perform or provide for the patient; or
- Determined by hospital size; or
- Determined through output measures that are adjusted for differences in case-mix among hospitals in terms of the service unit treating the patient.

This thesis will attempt to explore possible measures that could be used to describe case-mix.

There are two main reasons why few attempts have been made to specify a cost function for adult critical care units. Critical care units do not collect the type of information needed to help estimate a cost function that includes both data describing the case-mix of patients treated. This is not a problem specific to critical care units but common to other areas of medicine where there are no straightforward definitions of output). Furthermore, data (presented in a standard format) on the expenditure of patients and the critical care unit itself are not collected so as to perform multi-centre studies[3].

Critical care units cannot easily adjust its inputs to a change in conditions, as much of its high costs are fixed (e.g. nursing and medical staff). Only its variable costs would decrease following a decline in output. Similarly, faced with pressures to increase output, their options are limited as it is not often feasible to physically expand the critical

3 Most adult critical care units maintain budget statements relating to the expenditure of the unit over a given period (typically on a monthly basis), however not only do these statements include different cost items from one critical care unit to another but the descriptors given to each cost item can be very different from one unit to the next.

care unit (i.e. build a new unit or extend the existing facility) and/or study its skill-mix of nursing staff to see whether it can treat more patients with a different staff configuration and/or recruit additional staff members. There is presently no knowledge as to the optimal size of a critical care unit (number of beds) or the optimal quantity of output (treated patients).

The concept of profit does not easily translate to a critical care unit unless the unit was operating in a reimbursement system where 100% of its output was reimbursable where surplus inputs could accrue. These would not easily translate into profits however.

The goal of the critical care unit should be to ensure that the price at which care is reimbursed equals long run average costs (to break-even) or to ensure more financial stability that their long run average costs fall below the reimbursed price. In order to identify the best output (or ideal number of patients that a critical care unit should treat) to break even or make profits, the marginal condition (LMC = MR) is used. It is possible to use the average condition to see if the best positive output yields a profit or a loss; the average condition compares long term average costs at this output with the average reimbursement received.

The critical care unit has fixed factors of production i.e. inputs that cannot be varied that incur fixed costs that do not vary according to the number of patients treated. These inputs are a certain amount of necessary staffing and capital equipment. Short-run total costs can be estimated from the sum of both the short-run fixed costs and short run variable costs. Diminishing returns to labour can be estimated when the amount of work performed per person drops as the number of temporary staff employed in a critical care unit (for example), increases. To illustrate this further, if there are 3 agency nurses required to treat 2 patients, yet 4 agency nurses are hired, the fourth nurse will not be able to treat an additional patient since 5 nurses are required in order for that to happen. This analogy results in an under-

utilisation of the fourth nurse and also illustrates the marginal product of labour.

In conclusion, it is clear that the neoclassical theory of the firm does not readily apply to critical care for the following reasons:

- The complex nature of the inputs –that prevent straightforward substitution (of these inputs) and adjustments to changes in conditions (demand or otherwise);
- Limited knowledge of what time component would constitute the 'long- and short-run';
- Limited knowledge of where economies of scale can best be achieved;
- Critical care units do not operate in conditions of perfect competition where profit maximisation is the main goal;
- Lack of detailed information on the costs of the inputs used by the critical care unit thus limiting the scope for exploring short and long-run output decisions; and
- Ambiguity as to what best constitutes an appropriate output measure (of case-mix).

All of the above factors make the linking of inputs to the outputs from the critical care unit fraught with difficulty.

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CHAPTER 3: A SYSTEMATIC REVIEW OF THE LITERATURE ON COSTING METHODS

3.1 Introduction

A challenging element of economic evaluation is the proper measurement of costs (Smith & Barnett, 2003). A systematic review of the literature, as described in this Chapter, aimed to identify methods of costing patient care that have been applied previously to the adult critical care setting; the objective being to identify a method for estimating daily costs, amenable for use across a number of different critical care units. Literature on other high cost areas such as neonatal and paediatric critical care as well as burns and liver transplantation was also consulted.

A systematic review involves *'rigorous application of a methodical search, compilation, and inference technique to the body of literature identified'* (Hutton & Ashcroft, 1998). The techniques of reviewing methods differ somewhat to the techniques of reviewing empirical studies because of the formalised ways in which empirical studies can be evaluated according to well-established checklists and the results synthesized using a range of statistical approaches. Unfortunately, there is no *'gold standard'* against which different methods can be compared (Edwards *et al.*, 1998).

An Advisory Group formed prior to the commencement of the review (Section 3.2). Checks for ongoing and existing reviews were performed and the scope of the literature assessed (Section 3.4). This was important to determine whether a sufficient body of published evidence was available. A large number of abstracts were screened using pre-defined criteria prior to obtaining the full papers (Section 3.6). For inclusion in the review, studies had to provide a detailed description of the methods used for calculating the daily costs of adult critical care patients. Data extracted from 26 identified studies included the study

aim, the number of patients and centres studied, the method used for measuring care and the coverage of costs (Section 3.8). The results were then tabulated in Section 3.9.

The dates of publication ranged from 1980 until 2005 with the highest proportion of studies originating from the UK and France and with most of the identified studies conducted in a single centre. As far as the methods of allocating costs to patients were concerned, these were not mutually exclusive in all instances. There was some overlap between the direct measurement of costs at the patient level, and apportioned measurement of expenditure at the critical care unit level. A common set of cost components was however identified from the studies and data extracted on this basis. Costs were described under the headings of staff costs, treatment-related costs and overheads / hospital running costs.

Nine different approaches to estimating and apportioning costs were identified from the review (Section 3.9.11). These included direct measurement of costs at the patient level and the use of activities of care, and apportionment mechanisms that covered days by level / grade of care, use of dependency points, use of TISS points[4] and finally, use of the number of patient days, beds and patients.

The 26 studies were assessed for quality, using a set of criteria developed specifically for critical care cost studies by Burchardi *et al.*, (2001) (Section 3.12). The advantages and disadvantages of each of the different studies were highlighted (Section 3.13). The Chapter concluded with the knowledge that one method – the cost block method could be used in the multi-centre study (Chapter 4).

3.2 Formation of the review advisory group

An advisory group was formed in 2001 and guided the review. Links were also established with representatives from the Cochrane

[4] TISS stands for the Therapeutic Intervention Scoring System and lists 76 commonly performed interventions that can be scored on a daily basis to reflect the care needs of individual patients.

Collaboration and other researchers who were willing to provide support in areas of expertise that were not readily available (see Acknowledgements). The advisory group met before the review commenced to discuss the scope and orientation [of the review] and help refine the specific questions that the review would address.

Membership of this group consisted of the following individuals:

- John Brazier (Professor of Health Economics, Health Economics & Decision Science Section, School of Health and Related Research, University of Sheffield);
- Mike Campbell (Professor of Statistics, Department of General Practice, School of Health and Related Research, University of Sheffield);
- Nigel Coad (Consultant in Critical Care at the Northern General Hospital, Sheffield Teaching Hospitals NHS Trust);
- Miranda Mugford (Professor of Health Economics, School of Health Policy and Practice, University of East Anglia); and
- Jon Nicholl (Professor of Health Services Research, Health Services Research Section, School of Health and Related Research, University of Sheffield).

3.3 Checks for existing or ongoing reviews

Prior to performing the systematic review, it was important to ascertain that no such reviews had already been undertaken. Given that the best single source of systematic reviews was deemed to be the Cochrane Library, this was the first database that was searched. The databases searched differed in terms of their indexing terms and literature coverage (Appendix 3.1).

Table 3.1 describes the searches undertaken and the number of abstracts retrieved.

Table 3.1: Description of searches undertaken and the number of abstracts retrieved (checks for existing reviews)

Search Number	Database	Number of abstracts retrieved	Number of abstracts initially rejected that were outside of the subject area (%)
#1	NHS Centre for Reviews and Dissemination databases (DARE, NHS EED, HTA)	182	57 (31%)
#2	Office of Health Economics	44	26 (59%)
#3	Embase	768	701 (91%)
#4	Medline	68	57 (84%)
#5	National Research Register and Project Database	326	326 (100%)

From undertaking these searches and reading all of the abstracts identified, it became clear that one review of costs and methods had already been published (Gyldmark, 1995).

3.3.1 Identification of the review by Gyldmark (1995)

The review by Gyldmark (1995) had a broad aim; that of studying methods for costing critical care services. The author had performed a MEDLINE search of the international literature and identified 20 English-language adult critical care cost studies published between 1977 and 1994. Studies were selected on the basis that they:

- Were published in English; AND
- Described ICU costs; AND
- Described in detail the methods used for calculating costs; AND
- Costs per patient or per severity score could be derived from the study.

Costs per patient were reported and a significant variation in these observed. The author looked for appropriate papers by searching MEDLINE, however did not state which other bibliographic databases or search strategies were used and this has prevented updates or

additions to the review. The reference lists of the twenty papers identified were not followed-up and Non-English language papers were excluded.

A cost-to-charge index was used to convert the charges reported in some studies into costs. Although acknowledged that this transformation into costs was '*not very transparent*', it may have been more appropriate to isolate those studies that reported costs from those reporting charges. The inclusion of different cost components was described in detail, however not enough was done to assess the rigour of the individual studies included.

Possible reasons for the considerable variation in costs observed from the papers studied were given as; advances in technology, differences in patients' severity of illness, age, diagnoses and other characteristics and unit characteristics namely unit size, staffing, admission criteria, treatment policies and research and training activities. These were mooted by the author but were not substantiated by the evidence presented.

A systematic review of the literature was required for this thesis to summarise and appraise those costing methods developed since the publication of this review in 1995 and as already alluded to, to identify a method with which daily costs of critical care patients could be estimated and that which could be employed across a number of different critical care units.

3.4 Scope of literature in field

It was important to assess the volume of literature in the field before proceeding with the full review (to ensure that an adequate quantity of papers existed). The search strategies (described in Appendix 3.1) were focused towards identifying systematic reviews and not cost studies so additional searches were performed.

Information about search terms gathered in the preliminary search for existing reviews was used to inform the design of the search strategies for the proceeding systematic review.

Use of specific economic and other search filters (mostly written for MEDLINE) was not extensive, as they tend not to provide the most accurate indication of the actual volume of the literature available, because of their low recall. For this reason, the search strategies were kept relatively broad with limits to 'Intensive Care' and 'Critical Care'. The problem with this however, was that despite having high sensitivity (i.e. ability to identify relevant articles), use of broad search terms also produced low specificity. This meant that a number of irrelevant articles were also identified and these had to be removed manually. Unlike reviews of effectiveness, the difficulty with reviews of methodology mean that it is not possible to search using design filters such as 'RCT' etc., so as to exclude irrelevant or inappropriate papers. All types of potentially relevant studies had to be included in case valuable details were missed.

The abstracts already identified through the process of identifying an existing review were complimented by additional searches of MEDLINE, EMBASE, the Health Management Information Consortium (HMIC) database, the Social Sciences Citation Index (SSCI) (1981-August 2001), the Science Citation Index Expanded (SCI-EXPANDED) (1981-August 2001), EconLit (1969-August 2001) and the Royal College of Nursing (RCN) Journals database (1985-1996) (Appendix 3.2).

Table 3.2 describes the searches undertaken together with the number of abstracts retrieved. Of the 2,105 abstracts identified, 885 (42%) were considered relevant. A total sample of 665 abstracts remained after duplicate references were removed.

Table 3.2: Description of searches undertaken and the number of abstracts retrieved (scope of literature / full review)

Search Number	Database	Search terms	Number of abstracts retrieved	Number of abstracts initially rejected that were outside of the subject area
#6	**Medline**	1 Critical Care AND Health Care Costs (MeSH terms) NOT editorial NOT letter	188	52 (27%)
#7		2 Exp Critical care/ AND exp "costs and cost analysis"/ NOT editorial.pt NOT letter.pt	655	385 (59%)
#8	**Embase**	1 Explode 'intensive-care'/all subheadings AND explode 'economic-aspect' AND explode 'cost-'/all subheadings NOT editorial in dt NOT letter in dt AND 'resource-allocation'/all subheadings	33	11 (33%)
#9	**HMIC**	1 Intensive care AND cost AND resource*	34	14 (41%)
#10		2 Critical care AND cost*	37	25 (68%)
#11		3 Intensive care AND cost	145	66 (45%)
#12	**Social Sciences Citation Index**	1 Intensive Care AND Cost* (all document types)	226	144 (64%)
#13		2 Intensive Care AND Resource* (all document types)	498	422 (85%)
#14	**Science Citation Index-Expanded**	(Intensive Care OR Critical Care) AND Cost* (title only)	246	76 (31%)
#15	**Royal College of Nursing Journals Database**	Cost* AND (Critical Care OR Intensive Care)	34	21 (62%)
#16	**EconLit**	Intensive Care AND Cost*	9	4 (44%)

The overlap between the different search strategies is shown in Table 3.3.

Table 3.3: Overlap of articles considered relevant using the different search strategies (full review)

Search Number	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16
#1		3	2	29	0	1	48	15	1	1	6	12	10	30	0	3
#2			0	7	0	1	6	4	0	0	0	2	3	2	1	0
#3				3	0	0	3	4	1	0	2	0	0	2	1	0
#4					0	4	109	9	1	0	6	83	8	16	1	1
#5						0	0	0	0	0	0	0	0	0	0	0
#6							3	3	0	0	1	1	0	1	0	0
#7								21	3	2	13	17	14	33	3	1
#8									1	1	4	6	4	6	1	0
#9										2	16	3	3	1	1	0
#10											7	0	0	0	1	0
#11												10	10	12	5	1
#12													67	21	3	2
#13														19	3	2
#14															3	2
#15																0
#16																

3.5 Methods used for the screening of abstracts

The aim of the systematic searches was to provide a list of primary studies that met the inclusion criteria for the review - a list that was as comprehensive as feasible, and as unbiased as possible. The inclusion criteria used to identify the 665 potentially useful articles was subjective and a very forgiving standard was used to retain as many potentially relevant studies as possible.

In order that this large number could be reduced to a more manageable quantity, objective screening criteria were developed and applied. The full papers relating to the abstracts were obtained if they met one or more of the following content criteria.

3.5.1 Inclusion criteria for abstract screening

For inclusion, the abstract needed to describe the actual costs incurred / projected of either:

- The critical care unit(s) as a service; AND/OR
- Patients treated in the adult general critical care unit; AND/OR
- Treatments offered / provided within the adult general setting; AND
- Describe, or appear as though it would describe in the full article, the methodology used for estimating these costs.

3.5.2 Exclusion criteria for abstract screening

Abstracts were excluded if they:

- Described charges NOT costs; AND/OR
- Described a methodology for determining charges NOT costs.

The above criteria were thought sufficiently robust to identify suitable studies. Screening forms were produced and each of the 665 abstracts identified were screened. Most of the abstracts that presented in the form of a letter or editorial had already been excluded through electronic means and hand sifting. No language restrictions were enforced at this stage.

3.6 Results from abstract screening

Figure 3.1 illustrate how many of the abstracts screened were relevant (57%) and of those, the numbers included in the final review (n=376).

3.7 Selection of relevant papers

The full papers for 365 of the 376 references (97%) were obtained. It was not possible to obtain 11 papers. Of the 365, 31 papers (8.5%) required translation into English. Unfortunately, there were insufficient resources to cover translation costs, so these were excluded. A further process of screening the 334 papers was undertaken to eliminate any irrelevant articles before proceeding with the task of data extraction. This was done using the expanded inclusion / exclusion criteria described as follows:

3.7.1 Inclusion criteria for the review

For inclusion in the review, the article had to meet the following criteria:

- Provide a detailed description of the methods used for calculating the daily costs of critical care patients. Note that the resultant costs had to be reported following a description of the methods used, so as to exclude studies that were theoretically as opposed to empirically grounded; AND
- Describe adult patients receiving critical care. Adult patients were defined as those ≥ 16 years of age.

3.7.2 Exclusion criteria for the review

It was important to exclude studies reporting charges or methods of charging since these bear little resemblance to the costs of care. Furthermore, there is a large body of literature discussing the costs of adult critical care without any discussion of methods. It was felt important to exclude these types of studies as well.

The formal exclusion criteria were as follows:

A study was excluded if it:

- Was written in the form of an editorial, letter, post-graduate degree thesis or conference abstract[5]; AND/OR
- Described a method for estimating charges; AND/OR
- Reported the results of studies looking at resource use e.g. use of drug products NOT methods for estimating the costs of the resources used; AND/OR
- Reported partial components of critical care costs (e.g. nursing and drug costs) but not the full costs of a day of critical care unit stay; AND/OR
- Reported expenditures of a critical care unit without any apportionment to a patient-level cost ; AND/OR
- Described a method of workload measurement without any empirical validation / results; AND/OR
- Reported costs but gave no details of the costing method; AND/OR
- Studied non-critical care unit patients; AND/OR
- Studied paediatric or neonatal critical care patients.

After the exclusion criteria had been applied, 20 papers remained (6%). Following updated electronic searches of Medline performed in

5 Conference abstracts were initially obtained however it became clear that due to the word restrictions, there was insufficient detail given on the costing methods to merit their inclusion in the review.

September 2006, 6 additional papers were identified and included in the review.

3.7.3 Bibliographic Details Of Papers That Met The Inclusion Criteria

The bibliographic references of those papers selected for the review are listed in Appendix 3.3.

3.8 Data Extraction

Descriptive summary information relating to each study was extracted (Table 3.4).

- Aim of Study;
- Number of Patients (P);
- Number of Centres (C);
- City / Country where study was performed;
- Method used for measuring care (i.e. name of data base or scoring system);
- Coverage of included costs (i.e. types of cost covered by the method); and
- Coverage of excluded costs (i.e. types of cost excluded by the method).

Table 3.4: Summary of included studies

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Slatyer *et al.*, (1986)	To estimate the direct costs of intensive care and to define the relationship between direct cost, severity of illness and outcome.	P=100 C=1	New South Wales, Australia	Not stated	Direct clinical costs e.g. nurses' time, salaried medical staff time, consultant medical staff time, diagnostic tests, disposables, drugs, intravenous fluids, physiotherapy, oxygen, light and power.	Capital equipment
Løes *et al.*, (1987)	To investigate the costs and benefits of intensive care	P=961 C=1	Oslo, Norway	Computerized registration system	Salaried costs, medical supplies, technical equipment and other expenses	No details provided
Gilbertson *et al.*, (1991)	To estimate the costs of intensive care patients	P=156 C=1	Liverpool, UK	Tick charts were used to collect data that was then entered into a database	All ICU procedures, drugs, disposables, equipment, laboratory and radiology services, physiotherapy, nuclear medicine, salaried costs, pharmacy, hospital administration, laundry, light, stationary, records	Emergency investigations performed outside the ICU's own laboratory
Byrick *et al.*, (1980)	To characterize the ICU patient population using TISS and to estimate the effectiveness and cost of care	P=58 C=1	Ontario, Canada	TISS data	Medical staff costs, drugs and disposables, respiratory therapy supplies, nursing staff costs, housekeeping costs, respiratory technicians salaries.	No details provided
Parikh & Kamad (1999)	To study the quality, cost, and benefits of intensive care	P=993 C=1	Bombay, India	FoxPro database application (ICUREX, Medirex Corporation, Bombay)	Infrastructure, wages, equipment, disposable items, drugs, laboratory tests, microbiology, blood bank, radiology, ultrasonography, stationary, administration	No details provided

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Sznajder *et al.*, (2001)	To evaluate patient outcome and the efficiency of stays in intensive care units	P=211 C=7	Paris, France	CubRea	Drugs, disposables, blood products, procedures, nursing costs, auxiliary nursing costs, medical staff, head nurses, overheads (heating, lighting, hostelry, cleaning, administration, management and building amortization	No details provided
Noseworthy *et al.*, (1996)	To cost adult intensive care by determining inputs to production, resource consumption per patient, and total cost per intensive care unit stay	P=690 C=1	Alberta, Canada	Not stated	Nursing staff, medical staff, professional and support staff, laboratory, diagnostic imaging, supplies, drugs and equipment.	Operative interventions, hospital administration, heating and lighting
Mälstam & Lind (1992)	To measure the workload generated by intensive care patients, to describe a way of determining whether ICU resources are optimally utilized and to estimate the costs of each TISS-point	P=2,693 C=1	Gävle, Sweden	Modified TISS data	Salaried costs, medicines, expendable supplies and investments in new techniques and apparatus	Fixed costs (not described)
Chaix *et al.*, (1999)	To identify, among the information routinely collected on patients in intensive care units, data that determine the total cost for a given patient.	P=73+29 (validation sample) C=1	Paris, France	Retrospective review of medical records and existing computerised databases	Supplies, pharmacy and blood products and tests	Ambulatory care and production costs Medical and non-medical salaries Social charges Overheads Other fixed costs (not described)
Doyle *et al.*, (1996)	To apply an activity-based costing methodology to determine the full cost of intensive care service at a community hospital, a university hospital and a health maintenance organisation (HMO)-affiliated hospital	C=5	Texas, Pennsylvania, Orlando, USA	Not stated	Personnel costs including non-physician clinical salaries and physician salaries and fees (including interns and residents). All nursing staff and other clinical personnel including technicians, respiratory therapists and physiotherapists. Capital equipment.	No details provided

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Korkeila *et al.*, (2000)	To assess (1) the long-term outcome of patients requiring renal replacement therapy in terms of 6-month and 5-year mortality, (2) quality of life and (3) costs of the intensive care.	P=62 C=1	Kuopio, Finland	TISS	No details provided	No details provided
Edbrooke *et al.*, (1999)	To develop a costing method which incorporated the major components of resource use and to test the application of such a method in a number of intensive care units	C=11	UK	Not applicable	Capital equipment, estates, non-clinical support services, clinical support services, consumables and staff	No details provided
Ridley *et al.*, (1991)	To cost daily ICU treatment on an individual patient basis and to refine the method for use in a larger study	C=1 P=20	Norfolk, UK	Dependency points	Fixed costs (capital costs, purchase and maintenance of equipment and buildings and the supporting services such as portering and administration. Land opportunity cost, administration, utilities). Semi-fixed costs (nursing staff, medical staff) Marginal costs (type of ventilatory support, number and type of invasive lines, surgical procedures carried out in ICU or theatres, investigations performed, drug doses and fluids, laboratory services, disposable items, haematological services, blood products).	No details provided
Sznajder *et al.*, (1998)	To propose an instrument able to estimate the direct costs of stays in intensive care	P=121 C=18	Paris, France	Omega Scoring System and ICU regional database	Medical costs: drugs, blood products, supplies, tests and procedures, equipment Staff costs: nursing and auxiliary nursing costs	Fixed direct costs: salaries of physicians, head nurses and secretaries, hostelry and overheads

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Edbrooke *et al.*, (1997)	A new method of accurately identifying costs of individual patients in intensive care: the initial results.	P=68 C=1	Sheffield, UK	Sheffield Health Care Costing System	Patient-related costs: Drugs, fluids, consumables, needles, catheters, equipment usage, laboratory services, medical imagining services, nursing time delivering patient care, medical time delivering patient care. Non-patient-related costs: Energy, heating, building maintenance, engineering maintenance, capital charges, portering services, cleaning and laundry rates, estates, nursing time not delivering patient care, medical time not delivering patient care.	No details provided
Halpern *et al.*, (1994)	To establish Department of Veteran Affairs' intensive care unit costs from a database and to use this information to validate the Russell equations, the most commonly used method of calculating ICU costs.	P=Not reported C=Not reported	USA	Department of Veterans Affairs' cost database	Direct costs: ICU personnel Clinical service costs Supplies, pharmacy costs Indirect costs: ICU portion of general hospital expenses, such as engineering, building management and capital depreciation.	No details provided

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Holt *et al.*, (1994)	To present an intensive care episode costing methodology using the example of a cost-benefit analysis of mask CPAP for severe cardiogenic pulmonary oedema (CPO)	P=39 C=1	Adelaide, South Australia	Not stated	Nursing salaries and wages, medical salaries and wages, drug supplies, medical and surgical consumables, clerical salaries, linen, domestic supplies, stationery and equipment maintenance, allied health departments, pathology, radiology, hospital overhead costs	No details provided
Shiell *et al.*, (1990)	To test the feasibility and value of an economic appraisal of intensive care.	P=100 C=2	Merseyside, UK Essex, UK	Not stated	Medical staff, nursing staff, ancillary and technical staff, use of major disposable items, drugs, diagnostic tests and procedures.	Capital costs, overheads, costs of subsequent hospital stays, outpatient attendances and visits to General Practitioners.
Griffiths *et al.*, (1997)	To test whether a glutamine-containing parenteral nutrition (PN) compared with an isonitrogenous, isoenergetic control feed would influence outcome.	P=84 C=1	Liverpool, UK	TISS	Medical staff, nursing staff, drugs and consumables	No details provided
Dickie *et al.*, (1998)	To determine whether the therapeutic intervention scoring system (TISS) reliably reflects the cost of the overall intensive care unit population, subgroups of that population and individual ICU patients	P=257 C=1	London, UK	TISS	Nursing costs, disposables, drugs / i.v. fluids, enteral nutrition, parenteral nutrition, hired beds, haemofiltration, blood products, linen, physiotherapy, pathology and microbiology tests, radiology / echocardiography / neurophysiology / medical physics, ICU share of central hospital costs, ICU medical staff salary costs, non-pay items and equipment charged to ICU, ICU administration salary costs, ICU technicians salary costs.	No details provided

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Parviainen *et al.*, (2004)	To evaluate changes of the patient characteristics and costs of intensive care over 5 years.	P = 11,323 C = 1	Kuopio, Finland	TISS	All salaries, materials, full allocation of step-down costs (e.g. administration, depreciation, rents) and all secondary costs (laboratory, imaging, consultations, etcl). In addition, total costs over four different cost blocks wre shared and changes evaluated. The cost-block staff included both medical and nursing staff. Consumables included drugs, fluids and nutrition, blood and blood products and disposables. Clinical support services represented physiotherapy, laboratory services, radiology and consultations from other departments. Other included equipment, estates and non-clinical support.	Use of the operating theatre.
Graf *et al.*, (2005)	To assess the five-year survival of a prospectively studied cohort of medical ICU patients, to evaluate the health-related quality of life of all long-term survivors, and to perform cost-effectiveness and cost-utility analysis on the basis of individual patient costs.	P = 303 C = 1	Aachen, Germany	The simplified Therapeutic Intervention Scoring System (TISS-28)	Clinical chemistry, radiology, dialysis, high-price interventions such as intraaortic balloon counterpulsation, coronary angiography and percutaneous coronary intervention; staff salaries (nurses and physicians), overheads such as energy, heating, maintenance and administrative costs.	No details provided

Study (Year)	Aim of study	N (P = Patients, C=Centres)	City / Country where study was performed	Method Used For Measuring Care	Coverage of costs: Included	Coverage of costs: Excluded
Graf *et al.*, (2002)	To evaluate the admission practice to a medical ICU utilising TISS-28, i.e. retrospectively to identify all patients that did or did not require intensive care services by means of active therapy. Furthermore, to analyse expenditure for patients receiving active treatment and non-active treatment and the association of severity of illness and ICU costs in order to identify cost-generating factors.	P = 303 C = 1	Aachen, Germany	The simplified Therapeutic Intervention Scoring System (TISS-28)	Clinical chemistry, radiology, dialysis, high-price interventions such as intraaortic balloon counterpulsation, coronary angiography and percutaneous coronary intervention; staff salaries (nurses and physicians), overheads such as energy, heating, maintenance and administrative costs.	No details provided
Flaatten & Kvåle (2003)	To document costs of intensive care in a Norwegian University Hospital and to perform an average cost-effectiveness study using the expected remaining life-years in survivors after 18 months.	P = 1,051 C = 1	Bergen, Norway	Nine equivalent manpower use score.	Staff wages (nurses and physicians), all consumables including drugs and infusions, the costs of capital equipment and the costs of estates (cleaning, electricity, information technology services, laundry and uniforms, administration, security and internal transport (ICU area in the hospital). Indirect costs were also included (e.g. procedures such as laboratory analysis, blood bank services, x-ray services, physiotherapy, visits by consultants outside the ICU and the use of operating theatres.	No details provided
Moran *et al.*, (2004)	To assess the ability of proxy cost measures, TISS and Omega scores and, in particular, cumulative daily severity of illness scores and ventilation days, to predict individual patient costs, derived from a "ground-up" utilization study.	P = 1,333 C = 3	Woodville, South Australia	TISS, Omega scores	Drugs, procedures, pathology costs, radiology, physiotherapy, nursing staff, medical staff, overheads, other (e.g. administration, repairs and maintenance, orderlies	Nursing time spent on educational activities

				salaries and wages, linen and domestic supplies)	
Rechner & Lipman (2005)	To investigate cost per occupied bed day in a tertiary ICU and to document cost drivers.	P = 1,615 C = 1	Brisbane, Australia	Staff, consumables, clinical support services, capital equipment, top ten drugs.	Excluded were the costs incurred for consultations from visiting medical teams and the resources used when patients went to the operating theatre. In addition, no blood products are paid for by the ICU, but are instead centrally funded through the Australian Red Cross. Allied health specialities and hospital overheads such as infrastructure were excluded, as were the costs that were incurred in the emergency department and other wards when the patient was first admitted.

More detailed extraction of these data allowed the studies to be further classified by design, method of cost estimation, unit of output measurement and the cost components included in each study.

- **Publication Year**: 1980-1983; 1984-1987; 1988-1991; 1992-1995; 1996-1999; 2000-2003; 2004-2006;
- **Country of Origin**:
- **Number of Critical Care Units**: 1; ≥ 2 ≤ 5; ≥ 6 ≤ 10; ≥ 11; Not known;
- **Number of Critical Care Patients**: ≥ 1 ≤ 100; ≥ 101 ≤ 200; ≥ 201 ≤ 300; ≥ 301; Not known;
- **Design**: Single Centre / Multi-Centre Study;
- **Method of Cost Estimation**: Direct measurement at the patient level; apportioned measurement at the unit level; not known;
- **Type of Cost Reported**: Average cost per day (24hr period); Actual cost per day (24hr period); Average cost per patient (admission); Actual cost per patient (admission); Total cost per patient (admission) derived from average cost per day x actual LOS; total cost per patient (admission) derived from cost per Therapeutic Intervention Scoring System (TISS) point x cumulative number of TISS points; cost per patient day derived from (cost per TISS point x cumulative number of TISS points) ÷ patients' length of stay;
- **Cost Components Included**: These were sub-divided into Staffing Costs (nursing staff, consultant medical staff, junior medical staff, physiotherapy, pharmacy staff, respiratory technicians, dieticians), Treatment-Related Costs (diagnostic tests, drugs and fluids, disposable equipment, blood and blood products, nutrition, capital equipment, surgery / invasive procedures) and Overheads /

Hospital Running Costs (oxygen, light and power, institutional overhead costs; Paper not amenable to extraction[6]); and

Methods of apportioning costs: These were categorised by: direct measurement, activities of care, days by level / grade of care, dependency points, TISS, number of patient days, number of critical care beds and the number of patients.

3.9 Results

The descriptive characteristics of each study were summarized under the following sub-headings:

3.9.1 Year of publication

The review included studies published from 1980 up until 2005. The most prolific period yielding the highest number of publications was between 1996 and 1999 (Table 3.5).

[6] The category 'paper not amenable to extraction' represented papers where insufficient details relating to the cost components included prevented data extraction (on these cost components) from taking place.

Table 3.5: Year of publication

Study	Year of Publication						
	1980-1983	1984-1987	1988-1991	1992-1995	1996-1999	2000-2003	2004-2006
Slatyer *et al.*, (1986)		☑					
Løes *et al.*, (1987)		☑					
Gilbertson *et al.*, (1991)			☑				
Byrick *et al.*, (1980)	☑						
Parikh & Karnad (1999)					☑		
Sznajder *et al.*, (2001)						☑	
Noseworthy *et al.*, (1996)					☑		
Mälstam & Lind (1992)				☑			
Chaix *et al.*, (1999)					☑		
Doyle *et al.*, (1996)					☑		
Korkeila *et al.*, (2000)						☑	
Edbrooke *et al.*, (1999)					☑		
Ridley *et al.*, (1991)			☑				
Sznajder *et al.*, (1998)			☑				
Edbrooke *et al.*, (1997)					☑		
Halpern *et al.*, (1994)				☑			
Holt *et al.*, (1994)				☑			
Shiell *et al.*, (1990)			☑				
Griffiths *et al.*, (1997)					☑		
Dickie *et al.*, (1998)					☑		
Parviainen *et al.*, (2004)							☑
Graf *et al.*, (2005)							☑
Graf *et al.*, (2002)						☑	
Flaatten & Kvåle (2003)						☑	
Moran *et al.*, (2004)							☑
Rechner & Lipman (2005)							☑
Total (%)	**1 (3.8%)**	**2 (7.7%)**	**4 (15.4%)**	**3 (11.5%)**	**8 (30.8%)**	**4 (15.4%)**	**4 (15.4%)**

Key: ☑ = Yes

3.9.2 Country of origin

The highest proportion of studies included in the review originated from the UK followed by France. The 16 remaining studies were spread over the 8 other countries (Table 3.6).

Table 3.6: Country of origin

Study	Country of Origin									
	UK	Canada	USA	Australia	Finland	France	Sweden	Norway	India	Germany
Slatyer *et al.*, (1986)				☑						
Løes *et al.*, (1987)								☑		
Gilbertson *et al.*, (1991)	☑									
Byrick *et al.*, (1980)		☑								
Parikh & Karnad (1999)									☑	
Sznajder *et al.*, (2001)						☑				
Noseworthy *et al.*, (1996)		☑								
Mälstam & Lind (1992)							☑			
Chaix *et al.*, (1999)						☑				
Doyle *et al.*, (1996)			☑							
Korkeila *et al.*, (2000)					☑					
Edbrooke *et al.*, (1999)	☑									
Ridley *et al.*, (1991)	☑									
Sznajder *et al.*, (1998)						☑				
Edbrooke *et al.*, (1997)	☑									
Halpern *et al.*, (1994)			☑							
Holt *et al.*, (1994)				☑						
Shiell *et al.*, (1990)	☑									
Griffiths *et al.*, (1997)	☑									
Dickie *et al.*, (1998)	☑									
Parviainen *et al.*, (2004)					☑					
Graf *et al.*, (2005)										☑
Graf *et al.*, (2002)										☑
Flaatten & Kvåle (2003)								☑		
Moran *et al.*, (2004)				☑						
Rechner & Lipman (2005)				☑						
Total (%)	**7 (26.9%)**	**2 (7.7%)**	**2 (7.7%) (%)**	**4 (15.4%)**	**2 (7.7%)**	**3 (11.5%)**	**1 (3.8%)**	**2 (7.7%)**	**1 (3.8%)**	**2 (7.7%)**

Key: ☑ = Yes

3.9.3 Number of Critical Care Units

Most of the identified studies were conducted in a single critical care unit. There were only 2 studies with 11 or more critical care units included (Edbrooke *et al.*, 1999 & Sznajder *et al.*, 1998). It was not possible to determine in one study how many critical care units had been included (Halpern *et al.*, 1994) (Table 3.7).

3.9.4 Number of Critical Care Patients

There were 10 studies with large samples (≥ 301 patients). It was not possible to elucidate the size of the sample used in the study by Halpern *et al.*, (1994) (Table 3.7).

Table 3.7: Number of Centres / Patients

Study	Number of critical care units					Number of critical care patients				
	1	≥ 2 ≤ 5	≥ 6 ≤ 10	≥ 11	Not known / NA	≥ 1 ≤ 100	≥ 101 ≤ 200	≥ 201 ≤ 300	≥ 301	Not known / NA
Slatyer *et al.*, (1986)	☑					☑				
Løes *et al.*, (1987)	☑								☑	
Gilbertson *et al.*, (1991)	☑						☑			
Byrick *et al.*, (1980)	☑					☑				
Parikh & Karnad (1999)	☑								☑	
Sznajder *et al.*, (2001)			☑					☑		
Noseworthy *et al.*, (1996)	☑								☑	
Mälstam & Lind (1992)	☑								☑	
Chaix *et al.*, (1999)	☑					☑				
Doyle *et al.*, (1996)		☑								☑
Korkeila *et al.*, (2000)	☑					☑				
Edbrooke *et al.*, (1999)				☑						☑
Ridley *et al.*, (1991)	☑					☑				
Sznajder *et al.*, (1998)				☑			☑			
Edbrooke *et al.*, (1997)	☑					☑				
Halpern *et al.*, (1994)					☑					☑
Holt *et al.*, (1994)	☑					☑				
Shiell *et al.*, (1990)		☑				☑				
Griffiths *et al.*, (1997)	☑					☑				
Dickie *et al.*, (1998)	☑							☑		
Parviainen *et al.*, (2004)	☑								☑	
Graf *et al.*, (2005)	☑								☑	
Graf *et al.*, (2002)	☑								☑	

Flaatten & Kvåle (2003)	☑								☑	
Moran *et al.*, (2004)		☑							☑	
Rechner & Lipman (2005)	☑								☑	
Total (%)	**19 (73.1%)**	**3 (11.5%)**	**1 (3.8%)**	**2 (7.7%)**	**1 (3.8%)**	**9 (34.6%)**	**2 (7.7%)**	**2 (7.7%)**	**10 (38.5%)**	**3 (11.5%)**

Key:
☑ = Yes

3.9.5 *Methods of cost estimation*

As far as the methods of cost estimation were concerned, these were not mutually exclusive in all instances. There was some overlap between direct measurement at the patient level and apportioned measurement at the (critical care) unit level in 4 studies (Gilbertson *et al.*, 1991; Sznajder *et al.*, 2001; Noseworthy *et al.*, 1996 & Moran *et al.*, 2004). A slightly higher number of studies was performed at the critical care unit level (Table 3.8).

3.9.6 *Type of cost reported*

Eleven of the 26 studies identified estimated total costs per patient. One additional study estimated *average* total costs per patient, but these estimates assumed an equal use of resources per patient (Sznajder *et al.*, (1998). Three studies estimated total patient costs by multiplying an average cost per day by patients' length of stay (Løes *et al.*, 1987; Byrick *et al.*, 1980 & Flaatten & Kvåle (2003). Two studies calculated total patient costs by multiplying patients' cumulative TISS points by an estimated cost per TISS point (Parikh & Karnad, 1999 & Flaatten & Kvåle (2003) (Table 3.8).

Table 3.8: Study design, methods of cost estimation and unit of output measurement

Study	Study Design		Method(s) Of Cost Estimation		Unit of Output Measurement							
	Single Centre	Multi-centre	Direct measurement at the patient level	Apportioned measurement at the Unit level	Average cost per day (24h period)	Actual cost per day (24h period)	Average total cost per patient (admission)	Actual total cost per patient (admission)	Total cost per patient (admission) derived from average cost per day x actual LOS	Total cost per patient (admission) derived from cost per TISS point x cumulative number of TISS points	Cost per patient day derived from (cost per TISS point x cumulative number of TISS points) ÷LOS	Not reported
Slatyer *et al.*, (1986)	☑		☑		☑			☑				
Løes *et al.*, (1987)	☑			☑	☑				☑			
Gilbertson *et al.*, (1991)	☑		☑	☑		☑		☑				
Byrick *et al.*, (1980)	☑			☑	☑				☑			
Parikh & Karnad (1999)	☑			☑						☑	☑	
Sznajder *et al.*, (2001)		☑	☑	☑				☑				
Noseworthy *et al.*, (1996)	☑		☑	☑		☑		☑				
Mälstam & Lind (1992)	☑			☑						☑		
Chaix *et al.*, (1999)	☑		☑					☑				
Doyle *et al.*, (1996)		☑		☑								☑
Korkeila *et al.*, (2000)	☑			☑						☑		
Edbrooke *et al.*, (1999)		☑		☑	☑							
Ridley *et al.*, (1991)	☑		☑			☑		☑				
Sznajder *et al.*, (1998)		☑	☑				☑					
Edbrooke *et al.*, (1997)	☑		☑			☑		☑				
Halpern *et al.*, (1994)		☑		☑	☑							
Holt *et al.*, (1994)	☑		☑			☑		☑				

Study	Study Design		Method(s) Of Cost Estimation		Unit of Output Measurement							
	Single Centre	Multi-centre	Direct measurement at the patient level	Apportioned measurement at the Unit level	Average cost per day (24h period)	Actual cost per day (24h period)	Average total cost per patient (admission)	Actual total cost per patient (admission)	Total cost per patient (admission) derived from average cost per day x actual LOS	Total cost per patient (admission) derived from cost per TISS point x cumulative number of TISS points	Cost per patient day derived from (cost per TISS point x cumulative number of TISS points) ÷LOS	Not reported
Shiell *et al.*, (1990)		☑	☑			☑		☑				
Griffiths *et al.*, (1997)	☑			☑						☑		
Dickie *et al.*, (1998)	☑		☑			☑		☑				
Parviainen *et al.*, (2004)	☑			☑						☑		
Graf *et al.*, (2005)	☑			☑						☑		
Graf *et al.*, (2002)	☑			☑						☑		
Flaatten & Kvåle (2003)	☑			☑					☑		☑	
Moran *et al.*, (2004)		☑	☑	☑				☑				
Rechner & Lipman (2005)	☑			☑	☑							
Total (%)	**19 (73.1%)**	**7 (26.9%)**	**12 (46.2%)**	**18 (69.2 %)**	**6 (23.1%)**	**7 (26.9%)**	**1 (3.8%)**	**11 (42.3%)**	**3 (11.5%)**	**7 (26.9%)**	**2 (7.7%)**	**1 (3.8%)**

Key: ☑ = Yes

3.9.7 Cost components

A common set of cost components was identified from the studies and data extracted on this basis.

3.9.8 Cost components included: Staffing costs

Nursing

Twenty-three studies captured nursing costs. There were 2 studies where it was not clear whether nurses had been included in the cost estimates (Løes *et al.*, 1987 & Mälstam & Lind 1992). Only one study excluded nursing staff (Chaix *et al.*, 1999) (Table 3.9).

Consultant Medical Staff

Most studies captured senior or consultant medical staff costs. There were 2 studies where it was not clear whether senior medical staff had been included in the cost estimates (Løes *et al.*, 1987 & Mälstam & Lind 1992). There were also 2 studies where senior medical staff costs had been excluded from the cost calculations (Chaix *et al.*, 1999 & Sznajder *et al.*, 1998) (Table 3.9).

Junior Medical Staff

A similar pattern was observed with the junior medical staff as with the senior medical staff, other than an additional exclusion of junior medical staff costs by Noseworthy *et al.*, (1996) (Table 3.9).

Physiotherapy

Only 10 studies reported capturing physiotherapy costs. None of the remaining 16 studies explicitly excluded these costs but it was not clear from the remainder - with the exception of Rechner & Lipman (2005) and Moran *et al.*, (2004) whether physiotherapy costs had been included or excluded from the cost calculations (Table 3.9).

Pharmacy Staff

The term 'pharmacy staff' is open to misinterpretation. It can relate to either pharmacists working in a central pharmacy department servicing the hospital (as a whole) or to designated clinical pharmacists working exclusively for the critical care unit. It was not clear in 19 studies whether pharmacy staff had been included in the cost calculations. None of the 6 studies where this was captured provided a clear definition of what was meant by 'pharmacy staff' (Table 3.9).

Respiratory Technicians

Respiratory technicians attend to the equipment needs of ventilated patients. Five studies included these costs. It was not clear in 14 studies whether these costs had been included and two studies excluded these costs (Noseworthy *et al.*, 1996 & Rechner & Lipman, 2005) (Table 3.9).

Dieticians

Dieticians attend to the nutritional needs of critically ill patients. They tend not to work exclusively for the critical care unit but service the hospital as a whole, making daily visits to the critical care unit to recommend appropriate feeds. Only six studies included the costs of dieticians (Table 3.9).

Administrative Staff

The term 'administrative staff' refers to secretarial staff and administrative assistants working within the critical care unit – not hospital administrators i.e. managers. Eleven studies captured these costs. Whilst two studies excluded these costs (Sznajder *et al.*, 1998 & Rechner & Lipman, 2005), it was not clear from 13 studies whether these costs had been included (Table 3.9).

Table 3.9: Staffing Costs

Study	Nursing staff	Consultant Medical staff	Junior medical staff	Physiotherapy	Pharmacy Staff	Respiratory technicians	Dieticians	Administrative staff
Slatyer *et al.*, (1986)	☑	☑	☑	☑	?	?	?	?
Løes *et al.*, (1987)	?	?	?	?	?	?	?	?
Gilbertson *et al.*, (1991)	☑	☑	☑	☑	☑	?	?	?
Byrick *et al.*, (1980)	☑	☑	☑	☑	?	☑	?	?
Parikh & Karnad (1999)	☑	☑	☑	?	?	?	?	?
Sznajder *et al.*, (2001)	☑	☑	☑	?	?	?	?	?
Noseworthy *et al.*, (1996)	☑	☑	☒	☑	☑	☒	☑	?
Mälstam & Lind (1992)	?	?	?	?	?	?	?	?
Chaix *et al.*, (1999)	☒	☒	☒	?	?	?	?	?
Doyle *et al.*, (1996)	☑	☑	☑	☑	?	☑	?	☑
Korkeila *et al.*, (2000)	☑	☑	☑	?	?	?	?	?
Edbrooke *et al.*, (1999)	☑	☑	☑	☑	☑	☑	☑	☑
Ridley *et al.*, (1991)	☑	☑	☑	?	?	?	?	☑
Sznajder *et al.*, (1998)	☑	☒	☒	?	?	?	?	☒
Edbrooke *et al.*, (1997)	☑	☑	☑	☑	?	☑	☑	☑
Halpern *et al.*, (1994)	☑	☑	☑	?	?	?	☑	☑
Holt *et al.*, (1994)	☑	☑	☑	?	☑	?	?	☑
Shiell *et al.*, (1990)	☑	☑	☑	?	?	?	?	?
Griffiths *et al.*, (1997)	☑	☑	☑	?	?	?	?	?
Dickie *et al.*, (1998)	☑	☑	☑	☑	☑	☑	☑	☑
Parviainen *et al.*, (2004)	☑	☑	☑	☑	☑	?	☑	☑
Graf *et al.*, (2005)	☑	☑	☑	?	?	?	?	☑
Graf *et al.*, (2002)	☑	☑	☑	?	?	?	?	☑
Flaatten & Kvåle (2003)	☑	☑	☑	?	?	?	?	?
Moran *et al.*, (2004)	☑	☑	☒	☑	?	?	?	☑
Rechner & Lipman (2005)	☑	☑	☑	☒	☒	☒	☒	☒
Total (%)	**23 (88.5%)**	**22 (84.6%)**	**20 (76.9%)**	**10 (38.5%)**	**6 (23.1%)**	**5 (19.2%)**	**6 (23.1%)**	**11 (42.3%)**

Key: ☑ = Yes: ☒ = No: ? = Not clear

3.9.9 Cost components included: Treatment-related costs

Diagnostic Tests

The term 'diagnostic tests' typically includes laboratory services and radiology tests. These were included in 22 studies. It was not however clear from 4 studies whether these were included (Table 3.10).

Drugs and Fluids / Disposable Equipment

Drugs, fluids and disposable equipment were included in 22 studies with 4 studies not clarifying their inclusion / exclusion (Table 3.10).

Blood and Blood Products

A lower number of studies included blood and blood products. These were excluded in 2 studies (Slatyer *et al.*, 1986 & Rechner & Lipman, 2005), and it was not clear from 9 studies whether they had been included (Table 3.10).

Nutrition

Eleven studies included nutritional products. It was not clear from 15 studies whether these costs had been included (Table 3.10).

Capital Equipment Depreciation / Maintenance

Fifteen studies included the costs of capital equipment. Three studies however excluded these costs (Slatyer *et al.*, 1986; Sznajder *et al.*, 1998 & Shiell *et al.*, 1990) (Table 3.10).

Surgery or Invasive Procedures

Only a very small number of studies included surgery or invasive procedures (Chaix *et al.*, 1999; Ridley *et al.*, 1991; Halpern *et al.*, 1994; Shiell *et al.*, 1990; Flaatten & Kvåle (2003) (Table 3.10).

Table 3.10: Treatment-related costs

Study	Diagnostic tests	Drugs and fluids & disposable equipment	Blood and blood products	Nutrition	Capital equipment depreciation / maintenance	Surgery or invasive procedures
Slatyer *et al.*, (1986)	☑	☑	☒	☑	☒	?
Løes *et al.*, (1987)	?	?	?	?	?	?
Gilbertson *et al.*, (1991)	☑	☑	☑	?	☑	?
Byrick *et al.*, (1980)	?	☑	?	☑	☑	?
Parikh & Karnad (1999)	☑	☑	☑	?	☑	?
Sznajder *et al.*, (2001)	☑	☑	☑	?	?	?
Noseworthy *et al.*, (1996)	☑	☑	?	☑	☑	?
Mälstam & Lind (1992)	?	?	?	?	?	?
Chaix *et al.*, (1999)	☑	☑	☑	?	?	☑
Doyle *et al.*, (1996)	☑	?	?	?	☑	?
Korkeila *et al.*, (2000)	☑	?	?	?	?	?
Edbrooke *et al.*, (1999)	☑	☑	☑	☑	☑	?
Ridley *et al.*, (1991)	☑	☑	☑	?	☑	☑
Sznajder *et al.*, (1998)	☑	☑	☑	?	☒	?
Edbrooke *et al.*, (1997)	☑	☑	☑	☑	☑	?
Halpern *et al.*, (1994)	☑	☑	☑	☑	☑	☑
Holt *et al.*, (1994)	☑	☑	?	?	☑	?
Shiell *et al.*, (1990)	☑	☑	?	?	☒	☑
Griffiths *et al.*, (1997)	?	☑	?	?	?	?
Dickie *et al.*, (1998)	☑	☑	☑	☑	☑	?
Parviainen *et al.*, (2004)	☑	☑	☑	☑	☑	☒
Graf *et al.*, (2005)	☑	☑	☑	?	?	?
Graf *et al.*, (2002)	☑	☑	☑	?	?	?
Flaatten & Kvåle (2003)	☑	☑	☑	☑	☑	☑
Moran *et al.*, (2004)	☑	☑	☑	☑	☑	?
Rechner & Lipman (2005)	☑	☑	☒	☑	☑	☒
Total (%)	22 (84.6%)	22 (84.6%)	15 (57.7%)	11 (42.3%)	15 (57.7%)	5 (19.2%)

Key: ☑ = Yes: ☒ = No: ? = Not clear

3.9.10 Cost components included: Overheads / hospital running costs

Oxygen / medical gases

Oxygen / medical gases were excluded from 2 studies (Shiell *et al.*, 1990 & Rechner & Lipman, 2005) and included in only 4 studies (Slatyer *et al.*, 1986; Doyle *et al.*, 1996; Edbrooke *et al.*, 1997 & Holt *et al.*, 1994). A large number of studies failed to state whether these costs had been included (Table 3.11).

Light and power

Three studies excluded light and power from their cost calculations (Noseworthy *et al.*, 1996; Shiell *et al.*, 1990 & Rechner & Lipman, 2005). Thirteen studies however did include these (Table 3.11).

Institutional overhead costs

Institutional overhead costs cover hospital running costs such as the cost of buildings, hospital administration costs etc. The components of costs included within this broad category will however vary between hospitals depending on the infrastructure in place. Fourteen studies did make some attempt to include these costs and 7 studies excluded institutional / overhead costs from their calculations (Table 3.11).

Not amenable to extraction

Of the 26 studies, there were 2 studies where it was not possible to determine from the information presented whether any of the above cost components had been included or excluded (Løes *et al.*, 1987 & Mälstam & Lind 1992) (Table 3.11). It is important to be able to ascertain what components of cost are included in costing studies, so as to understand the reasons why the results may differ between studies.

Table 3.11: Overheads / hospital running costs

Study	Oxygen / Medical Gases	Light and power	Institutional overhead costs	Not amenable to extraction
Slatyer *et al.*, (1986)	☑	☑	☒	☒
Løes *et al.*, (1987)	?	?	?	☑
Gilbertson *et al.*, (1991)	?	☑	☑	☒
Byrick *et al.*, (1980)	?	?	☒	☒
Parikh & Karnad (1999)	?	?	☑	☒
Sznajder *et al.*, (2001)	?	☑	☑	☒
Noseworthy *et al.*, (1996)	?	☒	☒	☒
Mälstam & Lind (1992)	?	?	?	☑
Chaix *et al.*, (1999)	?	?	☒	☒
Doyle *et al.*, (1996)	☑	☑	☑	☒
Korkeila *et al.*, (2000)	?	?	?	☒
Edbrooke *et al.*, (1999)	?	☑	☑	☒
Ridley *et al.*, (1991)	?	☑	☑	☒
Sznajder *et al.*, (1998)	?	?	☒	☒
Edbrooke *et al.*, (1997)	☑	☑	☑	☒
Halpern *et al.*, (1994)	?	?	☑	☒
Holt *et al.*, (1994)	☑	☑	☑	☒
Shiell *et al.*, (1990)	☒	☒	☒	☒
Griffiths *et al.*, (1997)	?	?	?	☒
Dickie *et al.*, (1998)	?	☑	☑	☒
Parviainen *et al.*, (2004)	?	☑	?	☒
Graf *et al.*, (2005)	?	☑	☑	☒
Graf *et al.*, (2002)	?	☑	☑	☒
Flaatten & Kvåle (2003)	?	☑	☑	☒
Moran *et al.*, (2004)	?	?	☑	☒
Rechner & Lipman (2005)	☒	☒	☒	☒
Total (%)	4 (15.4%)	13 (50.0%)	14 (53.8%)	2 (7.7%)

Key: ☑ = Yes: ☒ = No: ? = Not clear

3.9.11Method of apportioning costs

Table 3.12 describes the method(s) of apportioning costs used in each study.

Table 3.12: Method of apportioning costs

Study	Direct Measurement	Activities of care	Days by level / grade of care	Dependency points	TISS	Unweighted number of patient days	Number of Critical Care Beds	Throughput (Volume) of Patients
Slatyer *et al.*, (1986)	☑							
Løes *et al.*, (1987)			☑					
Gilbertson *et al.*, (1991)	☑					☑		
Byrick *et al.*, (1980)						☑		
Parikh & Karnad (1999)					☑	☑	☑	☑
Sznajder *et al.*, (2001)	☑					☑		
Noseworthy *et al.*, (1996)	☑					☑		
Mälstam & Lind (1992)					☑			
Chaix *et al.*, (1999)	☑							
Doyle *et al.*, (1996)			☑					
Korkeila *et al.*, (2000)					☑			
Edbrooke *et al.*, (1999)						☑	☑	
Ridley *et al.*, (1991)	☑			☑		☑		
Sznajder *et al.*, (1998)	☑							
Edbrooke *et al.*, (1997)		☑				☑		
Halpern *et al.*, (1994)						☑		
Holt *et al.*, (1994)	☑					☑		
Shiell *et al.*, (1990)	☑			☑		☑		
Griffiths *et al.*, (1997)					☑			
Dickie *et al.*, (1998)	☑			☑				
Parviainen *et al.*, (2004)					☑			
Graf *et al.*, (2005)					☑	☑		
Graf *et al.*, (2002)					☑	☑		
Flaatten & Kvåle (2003)						☑		☑
Moran *et al.*, (2004)	☑					☑		
Rechner & Lipman						☑		

(2005)								
Total (%)	11 (42.3%)	1 (3.8%)	2 (7.7%)	3 (11.5%)	7 (26.9%)	16 (61.5%)	2 (7.7%)	2 (7.7%)

Key: ☑ = Yes

Nine different approaches were identified and are described as follows:

Direct measurement

Direct measurement describes studies where resources have been captured at the patient-level (normally at the bed-side) using either prospective or retrospective means of data collection. Typically these sorts of studies are designed to study consecutive admissions over a defined period of time (Slatyer *et al.*, 1986; Gilbertson *et al.*, 1991; Noseworthy *et al.*, 1996; Ridley *et al.*, 1991; Holt *et al.*, 1994 & Dickie *et al.*, 1998), although Sznajder *et al.*, (2001) collected data on every one in three consecutive stays. With direct measurement, resources are broken down into their smallest quantity (e.g. a syringe, a needle, a minute of a nurse's time etc) and counted for each patient according to their identified use of resources. Eleven studies reported costs that had been estimated using this approach. One of the difficulties with direct measurement studies, aside from their time consuming nature is being able to determine how many resources (and costs) are captured as a percentage of the overall expenditure of the critical care unit. Methods of validation are a problem with these these approaches and are rarely, if ever, undertaken.

To improve the accuracy of the data, it is preferable to collect these sorts of data prospectively. However, it is possible, as demonstrated by Chaix *et al.*, (1999) to perform a retrospective review of patients' medical records and existing computerized databases to extract resource use data. Shiell *et al.*, (1990) also adopted a retrospective design however they added *'this approach is not advocated in preference to a prospective study design'* (page 257).

Activities of care

There was only one study where activities of care were used to estimate the costs of patients. The 'activities of care' methodology is not the same as 'activity-based' costing (which is an accounting approach that apportions total expenditure using activity measures in a clearly

defined and transparent manner). The study by Edbrooke *et al.*, (1997) partitioned the care received by patients into discrete activities [of care] so that individual resources could be grouped together to facilitate their prospective collection at the patients' bedside. Activities of care were defined by Wilson *et al.*, (1995) as '*any patient related task requiring the use of ICU resources*' and were prospectively recorded by the nursing and medical staff [as and when each activity was performed on patients] into Patient Data Management Systems (PMDS) that were located at the patients' bedside. These data were then extracted at regular time intervals and stored in an Access database. Patients' use of drugs and fluids was entered into the PDMS but the unit costs attached to the drugs and fluids were based on standard instead of actual doses received by patients. The list of activities was compiled based on the clinical knowledge and experience of the critical care staff (See Chapter 4, Section 4.4.3). Consultation with the senior nursing staff was performed when any changes in clinical practice occurred in order to add to the list of activities covered, however during this study, no changes were made to the list.

The way in which activities of care compares to direct measurement is that with the former approach, resources are allocated to each activity on the basis of their expected use and the costs of these (resources) estimated instead of counting each unit of resource separately which is required with the latter (Wilson *et al.*, 1995).

Days by level / grade of care

Two studies allocated costs to patients using days by level of care / grade of care. Doyle *et al.*, (1996) defined 4 distinct levels of ICU care in order to develop their activity-based costing model (Table 3.14). They then established the types of resources needed when delivering each level of care, the quantity of those resources, and the cost per unit of resource use. One limitation of this approach was its focus on neuromuscular blocking drugs (NMBs) that limited the generalisability of the described levels of care to non-NMB patients.

In the study by Loes *et al.*, (1987) patients were allocated care grades according to their severity of illness. The care grade scale ranged from 1 to 5 with defined criteria for each grade (Table 3.13). The average care grade during the stay in the critical care unit multiplied by the duration of stay in days produced the 'care product' that reflected the patients' requirements for critical care. The sum of care products for all patients (over a given time period) was regarded as an expression of the total workload in the unit over that same given time period. To calculate the costs of individual patients, the authors assumed a linear relationship between care grade and expenditure. By relating the total care product for one year to the total critical care unit expenses obtained from the hospital accounts for the same year, costs for treatment of individual patients or groups of patients were calculated.

Table 3.13: Care Grades 1- 5 (Loes et al., 1987)

Care Grade	Definition
1	No special therapeutic measures required. Several patients under observation by one nurse. Minor risk of developing need for intensive therapy
2	Closer observation necessary. Substantial risk of developing need for intensive therapy
3	Increasing need for stabilizing therapy. Near constant observation by one nurse. Nurse / patient ratio = 1
4	Uninterrupted supportive treatment of disturbed organ functions, i.e. mechanical ventilation
5	Intensive therapy of failing vital organ functions. More than one person present for therapy and control.

Dependency Points

Three studies used dependency points to allocate nursing staff costs to patients (Ridley *et al.*, 1991; Dickie *et al.*, 1998; Shiell *et al.*, 1990). They used the Intensive Care Society of Great Britain's dependency point classification of nursing support for intensive therapy. The dependency points ranged from 2 for the most seriously ill patients to 0.5 for patients that needed little nursing care. In the study by Ridley *et al.*, (1991), the dependency points were allocated to patients on a daily basis by a senior nurse. Limited details were reported in the study by

Shiell *et al.*, (1990) as to how these costs were allocated, however it was possible to elicit more information from the other two studies.

Ridley *et al.*, (1991) calculated the gross combined salaries of the nursing staff present on each of the study days using records of daily work rosters and pay scales (including overtime). The nursing staff cost per patient dependency point was then calculated for each day of stay. An estimate of the costs for nursing care for each patient was obtained by multiplying the cost per dependency point by the number of dependency points ascribed to that patient.

Dickie *et al.*, (1998) adopted a slightly different approach to allocating nursing staff costs to patients' dependency points. Instead of estimating daily costs that took into account staffing variability, they apportioned the total nursing staff costs over a 12-week period by the cumulative number of dependency points.

Therapeutic Intervention Scoring System (TISS)

The Therapeutic Intervention Scoring (TISS), developed at the Massachusetts General Hospital in 1974 (Cullen *et al.*, 1974) and updated in 1983 (Keene & Cullen, 1983) included 57 therapeutic activities, each weighted using a point scale of 1 to 4. The activities with 4 points were used only for the most severely compromised patients, for example those who received artificial ventilation with PEEP, G. Suit and pressurised blood transfusions. In 1983, the number of therapeutic interventions increased to 76.

The aims of TISS were to measure the severity of patients' illness and therapy level, to compare critical care units, to calculate the number of nurses required and to assess the costs of care (Dickie *et al.*, 1998). Seven of the 26 studies used TISS as a means of apportioning costs (Parikh & Karnad 1999; Korkeila *et al.*, 2000; Mälstam & Lind 1992; Griffiths *et al.*, 1997; Parviainen *et al.*, 2004; Graf *et al.*, 2002 & 2004). TISS has also been employed as a method of cost apportionment in the paediatric intensive care population (de Keizer *et al.*, 1998)

Parikh & Karnad (1999) assessed TISS points daily until discharge or death for each patient admitted over a three-month period. Costs were prospectively calculated for each month and by dividing these costs by the total number of TISS points, a cost per TISS point was estimated. Korkeila *et al.*, (2000), Griffiths *et al.*, (1997) and Parviainen *et al.*, (2004) estimated costs per patient in a very similar manner by dividing the yearly total costs of the critical care unit by the total number of TISS points. In all 4 studies, patient costs were then calculated on the basis of their individual TISS points. Graf *et al.*, (2002 & 2004) estimated a cost per TISS point using data gathered over a 3-month period for their patient-specific costs. Mälstam & Lind (1992) did a very similar study but instead used a heavily modified version of TISS to apportion the variable costs of their patients (staff, drugs and fluids and disposables) on the basis of their scores.

Number of patient days / length of stay

Sixteen studies used the observed number of patient days incurred by the critical care unit to allocate their costs. Four studies used this approach exclusively to estimate patient costs (Byrick *et al.*, 1980; Edbrooke *et al.*, 1999; Halpern *et al.*, 1994; Flaatten & Kvåle 2003 & Rechner & Lipman 2005, whereas the other 12 studies used this approach in combination with other approaches. Gilbertson *et al.*, (1991) allocated the fixed costs of the critical care unit to patients on the basis of their length of stay. They described these fixed costs as:

- Salaries for all staff (medical, nursing and ancillary) employed directly or indirectly with the ICU;
- The entire stock of equipment in the ICU (e.g. ventilators and ECG monitors etc); and
- Hospital administrative and estate costs (that included laundry, records, lights and stationery).

Byrick *et al.*, (1980) used the number of patient days to estimate average daily costs for patients' use of drugs (with alimentation), medical and surgical supplies, respiratory therapy equipment, printing,

stationery, housekeeping, nursing salaries, physiotherapist salaries, respiratory technologist salaries and physician costs (including anaesthetic and surgical fees for procedures carried out during the study period).

Parikh & Karnad (1999) in addition to estimating total patient costs using TISS points apportioned the critical care expenditure by the number of patient days to estimate average costs per day.

Sznajder *et al.*, (1998) estimated the variable costs using direct measurement but allocated the fixed and indirect costs of the critical care unit by the number of patient days. They described the fixed costs as those for the medical staff and head nurses. The indirect costs included heating, lighting, hostelry, cleaning, administration, management and building amortization.

Noseworthy *et al.*, (1996) allocated indirect patient care costs on the basis of patients' length of stay. They described these costs as follows:

- Nursing management (unit manager [8 hours / day; 5 days / week], Associate unit manager [24 hours / day], Patient care coordinator [20 hours / week];
- Differential rates for overtime;
- Float time;
- Orientation;
- Educational costs.
- Costs for a clerk (8 hours / day; 5 days / week), unit clerk (24 hours / day), ward aide (24 hours / day), housekeeper (12 hours / day) and biomedical technician (8 hours / day, 5 days / week).

Edbrooke *et al.*, (1997) allocated what they described as the non-patient-related costs on the basis of patients' length of stay. These included energy, heating, building maintenance, engineering maintenance, capital charges, portering services, cleaning and laundry,

rates, estates, nursing time not delivering patient care and medical time not delivering patient care.

Holt *et al.*, (1994) allocated costs associated with the provision of services to critical care patients but not costed directly to the critical care unit on the basis of patients' length of stay. These costs included administration, electricity, piped gases and cleaning.

Shiell *et al.*, (1990) apportioned medical, ancillary and technical staff expenditure to patients on the basis of their length of stay.

Graf *et al.*, (2002 & 2005) divided the non-patient-specific costs which they itemised as heating, lighting, capital costs, management and administrative services, equipment, maintenance and cleaning, linen, hidred beds and 'back-up' salaries for off-duty nurses and physicians, by the number of patient days to estimate a daily cost.

Flaatten & Kvåle (2003) employed a 'top-down' costing method to estimate an average cost of an ICU day as well as an average cost per patient. Included in their costings were expenditures on staff, consumables, capital equipment, estates and clinical support services which included visits by consultants outside the ICU and the use of operating theatres.

Moran *et al.*, (2004) allocated overhead costs and unallocated costs to patients such as administration, repairs and maintenance, orderlies salaries and wages, linen and domestic supplies on the basis of ICU length of stay.

Rechner & Lipman (2005) also employed a 'top-down' approach in order to estimate an average daily cost of care. Costs included in the calculations related to staff, consumables, clinical support services and capital equipment.

Number of critical care beds

In addition to allocating total costs to patients using their cumulative TISS points and the number of patient days, Parikh & Karnad (1999)

also allocated costs using the number of critical care beds to produce a cost per bed. Edbrooke *et al.*, (1999) also apportioned the total expenditures of their sample of critical care units by the number of beds to estimate average costs per bed.

Throughput (volume) of patients

There were only 2 studies where the total costs of the critical care unit were spread over the number of patients admitted to produce average total costs per patient (Parikh & Karnad 1999 & Flaatten & Kvåle 2003).

3.10 Summary of findings

Overall, there were 9 different approaches to estimating costs identified from the literature review that fell into two broad categories of direct measurement at the patient level and apportionment of total costs using levels of care, dependency points, scoring systems and the number of patient days, beds and patients. Section 3.11 attempts to evaluate the quality of each study.

3.11 Assessment of quality

Reviews of methodology differ from effectiveness reviews insofar that conventional checklists with criteria covering both study quality and level of informativeness such as the CONSORT statement are not strictly applicable. Chilcott *et al.*, (2003) explore the difficulties of appraising studies of methodologies and conclude that '*in a methodology review there is likely to be a broad range of types of evidence, hence a single checklist orientated to a particular study design is unlikely to suffice*'.

Jacobs & Bacnynsky (1996) propose a set of criteria for assessing costing methods used in economic evaluation. However, criteria specific to adult critical care proposed by Burchardi *et al.*, (2001) was felt more applicable to studies included in the review. They

recommend a system of quality assessment focused around nine criteria (Table 3.14).

Table 3.14: Quality criteria proposed by Burchardi et al., *(2001)*

Criterion	Definition	Notes
1a	The cost bearer should be clearly identified	The cost bearer relates to the study's perspective (that of a hospital, insurer and/or a patient or society). It is important that the point(s) of view considered are clearly defined and consistently taken into consideration when calculating costs or, as is frequently done, studying cost containment effects
1b	Costs should be defined accordingly	It must be clear that costs are not a concept *per se* but foregone alternatives for an individual or a specific organisation, implying that a cost for one particular cost bearer is not automatically a cost for someone else (Drummond *et al.*, 1987).
2a	The unit of analysis (cost center, cost object) chosen should be shown to determine the distinction between direct and indirect costs).	The choice of cost centers must be made clear as it impinges on the distinction between direct and indirect costs.
2b	The choice between direct costs / unit or (direct + some indirect) costs / unit should be made.	The choice must be explicitly made as to whether to include only direct costs or include the full costs (defined as the sum of direct and indirect costs).
2c	If indirect costs are included, allocation rules should be described and justified.	When including indirect costs, the allocation rules applied should be described and justified.
3	All direct ICU costs should be measured at the ICU level.	Direct ICU cost measurement should be performed at the ICU level instead of being derived from a more aggregate cost figure, such as hospital costs.
4	Fixed, variable and marginal costs should be made explicit and correctly handled.	Apart from the distinction between direct and indirect costs, the difference between fixed and variable costs is equally important and different in nature. The traditional economic concepts of total costs, average costs, total fixed costs, average fixed costs, total variable costs, average variable costs and marginal costs, cover differing economic contents and mechanisms, and should therefore be used thoughtfully, especially when cost data are used for simulation purposes and ensuring policy recommendations. It is generally known that in the long run, all costs are variable. The authors propose that one year can be considered as a relevant time span to make the distinction between fixed and variable costs. Particularly, when indirect methods such as TISS-based expressions are applied, the distinction between cost categories can be blurred. Furthermore, in ICU cost studies, fixed costs and indirect costs are frequently, but wrongly, considered to be equivalent concepts (Dickie *et al.*, 1998; Gilbertson *et al.*, 1991).
5a	Costs should be calculated comprehensively. Only immaterial components may be ignored.	Once researchers have determined the kind of cost they wish to determine, they should aim at comprehensiveness; all important components of the costs studied should be included in the calculation, and for others it should be justified why they were left out, the only good reason being their relative unimportance. Difficulties in determining or estimating costs are not a good argument to ignore them. In the same vein, the way in which costs are determined should be made explicit, allowing the reader to assess the quality of the data presented.

5b	Determination of each component of costs studied should be made explicit. Furthermore a sensible methodology should be applied.	It is clear that an assessment of cost studies in respect of Criterion 5b can only be made on an *ad hoc* basis.

Table 3.15 shows how each study performed against each criterion.

Table 3.15: Assessment of studies according to quality criteria proposed by Burchardi et al., *(2001)*

Study	1a	1b	2a	2b	2c	3	4	5a	5b	Total
Slatyer *et al.*, (1986)	☑	☑	☑	☑	n/a	☑	☒	☑	☑	7/ 8
Løes *et al.*, (1987)	☒	☒	☑	☒	n/a	☑	☒	☒	☒	2/ 8
Gilbertson *et al.*, (1991)	☑	☑	☑	☑	☒	☑	☒	☑	☑	7/ 9
Byrick *et al.*, (1980)	☒	☒	☒	☒	☒	☑	☒	☑	☒	2/ 9
Parikh & Karnad (1999)	☒	☒	☒	☒	n/a	☑	☒	☑	☒	2/ 8
Sznajder *et al.*, (2001)	☑	☑	☑	☑	☑	☑	☑	☑	☑	9/ 9
Noseworthy *et al.*, (1996)	☑	☑	☑	☑	☑	☑	☒	☑	☑	8/ 9
Mälstam & Lind (1992)	☒	☒	☒	☒	☒	☑	☒	☒	☒	1/ 9
Chaix *et al.*, (1999)	☑	☑	☑	☑	n/a	☑	☑	☒	☑	7/ 8
Doyle *et al.*, (1996)	☑	☑	☑	☑	☑	☑	☑	☑	☑	9/ 9
Korkeila *et al.*, (2000)	☑	☒	☒	☒	n/a	☑	☒	☒	☒	2/ 8
Edbrooke *et al.*, (1999)	☑	☑	☑	☑	☑	☑	☒	☑	☑	8/ 9
Ridley *et al.*, (1991)	☒	☑	☑	☒	☒	☑	☑	☑	☑	6/ 9
Sznajder *et al.*, (1998)	☑	☑	☑	☑	☑	☑	☑	☑	☑	9/ 9
Edbrooke *et al.*, (1997)	☑	☑	☑	☑	☑	☑	☒	☑	☑	8/ 9
Halpern *et al.*, (1994)	☑	☒	☒	☑	☒	☑	☒	☑	☑	5/ 9
Holt *et al.*, (1994)	☒	☑	☑	☑	☑	☑	☒	☑	☑	7/ 9
Shiell *et al.*, (1990)	☒	☑	☑	☒	☒	☑	☒	☒	☑	4/ 9
Griffiths *et al.*, (1997)	☒	☒	☑	☒	☒	☑	☒	☒	☒	2/ 9
Dickie *et al.*, (1998)	☒	☑	☑	☒	☑	☑	☒	☑	☑	6/ 9
Parviainen *et al.*, (2004)	☒	☑	☑	☑	☒	☑	☒	☑	☑	6/ 9
Graf *et al.*, (2005)	☑	☒	☑	☑	☑	☑	☒	☑	☑	7/ 9
Graf *et al.*, (2002)	☑	☒	☑	☑	☑	☑	☒	☑	☑	7/ 9
Flaatten & Kvåle (2003)	☑	☒	☑	☑	☑	☑	☒	☑	☑	7/ 9
Moran *et al.*, (2004)	☑	☑	☑	☑	☑	☑	☒	☑	☑	8/ 9
Rechner & Lipman (2005)	☑	☒	☒	☒	n/a	☑	☒	☑	☑	4/ 8
Total	**16 (61.5%)**	**15 (57.7%)**	**20 (76.9%)**	**16 (61.5%)**	**12 (46.2%)**	**26 (100%)**	**5 (19.2%)**	**20 (76.9%)**	**20 (76.9%)**	

Key: ☑ = Yes: ☒ = No: N/A = Not applicable

3.11.1 1a: The cost bearer should be clearly identified

Only 16 of the 26 studies clearly stated the perspective of the study.

3.11.2 1b: Costs should be defined accordingly

Fifteen studies provided some form of description relating to each of the cost components included.

3.11.3 2a: The unit of analysis (cost center, cost object) chosen should be shown to determine the distinction between direct and indirect costs).

Three quarters of the studies specified the unit of analysis adopted in their respective studies (e.g. the patient, the patient day or the critical care unit).

3.11.4 2b: The choice between direct costs / unit or (direct + some indirect) costs / unit should be made.

A smaller proportion of studies (61.5%) made a distinction between direct and indirect costs in their cost calculations and provided a rationale for their inclusion / exclusion.

3.11.5 2c: If indirect costs are included, allocation rules must be described and justified.

There were 6 studies for which this criterion did not apply (Slatyer *et al.*, 1986; Løes *et al.*, 1987; Parikh & Karnad 1999; Chaix *et al.*, 1999; Korkeila *et al.*, 2000 & Rechner & Lipman, 2005). The allocation rules applied to the inclusion of indirect costs were described in 12 of the remaining 20 studies.

3.11.6 3: All direct ICU costs should be measured at the ICU level.

All of the 26 studies performed the measurement of costs at the critical care unit level as opposed to deriving these costs from total hospital costs.

3.11.7 4: Fixed, variable and marginal costs should be made explicit and correctly handled.

Only a very small number of studies engaged in any discussion of the fixed, variable and marginal components of critical care unit costs. As was observed by Burchardi *et al.*, (2001), fixed costs and indirect costs are frequently, but wrongly, considered to be equivalent concepts (Dickie *et al.*, 1998 & Gilbertson *et al.*, 1991).

3.11.8 5a: Costs should be calculated comprehensively. Only immaterial components may be ignored.

All of the important components of cost were included in 20 studies.

3.11.9 5b: Determination of each component of costs studied should be made explicit. Furthermore, a sensible methodology should be applied.

Twenty studies made explicit each component of cost included in their studies and applied an appropriate methodology for their calculation.

3.12 Ranking of studies

There were only 3 studies that met all of the 9 criteria (Doyle *et al.*, 1996; Sznajder *et al.*, 1998; Sznajder *et al.*, 2001). The studies by Noseworthy *et al.*, (1996), Edbrooke *et al.*, (1997 & 1999) and Moran *et al.*, (2004) met 8 of the 9 criteria and there were 7 studies that met 7 of the 9 criteria (Slatyer *et al.*, 1986; Gilbertson *et al.*, 1991; Chaix *et al.*, 1999; Holt *et al.*, 1994; Graf *et al.*, 2002 & 2005 and Flaatten & Kvåle 2003). The studies by Ridley *et al.*, (1991), Dickie *et al.*, (1998) & Parviainen *et al.*, (2004) met 6 of the 9 criteria. Halpern *et al.*,

(1994) met 5 of the 9 criteria with Shiell *et al.*, (1990) and Rechner & Lipman (2005) meeting 4 criteria. Five studies met only 2 criteria (Løes *et al.*, 1987; Byrick *et al.*, 1980; Parikh & Karnad 1999; Korkeila *et al.*, 2000 & Griffiths *et al.*, 1997). Finally, there was one study that met only 1 of the 9 criteria (Mälstam & Lind 1992).

3.13 Advantages and disadvantages of the costing methods

The aim of the systematic review was to identify what methods exist for costing critically ill patients. Although lack of detailed reporting has been identified as a problem with the cost literature (Jacobs & Bachynsky (1996), nine different costing methods were identified (Section 3.9.11).

The quality of studies as determined according to the criteria proposed by Burchardi *et al.*, (2001) was variable. Of particular interest to the work of the thesis were studies that employed methods that could be applied to a multi-centre setting and for practical reasons, did not require detailed measurement of resource use at the patient-level. For this reason, the 12 studies that had employed direct measurement techniques were not considered further (Slatyer *et al.*, 1986; Gilbertson *et al.*, 1991; Sznajder *et al.*, 2001; Noseworthy *et al.*, 1996; Chaix *et al.*, 1999; Ridley *et al.*, 1991; Sznajder *et al.*, 1998; Edbrooke *et al.*, 1997; Holt *et al.*, 1994; Shiell *et al.*, 1990; Dickie *et al.*, 1998 and Moran *et al.*, 2004).

There were 19 studies that were performed in a single center.

The study by Løes *et al.*, (1987) weighted average daily patient costs by care grade (see table 3.13). The limitation of these care grades was that most patients treated in British Critical Care Units would incur the highest care grade, hence reducing the potential of this method to discriminate effectively between individual patients. The first three care grades would typically relate to patients treated in a hospital ward

environment or post-operative unit. As such, this approach was not considered further.

The study by Byrick *et al.*, (1980) estimated average daily costs for individual patients by apportioning the total expenditure of the critical care unit by the observed number of patient days. In doing so, they assumed that patients consumed the same level of resource use on a daily basis – which is not the case in normal clinical practice. The standard method for measuring expenditure was not described in the paper and so this study was also excluded from further consideration.

The study by Parikh & Karnad (1999) apportioned the expenditure of the critical care unit by the cumulative number of patients' TISS points to derive a mean cost per TISS point. Total patient costs were estimated by summing together their TISS points and multiplying these by the derived mean cost. Mälstam & Lind (1992), Korkeila *et al.*, (2000), Griffiths *et al.*, (1997) and Parviainen *et al.*, (2004) adopted the same design, however Mälstam & Lind (1992) used a modified version of the TISS scoring system (limiting the generalisability of its methodology and resultant findings to other critical care units).

The TISS scoring system is designed to be collected on individual patients on a daily basis. It aims to document the nature of therapeutic interventions performed over the previous 24-hour period. Whilst the TISS costing approach has some appeal in its simplicity, there are several limitations and methodological problems in adopting this method for routine use, as a costing tool, in the UK:

- Although the elements that make up the TISS score are related to the care delivered to the patient, a wide variety of combinations of care with very different resource implications can give the same score;
- TISS has not been updated since 1983 nor the weighting of items validated; and

- TISS has also been extensively adapted in individual critical care units to reflect local practice (as was observed in the study by Mälstam & Lind (1992). Indeed in the UK, some 471 different statements were in use in 2001 (Nightingale, P. Intensive Care National Audit & Research Centre, TISS Working Group, Personal Communication). This clearly undermines any valid comparison between different critical care units.

Left remaining were 3 studies where attempts had been made to cost patient care in a multi-centre setting (Doyle *et al.*, 1996; Edbrooke *et al.*, 1999 & Halpern *et al.*, 1994) – all of which adopted a 'top-down' method of costing. Jacobs & Bachynsky (1996) offer a straightforward description for this type of costing method where '*the base statistic is usually the total cost of the cost center in which the services are provided divided by the quantity of output of that cost center.*'

Doyle *et al.*, (1996) employed an activity-based costing (ABC) approach to allocating the critical care unit costs to individual patients. This paper received top scores for quality (see Table 3.16) and appeared methodological robust and scientifically sound. Activity-based costing '*accounts for the inter-relationship between cost and activity by dividing total cost by individual activity-measuring units...accordingly, a graduation of cost level correlates with a gradation of care level*' (Doyle *et al.*, 1996 page 396). Doyle *et al.*, (1996) advocate the merits of activity-based costing as a means of providing '*a systematic means of determining the full cost of a service*' (Hilton, 1991). The financial accounting definition of 'full cost' consists of the following elements: consumables, labour and facility. In determining an average cost per service, the total accounting cost is divided by a predetermined activity base. The ABC approach to valuing resource utilisation, accounts for the inter-relationship between cost and activity by dividing total cost by individual activity-measuring units (Doyle *et al.* 1996). In this paper, the authors presented an ABC model for full-cost determination of different levels of care in the

critical care unit. In this study, no patient-level cost data are collected, instead the total expenditure of the critical care unit is allocated to patients in a way that takes into account their length of stay and the level of care received during their stay.

Cost allocation based on levels of care has been successfully employed in neonatal critical care. A study by Tubman *et al.*, (1990) apportioned the total costs of neonatal intensive care (that included staff salaries, laboratory and radiology tests, hospital maintenance and capital equipment) by the number of cot days that were then weighted on the basis of the levels of care received by the babies. The weightings had been derived from a detailed study at Birmingham Maternity Hospital that determined ratios of costs per cost day for levels I (intensive[7]) and II (high dependency[8]) and special care[9] of 6:3:1 (see Newns *et al.*, 1984).

The major problem with the study by Doyle *et al.*, (1996) related to the levels of care proposed by the authors. The levels of care (described in table 3.16) are based around patients' need for mechanical ventilation and the use of NMB therapy. These levels of care fail to consider other forms of organ support that can influence the level of care received by patients and so the paper was excluded from further scrutiny.

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[7] Intensive care. Those infants requiring positive pressure mechanical ventilation or total parenteral nutrition, and initially all those infants with birthweights of less than 1000 g.

[8] High dependency care. Those infants requiring constant positive airway pressure, continuous monitoring of vital functions, oxygen therapy, intravenous therapy, and initially, those babies with birthweights of less than 1500 g.

[9] Special care. Those infants who have required intensive care and high dependency care, but now require skilled nursing supervision of temperature regulation, feeding, and simple treatments, and those infants admitted only for this form of care.

Table 3.16: Levels of ICU care (Doyle et al., 1996)

Level of care	Definition	Resources Related To Care
1	Usual or normal care for patients breathing normally or without assistance	Direct nursing / physician care + consumables (e.g. drugs) + overheads
2	Care for patients receiving mechanical ventilation	Level 1 + increase in nursing care and consumables+ ventilator + respiratory and physical therapy
3	Care for patients receiving mechanical ventilation and NMB therapy	Level 2 + NMB costs and concomitant medication
4	Care for patients experiencing NMB-attributed prolonged neuromuscular blockade	Level 3 + neurological evaluation + possible increase in ICU length of stay + rehabilitation + NMB costs

The study by Halpern *et al.*, (1994) did not score as highly as the study by Doyle *et al.*, (1996) meeting only 5 of the 9 criteria. Here the ICU patient cost per day was estimated using the Russell Equation:

$$A = (B \times C) + (D \times E)$$

Where A is patient cost per day; B is percentage of occupied non-ICU beds; C is non-ICU patient cost per day; D is percentage of occupied ICU beds; and E is ICU patient cost per day.

The authors attempt to solve the Russell equation using aggregated financial data. This method was employed to compare United States' health care cost trends with trends in the gross domestic product, so was not intended for estimating individual patient costs (more for studying overall patient populations) and hence was excluded from further scrutiny.

The Cost Block Method developed by the Critical Care National Working Group on Costing identified the budgetary components associated with resource use in critical care and defined a series of 'Cost Blocks' with which to perform top-down costing of adult critical care units (Edbrooke *et al.*, 1999). The full definitions of each cost block are shown in Appendix 3.4).

These cost blocks are described as follows:

- Cost Block 1: Current cost of using equipment (linear standard depreciation; total maintenance and annual lease / hire charges);
- Cost Block 2: Estates (building depreciation; water, sewerage, waste disposal and energy; building maintenance, engineering maintenance and decoration; rates);
- Cost Block 3: Non-Clinical Support Services (administration; management and cleaning);
- Cost Block 4: Clinical Support Services (pharmacy, physiotherapy, radiology, dieticians, cardiology, renal support from another critical care unit , clinical neuroservices and laboratory services);
- Cost Block 5: Consumables (drugs, fluids and nutrition, blood and blood products and disposables); and
- Cost Block 6: Staff (medical staff – consultant and non-consultants; nursing staff and technicians).

After a period of piloting the collection of cost data (according to the definitions) in those hospitals represented by members of the Group, discussions were held amongst the Working Group to modify the definitions, with the aim of improving clarity and ease of use. Having refined the definitions relating to the 6 cost blocks, pilot studies were undertaken in 11 critical care units over two consecutive financial years (1994/1995 and 1995/1996) (Edbrooke *et al.*, 1999) and in 21 critical care units over one financial year (1996/1997) (Edbrooke *et al.*, 2001). Cost components within cost blocks 1 to 3 (Current Cost of Using Equipment, Estates and Non-Clinical Support Services) were difficult to collect, inaccurate and not within the control of the critical care unit, e.g. overhead costs that were difficult to apportion. Given that these costs accounted for only 15 percent of the total cost, it was agreed by the Group that they would not be collected in any future studies.

Having been involved in the development and piloting of the cost block method, its main limitation became evident; that a single average daily cost is used for all patients, regardless of case-mix (Baskett & Parsons, 1990).

3.14 Discussion

Hutton & Ashcroft (1998) observe that '*systematic reviews of methods have become an important issue as the quantity and forms of research done vary enormously*'. At the time of the review, there was a dearth of information on standards and guidelines for methodological reviews (Chilcott *et al.*, 2003).

Whilst attempts were made to conduct exhaustive searches for potentially relevant studies, the review had some limitations because of the language restrictions that biased the review towards English-language studies. One reviewer was charged with the entire review that involved both screening the abstracts and full papers and performing the data extraction and quality assessment tasks. Had resources allowed, it would have been better practice to use an additional reviewer. The quality criteria proposed by Burchardi *et al.*, (2001) were focused very much toward the inclusion and classification of the cost components of the studies and less towards the generalisability and transferability of the methods, which was another potential limitation of the review.

The strengths of the review were its comprehensiveness; that being the efforts made to identify all relevant studies through the coverage of databases searched and the amount of screening that took place at the beginning with the abstracts.

The literature on adult critical care has been well described by the review however there is much to be learned from the research conducted in other high cost specialties such as neonatal and paediatric intenhe costing literature on these other high cost areas of medicine was examined so as to determine whether any of the methods /

approaches employed in these other areas could help inform the work of this thesis.

A review of the neonatal cost literature by Mugford (1995) identified a number of studies that had estimated mean patient costs by birthweight category (see Boyle *et al.*, 1983; John *et al.*, 1983; Sandhu *et al.*, 1986, Connolly *et al.*, 1989; Stevenson *et al.*, 1991, Kitchen *et al.*, 1993 and more recent studies by Stevenson *et al.*, 1996[1-2]; Kotagal *et al.*, 1997; Rogowski, 1998 & St. John *et al.*, 2000). Preterm or low birth weight infants are significantly more likely to be rehospitalized than infants born at full term or at normal birth weight (Petrou *et al.*, 2001). Mean health service costs per day had also been determined by level of neonatal intensive care, stratified into 3 care areas (intensive, high dependency and special care) (see Kaufman & Shepard, 1982; Newns *et al.*, 1984, Tudehope *et al.*, 1989, Marshall *et al.*, 1989 & Ewald 1991). Interestingly, the same methodological considerations required when predicting the costs of neonatal care also appear to apply to adult critical care insofar that the process of cost measurement can encompass a variety of methods of varying degrees of complexity. Like adult intensive care, the use of mechanical ventilation (see Phibbs *et al.*, 1981 for neonates and Dasta *et al.*, 2005 for adults) and the duration of stay on the unit have been found to relate to the costs of care (see Cooke, 1988). Furthermore, specific organizational features have been found to affect the costs of neonatal intensive care like adult intensive care (e.g. the high proportion of fixed costs relating to staffing and capital equipment requirements that can result in scale economies (see Fordham *et al.*, 1992 & O'Neill *et al.*, 2000). The design of economic studies also appears to be predominantly observational in both.

The method of 'top-down' costing has been successfully employed in neonatal intensive care units to determine average costs per day for different levels of care (Petrou & Davidson, 2000; Petrou & Edwards, 2004; Roberts *et al.*, 1998) yet data on levels of care are not routinely collected in adult critical care. The study by O'Neill *et al.*, (2000) was

mentioned in Chapter 2 but these authors performed a major multicentre study of neonatal units in the UK in order to better understand the relationship between costs and activity to investigate possible economies of scale. Five statistical models were developed in order to identify the best model fit for the data collected where a model defined by a double-log function relating variations in total costs to total days, case-mix and an interaction term was deemed most appropriate. Evidence of scale economies present in neonatal unit daily costs of care was found. This study also successfully employed the use of postal questionnaires in order to estimate neonatal unit expenditure on medical, nursing, overhead and support costs measured using 'top-down' costing.

Garcia *et al.*, (1999) performed a cost analysis of paediatric ICU patients and De Keiser *et al.*, (1998) studied the relationship between TISS and paediatric ICU costs. Interestingly, exactly the same problems identified with the TISS scoring system in paediatric patients exist with the adult population, namely its inability to capture the costs related to medical staff and issues with the same score incuring differing use of resources. As far as the literature on liver transplantation patients, only one empirical study was identified where the costs of 8 liver transplantation patients had been estimated (Skeie *et al.*, 2002), however very little could be gleaned from such a small sample.

From performing the literature review, the main endeavour of the thesis became clear; that being to incorporate a case-mix measure or weight into the average daily cost estimates so as to reflect the variation in cost (on a daily basis) between individual patients. The cost block method was identified as the method of choice for this task based on its previous applications.

The cost block method had an important advantage, other than scoring highly for quality, that standard definitions had been developed and piloted in a number of critical care units (Edbrooke *et al.*, 1999 &

2001). By 2001, the cost block method was being routinely adopted in approximately 80 critical care units across the UK through the implementation of the Critical Care National Cost Block Programme (Dean *et al.*, 2002). The Cost Block Programme was further endorsed by the Department of Health who recommended in their '*Comprehensive Critical Care*' Report (2000) that all critical care units be encouraged to take part (Department of Health, 2000). This endorsement carried with it an acceptance of the method as the method of choice for costing critical care units so rather than adapt the method significantly (thus introducing the problem of having different versions in use), it seemed logical and sensible to use the method and explore ways in which its use could be enhanced (by investigating an appropriate case-mix adjustor).

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"Not everything that can be counted counts, and not everything that counts can be counted"

Albert Einstein (1879-1955)

CHAPTER 4: EXPLORATORY STUDY OF COST PREDICTORS

4.1 Introduction

The aim of Chapter 4 was to identify a set of case-mix related variables that could be used to predict the daily costs of critical care patients. To this end, two exploratory analyses of patient level case-mix and cost data were performed.

This study was important since it had the core objective of exploring statistically the key '*cost generating events*' and patient characteristics of critical care units (Johnston *et al.*, 1999). Knowledge gained in this way would then be used to determine the design of a multi-centre study to generate the necessary data with which to develop a set of appropriate HRGs (Chapters 5, 6 and 7) and to inform the design of the economic evaluation alongside the CESAR trial (Chapter 8). To achieve this, patient-level data permitting exploratory analyses of a set of case-mix related variables and their statistical relationship to the daily costs of critical care were needed.

Selection of the case-mix related variables included in the first analysis were directed, in the most part, by a survey of clinical opinion conducted by Dr. John Morris in 1995. Added to these variables were patients' age, gender and some very crude data on organ support. .

Two exploratory studies were performed; the first study used data collected over a 12-month period (from 1st April 1996 until 31st March 1997). The second study was conducted over a 6-month period (from 1st October 1997 until 31st March 1998) and collected additional (daily) data on patients' organ support and their daily costs of care.

Nursing and medical staff collected all of the data used in these analyses from consecutively admitted patients receiving treatment in the adult critical care unit based at the Royal Hallamshire Hospital in Sheffield. Data were provided in an anonymous form so as to protect the identity of patients. The 'activities of care' costing methodology was used to estimate the costs of individual patients, which is a form of '*bottom-up*' costing. This method of costing care is explained in detail in Section 4.4.3. The statistical relationship between each of the case-mix variables and patients' daily costs of care were evaluated using univariate and multivariate techniques.

The results of this exploratory work found patients' TISS points to yield the highest predictive power of all of the case-mix variables included in the first study (R^2 =0.378). None of the other variables were found to influence patients' costs of care, when studied separately. However, when these variables were studied in a multivariate analysis, 35.8% of the variation in average daily costs of care could be explained. The second study investigated the relationship between daily costs of care and patients' daily organ support. A multivariate analysis showed organ support alone to explain 30.7% of the variation in daily costs, which was considered a favourable result.

A discussion of these findings and the implications for the multi-centre study conclude this Chapter.

4.2 Background

The systematic review performed in Chapter 3 described the '*activities of care*' costing methodology reported by Edbrooke *et al.*, (1997). This method was used here in these exploratory analyses to estimate detailed costs of individual critical care patients in order that the relationship between these and a list of potentially relevant case-mix variables could be evaluated. Case-mix variables of interest had been identified previously through a survey of clinical opinion conducted by Morris (1995) (see Chapter 7). Those variables that the clinicians had

proposed and reasons for their inclusion in these exploratory analyses are hereby described:

1. Patients' severity of illness within the first 24 hours of admission

    - Acute Physiology and Chronic Health Evaluation (APACHE) II scores were measured within the first 24 hours of admission to the critical care unit. APACHE II is the most widely used severity of illness score in adult critical care units and provides a validated means of enumerating a patient's severity of illness by quantifying the acute changes of 14 physiological parameters and includes the patients' chronic health status and age (Knaus *et al*, 1985). It was developed through the screening of a selection of clinical variables for their ability to predict resource use and patient outcomes (death) (Bardsley, 1987).

2. Critical Care Unit Mortality

    - The costs of patients were described according to their survival status at discharge from the critical care unit (expressed as survivors / non-survivors).

3. Length of Critical Care Unit Stay

    - Length of stay was measured in fractions of a day from the date and time of admission to the critical care unit until the date and time of discharge from the critical care unit.

4. Daily Therapeutic Intervention Scoring System Scores

    - A modified version of the TISS scoring system was used (Keene & Cullen, 1983). Daily TISS data was collected on all patients from the point of admission to, and discharge from the critical care unit.

5. Clinical Procedures

- Clinical procedures were suggested as potentially important by the clinicians surveyed; however, there was no validated classification system of describing clinical procedures that could be tested in this exploratory study. For this reason, a simple method of describing patients' organ support based on the Augmented Period Data Set (ACP) was used (National Case-Mix Office, 1997). The ACP data set contained organ support variables that covered basic respiratory support, advanced respiratory support, circulatory support, renal support and neurological support.

6. Patient Dependency

    - Patient dependency (on the nursing staff) was identified as a potentially relevant variable by the clinicians surveyed but was not studied due to the absence of a patient dependency scoring system in routine use in the critical care unit where the data collection took place.

7. Emergency or Elective Admission (to the Critical Care Unit)

    - This descriptor related to whether patients presented as planned (elective) or unplanned (emergency) admissions to the critical care unit.

Added to the above list of variables was the age and gender of critical care patients that had not been picked up in the consensus of opinion survey but were data items routinely collected in the critical care unit.

4.3 Study design

Two exploratory analyses were performed using patient-level case-mix and cost data collected from the Adult General Critical Care Unit at the Royal Hallamshire Hospital in Sheffield. The design of the first study is described in Section 4.3.1, and the second study described in Section 4.3.2.

4.3.1 Study 1: Analysis of daily costs vs. APACHE II scores, critical care unit mortality, length of stay, daily TISS points, age and gender; post-operative status; emergency / elective status and advanced respiratory support (Y/N).

The first study used data from a cohort of patients consecutively admitted to the critical care unit over a 12-month period to investigate the statistical relationship between their daily costs of care and 6 case-mix variables (APACHE II scores, critical care unit mortality, length of critical care unit stay, daily TISS scores, age and gender). Data on three additional variables (advanced respiratory support – y/n; post-operative status and emergency / elective status) were collected retrospectively[10]. Data on the 6 variables had been routinely collected by staff working in the critical care unit and were readily available for analysis, with the exception of data on advanced respiratory support – y/n, post-operative status and emergency / elective status) which were obtained retrospectively using patients' medical records. The time frame of the study was 1st April 1996 and 31st March 1997.

4.3.2 Study 2: Analysis of daily costs vs. patients' organ support

The second study analysed six months of data collected over a different time period because detailed data on patients' organ support had not been routinely collected during the financial year 1st April 1996 – 31st March 1997. This meant that additional parameters on patients' organ support were introduced into the routine data collection programme and so from 1st October 1997 until 31st March 1998 these data were collected.

4.4 Methods

As explained in Sections 4.3.1 and 4.3.2, different case-mix variables were collected for each study. The same exclusion criterion applied for

[10] This decision was made in accordance with the wishes of the journal reviewers once a manuscript reporting the findings of the multivariate analysis had been submitted for publication

both studies, which was the exclusion of patients with a length of stay of less than 24 hours.

Section 4.4.1 describes how the data used in the analyses performed in the first study were recorded.

4.4.1 Collection of case-mix variables for study 1

Severity of Illness

- The nursing staff calculated and recorded patients' APACHE II scores within 24 hours of their admission to the critical care unit.

Length of Critical Care Unit Stay

- Length of stay was calculated automatically using the dates and times of admission to (and discharge from) the critical care unit. Time was measured in fractions of a day.

Critical Care Unit Mortality

- Patients' survival status was recorded by the nursing staff upon discharge from the critical care unit.

Therapeutic Intervention Scoring System (TISS) Scores

- The nursing staff recorded patients' daily TISS scores to reflect patients' need for therapeutic intervention over the previous 24-hour period.

Age and Gender

- These variables were routinely recorded for each patient at the point of admission to the critical care unit. Gender was coded in dichotomous form and age analysed as a continuous variable as advised by Altman & Royston 2006; Normand, 2006; Owen & Froman 2006; Finkelstein, 2005; Streiner, 2002; Dinero, 1996).

Post-Operative Status

- If patients had received surgery immediately prior to admission to the critical care unit, they were assigned a 'yes' against the post-operative status variable. All remaining patients were assigned a 'no'.

Emergency / Elective Status

- Patients whose admission was planned in advance of admission were considered to be 'elective' admissions and all remaining patients were considered 'emergency' admissions.

Advanced Respiratory Support (Y/N)

- Patients who received mechanical ventilation at any point during their critical care unit admission were assigned a 'yes' against this variable. All other patients were assigned a 'no'.

4.4.2 Collection of case-mix variables for study 2

The second study focused solely on patients' organ support. Note that these data constituted the 'proxy' for clinical procedures identified in the consensus of opinion survey (Section 4.2).

- Patients' Organ Support
    - Definitions relating to the five types of organ support, collected on a daily basis from the point of admission to the critical care unit until discharge from the critical care unit are given in Table 4.1. Patients with no organ support were those that did not score on any of the organ support variables. A coded value of 1 was assigned to individual patient days against each of the different types of organ support if they

were given during that patient day. A value of 0 was assigned if that type of organ support was not given. Note that the last day of each patient's stay was excluded from the analysis as this day varied from 0.1 - 0.9 days and the costs produced would not have reflected a complete day of stay.

Table 4.1: Organ support definitions

Type of organ support	**Definitions**
No organ support	Patients were recorded as having received no organ support if no organs were supported.
Basic respiratory support	Basic respiratory monitoring and support was indicated by one or more of the following: 1. More than 50% oxygen by fixed performance mask. 2. The potential for deterioration to the point of needing advanced respiratory support. 3. Physiotherapy to clear secretions at least two hourly, whether via a tracheostomy, minitracheostomy, or in the absence of an artificial airway. 4. Patients recently extubated after a prolonged period of intubation and mechanical ventilation. 5. Mask CPAP or non-invasive ventilation. 6. Patients who are intubated to protect the airway but needing no ventilatory support and who are otherwise stable.
Advanced respiratory support	Advanced respiratory monitoring and support was indicated by one or more of the following: 1. Mechanical ventilatory support (excluding mask (CPAP) by non-invasive methods e.g. mask ventilation. 2. Extracorporeal respiratory support.
Circulatory support	Circulatory monitoring and support was indicated by one or more of the following: 1. Vasoactive drugs used to support arterial pressure or cardiac output

	2. Circulatory instability due to hypovolaemia from any cause. 3. Patients resuscitated following cardiac arrest where intensive care is considered clinically appropriate. 4. Intra aortic balloon pumping.
Neurological support	Neurological monitoring and support was indicated by one or more of the following: 1. Central nervous system depression, from whatever cause, sufficient to prejudice the airway and protective reflexes. 2. Invasive neurological monitoring, e.g. ICP, jugular bulb sampling.
Renal support	Renal monitoring and support was indicated by: 1. Acute renal replacement therapy (haemodialysis, haemofiltration etc.)

4.4.3 Costing methodology

The 'activities of care' costing method was briefly described in Chapter 3, Section 3.9.11. The list of activities, relating to this methodology and collected on the patients studied, is shown in table 4.2.

Table 4.2: Summary list of activities (Hibbert et al., *1998)*

Group	Item	Group	Item
Administration	Admission to the ICU Discharge from the ICU Organ donation Relatives interview	***Procedures***	Abdominal drain Arterial line Cardiac output monitoring Chest drain Colostomy Central Venous Pressure (CVP) line Continuous Veno-Venous Haemofiltration (CVVH) filter change Epidural procedure Endotracheal tube Formal tracheostomy Illeostomy Mini tracheostomy Naso gastric tube Nasojejeunal Percutaneous tracheostomy Urine output Venous line Wound drain
Drugs	Standard doses for the products identified		
Colloids	Cryoprecipitate Fresh frozen plasma Haemacel Human Albumin Solution (HAS) HAS 20% Hespan Packed cells Platelets Whole blood		
Crystalloids	Continuous Veno-Venous Haemofiltration (CVVH) Nasogastric feeds All fluids listed in the BNF	***Treatment***	CPAP Defibrillation Inspired Oxygen KCl bed Plasmapheresis (FFP) Plasmapheresis (HAS) Ventilatory support
Drug method	Epidural Intramuscular Intravenous bolus Intravenous infusion Nasogastric Nebulised Oral Rectal Short infusion Subcutaneous Sublingual Topical Vaginal	***Ward rounds***	Weekday AM Weekday Bacteriologist Weekday Biochemist Weekday Evening Weekday PM Weekend
Investigations	Bronchoscopy Cardiac echo CAT scan (body) CAT scan (head) Electrocardiogram (ECG) Gastroscopy Lumbar puncture MRI/NMR scan Ultrasound	***Nursing shifts***	Morning Afternoon Night

Section 4.4.3.1 will describe how resources were allocated to the activities of care in order to estimate the costs of each activity.

4.4.3.1 Allocation of resources to the activities of care

The overall costing was achieved by: 1) allocating resources to each activity on the basis of their expected use and 2) assigning unit costs to these resources (Wilson *et al.*, 1995 & Edbrooke *et al.*, 1997). In this way, a cost per activity of care could be estimated.

The ways in which the first task was achieved (i.e. the determination of resource use) was by using a combination of protocols of care and by employing a consensus method based on the opinions and experience of clinicians and nurses working within the critical care unit. The consensus group comprised a small sample of clinicians (n=2), nurses (n=4), medical technical officers (n=2) and ward clerks (n=1) who studied the list of activities and using the protocols of care stipulated for each activity and their knowledge base, identified those resources that would typically be used to deliver the activity. The advantage of having more than one individual staff member involved in this task was that the care of patients is essentially multidisciplinary so it brought a wider range of direct knowledge and experience to the task. Furthermore, interaction between the individuals involved stimulated consideration of a wide range of treatment (hence resource) options (Murphy *et al.*, 1998). Care needed to be taken over the choice of individuals (ensuring that the different staff disciplines were sufficiently represented) and that no one person dominated the discussions.

Each member of staff recorded their lists of resource use independently and then were brought together to look over their responses (as a group) to ensure that for each activity, all of the resources involved in performing the activities of care had been correctly identified (i.e. the list was complete and the quantities corrected estimated). All initial estimates were shared among the respondents who were given the opportunity to refine their estimates based on those provided by their colleagues. The arithmetic means of the final estimates were used in the configuration (Murphy *et al.*, 1998).

4.4.3.2 Configuration of activities

Table 4.3 describes those resources included in the list of activities.

Table 4.3: List of included resource items

Staff	**Clinical support services**
Nursing staff Medical staff Administrative staff Medical Technical Officers Physiotherapists Dieticians	Laboratory tests Radiology tests
Consumables	**Capital Equipment**
Drugs and fluids Disposable equipment Blood and blood products	Ventilators Monitors Humidifiers Specialised bed therapy Maintenance costs

Mereu *et al.,* (1994) found that much of the care delivered in a critical care unit has a significant time-based component rather than the delivery of single isolated activities of care. For this reason, the activities of care methodology incorporated Mereu *et al.,*'s suggestion of describing the activities in terms of start-up events[11]; point events[12] and intervals events[13]. All activities had to have at least one type of event, but not all activities had to have all three types of event.

For each activity, respondents were asked to specify (in minutes) the time taken for each (relevant) staff member to perform each activity, the type and quantity of disposable equipment and blood and blood products used, the type of laboratory and radiology tests performed within the activities and finally, the time taken to set up items of capital equipment (then clean them).

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11 Start-up events – the resources used to initiate a clinical activity (e.g. insertion of a Swann Ganz catheter for cardiac output monitoring)

12 Point events – the resources used for discrete interventions in an ongoing activity of care (e.g. taking a measurement of cardiac output)

13 Interval events – the resources used for the ongoing care of the patient required as a result of a particular activity. This is measured in terms of the costs per hour.

The non-direct costs of care represented the 'overhead' costs that were defined by Wilson *et al.*, (1995) as '*costs not directly attributable to the care of an individual patient*'. Only the costs of the activities were included in the analysis as the overhead costs would have been constant (i.e. the same for every day) so were excluded. It is considered acceptable to do this on the basis that '*in order to study the relationship between [outcome], resource use and patient characteristics, there is no need to include overheads and capital costs*' (Gyldmark, 1995).

Appendix 4.1 tabulates the resources used (and their quantities) by activity of care. The consumables were expressed in single units (quantities), as were the drugs, contracts and equipment. Note that the drugs listed were just local anaesthetics and saline. All of the other drugs were assigned to individual patients rather than to the activities of care. Quantities assigned to staff members were units of time (minutes) taken to perform each activity. Time and motion studies were conducted to validate the completeness and accuracy of the identified configuration.

4.4.3.3 Allocation of unit costs to the activities of care

The costs of care were determined by allocating unit costs against the resources listed for each activity.

The costing of drug therapies, on the other hand was divided into two components:

- The unit costs of the drug multiplied by the quantities needed in vials (not necessarily used); and
- The resources used in administering the drug to the patient (according to the method of delivery e.g. intravenous infusion, short infusion, bolus administration).

Added together these two components formed the cost of the drugs and fluids.

4.4.3.4 Sources of unit cost data

The unit cost data came from a variety of sources, mainly within the Hospital (table 4.).

Table 4.4: Sources of unit cost data

Resources	Data Sources
Nursing staff costs	Critical Care Unit budget statement
Medical staff costs	Anaesthetic budget statement
Disposable Equipment costs	Supplies Department within Hospital
Capital Equipment costs	Equipment manufacturers
Laboratory test costs	Department of Laboratory Medicine within Hospital
Radiology test costs	Department of Radiology within Hospital
Blood and Blood Products	Pharmacy Department within the Hospital and the National Blood Bank
Microbiology tests	Department of Microbiology within the Hospital
Physiotherapy costs	Department of Physiotherapy within the Hospital
Dietetic costs	Department of Dietetics within the Hospital
Drug and fluid costs	Pharmacy Department within the Hospital

4.4.3.5 Estimation of unit cost data

The unit cost for a minute of nursing time was estimated using annual expenditure and whole-time equivalent data by grade-mix apportioned down to an hourly rate then to a rate per minute. The Departments of Laboratory Medicine and Radiology produced the unit costs of laboratory and radiology tests respectively, as did the Department of Microbiology with the microbiology tests. The hourly cost for a physiotherapist and a dietician was estimated from annual salaried information provided by the relevant Departments within the hospital. The Hospital Supplies Department produced a print out of all of the disposable items used by the critical care unit with a list of the unit costs. The drug costs used were supplied by the Hospital Pharmacy Department and were the prices paid by the Hospital rather than the British National Formulary costs. All of the unit costs were entered into the Access database.

In the second study the unit costs for each of the resource items had been updated, not by the use of inflation indices but by the re-collection of these unit costs.

No validation of the accuracy and completeness of the identified configuration (of activities) were performed.

4.4.4 Analysis plan

In the first study, the statistical relationship between each of the case-mix variables and patients' daily costs of care (described in Section 4.4.1) were evaluated using univariate and multivariate techniques.

TISS was the only variable where daily data were recorded which allowed an analysis of the actual (as opposed to average) daily costs of care to be performed. Other data items were collected at different times; the collection of APACHE II scores took place within 24 hours of critical care unit admission (i.e. a one-off collection of data) and other variables such as age and gender were collected on admission. Length of stay was calculated upon discharge from the critical care unit. For these data, it was not permissible to use daily costs of care in the analysis, so average daily costs were instead used. Average daily costs were estimated by apportioning the total costs of care by the time spent in the critical care unit (measured in fractions of a day from the time of admission). Actual daily costs were those that reflected the cost of activities received during that day.

4.4.4.1 Univariate analyses

Univariate statistical techniques were used to study the explanatory power of each of the independent variables on their ability to predict average daily cost variation.

Each of the dependent variables (cost predictors) were regressed against the daily costs of care which produced information on the overall model fit, namely the correlation (R) between cost and the variable(s) under evaluation and the extent to which the variation in cost could be explained (R^2). Linear regression was used on the basis that the model is additive, with the regression coefficients interpretable as the increase in cost for a one-unit increase in a given predictor variable (Myers, 1990). Analysis of variance (ANOVA) determined

whether the model, overall, resulted in a significantly good degree of cost prediction. It produced the sums of squares and the degrees of freedom associated with each and from these two values, the average sums of squares (the mean squares) could be calculated. The most important component of this analysis was the F-ratio – which tests the overall fit of the model to the data - and the associated significance value. The t-test statistic tests the null hypothesis that there is no linear relationsip between the dependent variable and the independent variable (i.e. H_0 states that the regression coefficient is 0) (Kinnear & Gray, 2000) with a statistically significant result confirming the view that the predictor variable is an important contributing factor to estimating costs (Field, 2000). The most accurate predictive model from the univariate analysis was judged on the strength of the R^2 value, the F ratio and significance value and the t-test statistic. The value R^2 is the proportion of variance of the original data explained by the model and the F ratio is the ratio of the mean square for regression to the residual mean square. For models with only one independent variable, like here, the R^2 is simply the square of the correlation coefficient (Campbell, 2001 & Swinscow, 1996).

Scatter plots of the variables were produced in order to assess whether the relationship between the two variables was genuinely linear. For each model, the regression equation was determined which was specified by the constant term and the coefficients. There are two main methods of cross-validation; the first involves calculation of the adjusted R^2 value that indicates the loss of predictive power or shrinkage, and the second method is concerned with data splitting. As the sample of data upon which the models were based was small, it was decided not to employ the data splitting approach and instead focus on the adjusted R^2 value.

4.4.4.2 Multivariate analyses

Multiple linear regression models attempt to predict or estimate the value of a single continuous response variable from the known values of two or more continuous or categorical explanatory variables (Lang & Secic, 1997) and are frequently used in health services and outcomes research to determine the association between patient characteristics and hospital costs (Taylor *et al.*, 1990; Ghali *et al.*, 1999; Austin *et al.*, 2003). The standard linear regression analysis is depicted mathematically using the equation of a straight line, where Y is the variable that one would wish to predict, β_0 is the constant value (or intercept term), β_1 is the coefficient of the first predictor (X_1), β_2 is the coefficient of the second predictor (X_2), β_n is the coefficients of the nth predictor (X_n) and the residual term (E) represents the difference between the variable (e.g. average daily cost for emergency admissions) predicted by the line for the critical care unit *i* and the average daily cost of emergency admissions actually incurred by the unit. The regression equation for *k* independent variables is given by:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_k + E$$

Where β_0, $\beta_1, \beta_2, \ldots, \beta$k are the regression coefficients that need to be estimated.

Three additional variables were included in the multivariate analysis that had not been included in the univariate analysis; these were emergency / elective admissions, whether patients had received advanced respiratory support at any point during their stay (Y/N) and whether patients had received surgery prior to admission to the critical care unit, denoted as post-operative (Y/N) (Jacobs *et al.*, 2001)[14]. In the second study, the statistical relationship between patients' daily costs of care and their type of organ support received on that day was explored. The organ support data were treatment-based, and not measures of organ *failure*. Organ support therefore could be viewed as

[14] This was because the univariate analyses proceeded the multivariate analysis, and here these additional variables had not been considered relevant to the analysis.

a driver of cost. However, this was not considered a problem as the aim of this study was to develop a greater understanding of the extent to which different variables could predict treatment costs and thus form part of a reimbursement system that was capable of accurately reflecting incurred costs at the point of discharge from the critical care unit.

In each study, forced entry was used whereby all variables were entered into the model simultaneously and log-transformations were performed to achieve a better model fit. A common analytical approach employed when faced with non-normal data is to transform the data (typically the dependent variable) to a scale on which it is reasonable to assume normality (Manning, 1998; Alman, 1991; Manning & Mullahy, 2001; Kilian *et al.*, 2002). Log transformation was defined by the equation $y = \ln(x)$, where x represents the original variable and y the transformed variable. When the coefficients are translated back into their natural units, they produce a non-linear relationship between the dependent and independent variables (Armitage & Berry 1994).

4.5 Results

4.5.1 Results of the univariate analyses: Study 1

Data on 265 consecutively admitted patients were available for analysis in Study 1 during the financial year 1st April 1996 - 31st March 1997.

4.5.1.1 APACHE II vs. Daily costs of Care during the first 24 hour period

The relationship between patients' APACHE II scores and costs incurred in the first 24 hours was studied using linear regression analysis where APACHE II scores were found to explain 8.7% of the variation in cost (R^2).

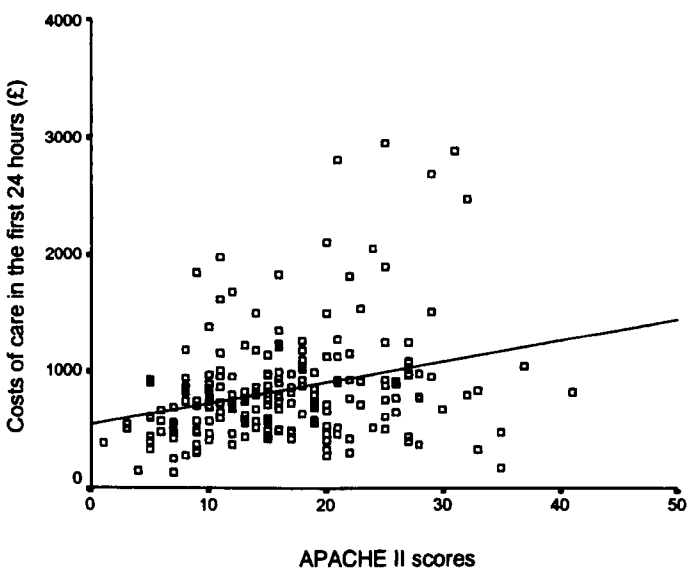
The model equation was defined as:

Predicted 24 Hour Cost (standard error) = £543 (£74) + (£18 (£4) x APACHE II score).

And suggested a positive relationship between the costs of care and severity of illness (see Figure 4.1), but whilst this relationship was statistically significant ($p<0.0001$) confirming a significantly better prediction of cost than the use of mean APACHE II scores alone, the increase in APACHE II scores represented only a small increase in cost as evident from the value of *t* (4.399).

Figure 4.1 shows a scatter plot of the APACHE II scores plotted against these costs together with the positive sloping regression line. As can be seen from the plot, the upward sloping direction of the line indicates that costs of care increase with patients' severity of illness, although there are a number of scores that deviate from the line.

Figure 4.1: Scatter plot of the costs of care in the first 24 hours vs. APACHE II scores



4.5.1.2 Critical care unit length of stay vs. average daily costs

It was not permissible to study the relationship between critical care unit length of stay and daily costs of care because length of stay is expressed as a summed observation and daily costs present as

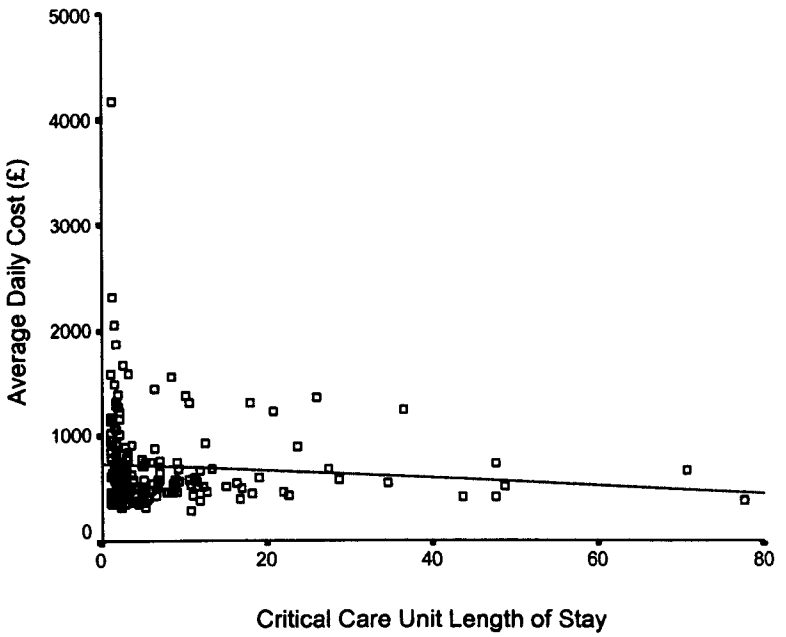
individual observations. Instead data on patients' length of stay were studied in a linear regression analysis to estimate the relationship between patients' *average* daily costs. The downward sloping regression line illustrated in Figure 4.2 is indicative of an inverse relationship between these two variables, suggesting a decrease in average daily costs as length of stay increases. The model equation confirms this hypothesis, as follows:

Predicted Average daily cost (standard error) = £727 (£36) + (Length of stay x –£3 (£3).

The statistical relationship was not highly significant (p=0.220) and explained only 8% of the variation in average daily costs between patients. Figure 4.2 illustrates the skewed distribution of the data, with a small number of outlier patients contributing to a long right-hand tail. Outliers are extreme values (Kinnear & Gray, 2000) (or '*cases that do not belong in the group to which they are assigned provisionally*' (Palmer & Reid, 2001).

Figure 4.2 shows a scatter plot of patients' length of stay against their average daily costs of care together with the regression line.

Figure 4.2: Scatter plot of patients' average daily costs of care vs. length of stay



4.5.1.3 Survival status vs. average daily costs

Non-survivors were found to cost more to treat on a daily basis than survivors. Although this difference was statistically significant with average daily costs for non-survivors costing close to £400 more than for survivors, the explanatory power of survival status was low (R^2 = 0.152). This was however better than the predictive accuracy of APACHE II scores and length of stay and the F-ratio of 34.480 was statistically significant ($p<0.0001$). This suggested that like the APACHE II data, adjusting for survival status produced a better prediction of average daily cost than using average daily costs alone.

The model produced equations for the average daily cost of survivors and non-survivors respectively:

Predicted average daily cost of survivors (standard error) = £1,001 (£58) - £388 (£66).

Predicted average daily cost of non-survivors = £1,001 (£58).

4.5.1.4 TISS points vs. daily costs

The analysis between patients' daily TISS points and their corresponding daily costs of care found TISS to explain 37.8% of the variation in cost ($p<0.0001$).

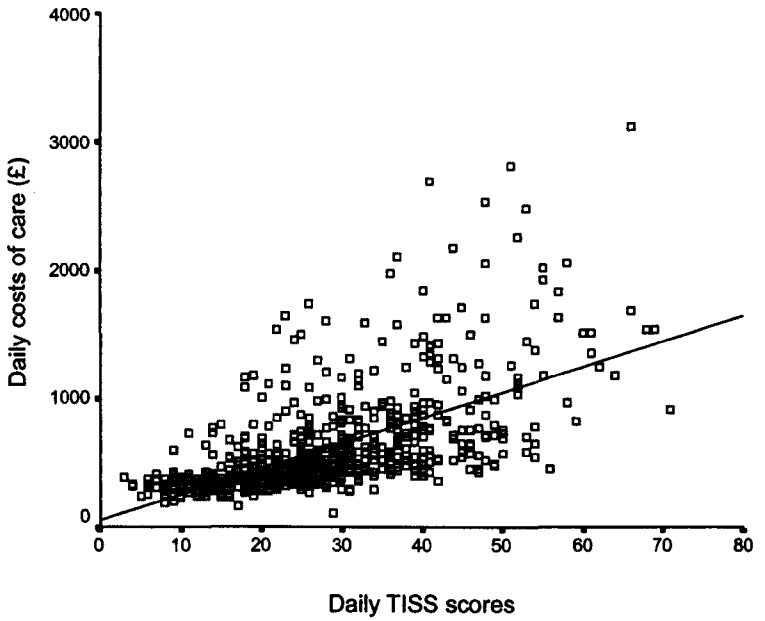
The upward sloping regression line seen in Figure 4.3 illustrates the linear relationship between TISS points and daily costs of care – with the higher the TISS point, the greater the daily cost. There are a small number of outliers but generally, the relationship between the two variables appears strong.

The model equation was defined as:

Predicted Daily Cost (standard error) = £59 (£26) + (£20 (£1) x TISS score).

Figure 4.3 shows a scatter plot for patients' daily TISS points plotted against their daily costs of care (for that day) together with the regression line.

Figure 4.3: Scatter plot of daily costs of care vs. TISS points



4.5.1.5 Gender vs. average daily costs

Gender was not a significant predictor of average daily cost in the sample studied (p=0.740) with very low explanatory power (R^2 = 0.003). Women were found to cost £687 per day to treat and men cost marginally more at £727.

The model produced equations for the average daily cost of women and men respectively:

Predicted average daily cost (standard error) of women = £707 (£31) - £20 (£31)

Predicted average daily cost (standard error) of men = £707 (£31) + £20 (£31).

4.5.1.6 Age vs. average daily costs

Age only explained 0.3% of the variation in average daily cost between the patients studied making it, along with gender, the weakest predictor of cost explored in this series of analyses and did not reach statistical significance (p=0.423)

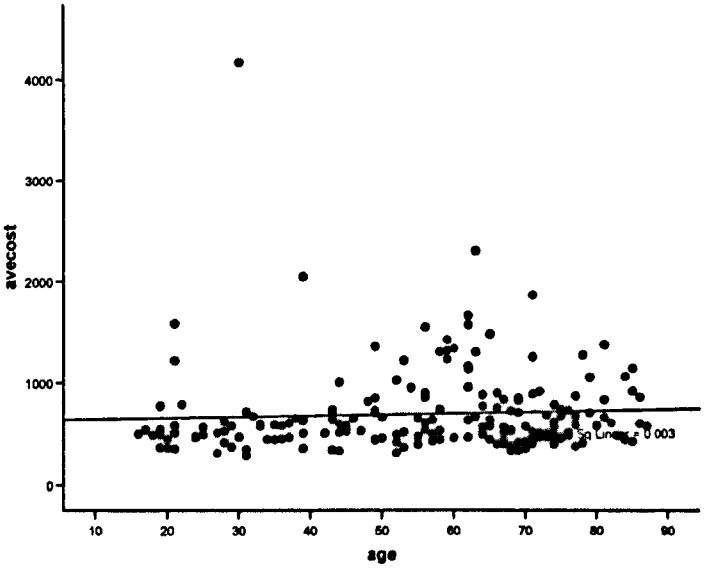
The model equation was defined as:

Predicted average daily cost (standard error) = £633 (£92) + (£1 (£1.5) x Age)

which for every year of age an increase of £1 was incurred.

Figure 4.4 shows a scatter plot of patients' age plotted against their average daily costs and the poor statistical relationship between the two is evident from the absence of any pattern as such. There are a small number of outlier cases (low age / high cost cases).

Figure 4.4: Scatter plot of average daily costs of care vs. age



4.5.2 Results of the multivariate analysis: Study 1

Data on 193 patients with a length of stay > 24 hours were included in the multivariate regression analysis. Excluded were patients staying less than 24 hours in the critical care unit for which average daily costs could not be estimated.

A multiple regression analysis was undertaken using average daily costs as the dependent variable and independent variables that included age, gender, APACHE II scores, length of critical care unit stay, survival at critical care unit discharge, admission status (emergency or elective admission), the percentage of patients receiving advanced respiratory support and whether patients had received surgery prior to their critical care unit admission (post-operative (Y/N)) (Jacobs *et al.*, 2001). Data on the latter three variables were included in this analysis but were not included in the univariate analysis. TISS data were excluded.

The exponential regression or double-log equation was found to best fit the data:

$$\ln Y_i = \ln\beta_1 + \beta_2 \ln X_i + \mu i$$

In a double-log linear regression, all variables (both X and Y) are translated into natural logarithms. One attractive feature of this model is that the slope coefficient β_2 measures the elasticity of Y with respect to X, that is, the percentage change in Y for a given (small) percentage change in X. The model also assumes that the elasticity coefficient between Y and X, β_2, remains constant throughout (Gujarati, 1995). Of particular interest was the functional form of the model with respect to length of stay. The results for the double-log case only (which expressed all variables except dummy variables in terms of natural logs) were reported since it performed as well as any other form. In a double-log regression equation, all variables except dummy variables are translated into logarithmic form. This means that the regression

coefficients of the logarithmic variables are expressed as relative rates of change. When the coefficients are transferred back into their original forms they produce a non-linear relationship between dependent and independent variables (Jacobs *et al.*, 2001).

Descriptive statistics relating to the variables included in the analysis are shown (table 4.5).

Table 4.5: Descriptive statistics of variables used in the multiple regression model (Jacobs et al., 2001)

Variable	Mean (SD)	Median (IQR)
Average daily cost (£)	703 (422)	578 (469-776)
Age (years)	55.3 (19.3)	58.6 (41-71)
Gender (% female	43	
Post-operative (% surgical)	44	
Emergency admissions, %	86.5	
APACHE II score	15.6 (7.1)	15.0 (10-20)
Advanced respiratory support (%)	69	
Length of critical care unit stay (days)	7.2 (11.0)	3.0 (1.8-8.1)
Survival at ICU discharge (%)	77	

The regression model explained 35.8% of the variation in average daily costs. The regression coefficient of the log of average daily costs on the log of length of critical care unit stay yielded a coefficient of –0.12, which meant that a 10% increase in length of stay was associated with a 12% decrease in cost per day (table 4.6).

Table 4.6: Results of the regression analysis of average daily cost (Jacobs et al., 2001)

Variable	Coefficient	P value
Constant	5.994	0.000
Age	0.0022	0.972
Gender	0.0169	0.738
Postoperative (1=Yes, 0 =No)	0.1040	0.057
Emergency admission (1=Yes, 0=No)	0.0281	0.729
APACHE II score on admission	0.211	0.000
Advanced respiratory support (1=Yes, 0=No)	0.255	0.000
Length of critical care unit stay	-0.120	0.000
Survival at ICU discharge (1=Yes, 0=No)	-0.256	0.000

Age, gender and emergency admissions were not found to be statistically significant, which is not surprising for gender or age given the findings from the univariate analyses. A non-linear relationship between average daily cost and length of stay suggested however that the longer the stay in the critical care unit, the lower the average daily costs of care.

4.5.3 Results of the multivariate analysis: Study 2

Data on 116 consecutively admitted patients over a six-month period was used in Study 2. Eighty-five patients (73%) had a critical care unit length of stay in excess of 24 hours and so were included in the study, yielding a total of 527 patient days for analysis. There were 5 (of the 527) patient days where no organs were supported. In 89 patient days there was only basic respiratory support, and in 225 patient days there was only advanced respiratory support. The remainder of cases had multiple organ support. The most frequently observed combinations of multiple organ support were advanced respiratory and circulatory (71 patient days) and advanced circulatory and neurological (54 patient days). The frequency of types of support is summarised in table 4.7.

Table 4.7: Frequency of the types of organ support received

No support	Basic respiratory support	Advanced respiratory support	Circulatory support	Renal support	Neurological support	Number of days observed (%)
X						5 (0.9)
	X					89 (16.9)
		X				226 (42.9)
			X			4 (0.8)
				X		0 (0)
					X	1 (0.2)
	X		X		X	1 (0.2)
		X		X		2 (0.4)
	X			X		3 (0.6)
		X	X	X	X	6 (1.1)
	X		X	X		6 (1.1)
	X				X	7 (1.3)
	X		X			9 (1.7)
		X	X	X		19 (3.6)
		X	X		X	24 (4.6)
		X			X	54 (10.2)
		X	X			71 (13.5)

Descriptive statistics for the daily costs of care by organ support are shown in table 4.8.

Table 4.8: Descriptive statistics of the daily costs of care by type and combination of organs supported

Organ support type	N (days) (%)	Mean (SD) (£)	Median (25%-75% IQR [Min-Max])
0	5 (0.9)	625 (479)	427 (373 – 976 [344-1,478])
1	89 (16.9)	496 (224)	430 (359 – 528 [275 – 1,460])
2	226 (42.9)	640 (352)	574 (415 – 758 [276 – 3,934])
3	4 (0.8)	667 (537)	431 (359 – 1,212 [338 – 1,470])
4	1 (0.2)	655	
5	9 (1.7)	687 (374)	503 (422 – 1,061 [364 – 1,350])
6	7 (1.3)	580 (154)	575 (434 – 719 [345. – 749])
7	3 (0.6)	577 (143)	527 (467 – n/a [467 – 739])
8	1 (0.2)	694	
9	6 (1.1)	2,090 (1,322)	1,847 (1,074 – 2,887 [838 – 4,513])
10	71 (13.5)	877 (455)	795 (542 – 1,028 [394 – 2,801])
11	54 (10.2)	804 (836)	596 (419 – 817 [296 – 6,011])
12	2 (0.4)	1,475 (455)	1,475 (1,153 – n/a [1,153 – 1,796])
13	24 (4.6)	1,023 (382)	912 (729 – 1,192 [538 – 2,038])
14	19 (3.6)	1,459 (519)	1,627 (859 – 1,846 [554 – 2,202])
15	6 (1.1)	1,391 (614)	1,591 (686 – 1,901 [609 – 1,967])

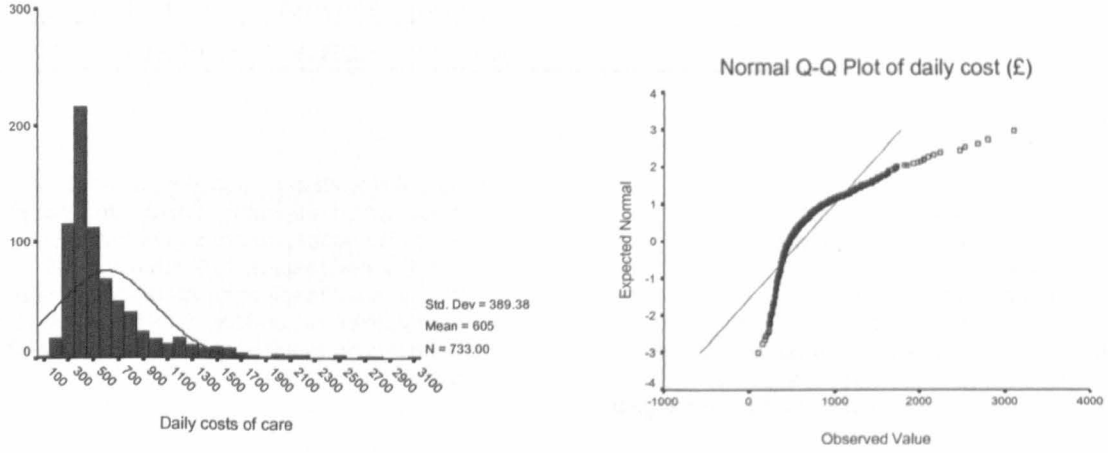
Key

0 = No organ support
1 = Basic respiratory support
2 = Advanced respiratory support
3 = Circulatory support
4 = Neurological support
5 = Basic respiratory & circulatory support
6 = Basic respiratory & neurological support
7 = Basic respiratory & renal support
8 = Basic respiratory, circulatory & neurological support
9 = Basic respiratory, circulatory & renal support
10 = Advanced respiratory & circulatory support
11 = Advanced respiratory & neurological support
12 = Advanced respiratory & renal support
13 = Advanced respiratory, circulatory & neurological support
14 = Advanced respiratory, circulatory & renal support
15 = Advanced respiratory, circulatory, renal & neurological support

As can be seen from table 4.8, multiple organ support is more costly than supporting a single organ. Advanced respiratory, circulatory and renal support incurred the highest cost.

The type and combinations of organ support received by patients on a daily basis (over a six-month period) was mapped out and a multiple regression analysis of these data and patients' daily costs of care performed. It was thought appropriate to use regression analysis here to characterize the relationship between cost per day (Y) and the number of days of different types (and combinations) of organ system support ($X_1, X_2 \ldots X_k$). As can be seen from the Figure 4.5, daily costs of care do not appear to follow a normal distribution and show evidence of substantial skewness.

Figure 4.5: Histogram and Q-Q plot showing the distributions of the daily costs of care



Daily costs Mean (SD) (£)	Median (25%-75% IQR [Min-Max])	Skewness	Kurtosis	Kolmogorov-Smirnov statistic	df	Sig
605 (389)	469 (373-698 [106-3107])	2.472	7.828	0.197	733	0.000

The Kolmogorov-Smirnov statistic is significant. Briggs & Gray (1999) recommend the use of median as opposed to mean estimates of central tendency when data are skewed, however add that it is inappropriate to use median costs in a cost analysis on the basis that the median cost will be below the mean (a view supported by the data presented below each histogram). The log-linear form of equation, by which costs were expressed in logarithmic form, the day of stay in ordinary form, and the categorical variables expressed as dummy variables was the best fit. The coefficients (and level of significance) are shown (table 4.9).

Table 4.9: Results of the regression model of organ support and daily costs

Dependent Variable	Log of cost per day (£) (p values)
Independent variables	
Constant	6.428 (p<0.0001)
Day of care	-0.0108 (p<0.0001)
Advanced respiratory support	.235 (p<0.0001)
Circulatory support	.257 (p<0.0001)
Renal support	.588 (p<0.0001)
Neurological support	.0707 (p=0.162)

The results suggest a statistically relationship between patients' organ support and their daily costs of care, and which also suggests that daily costs decline slightly as length of stay increases. Organ support does appear to influence the cost per day, especially for renal and circulatory support. With regard to the daily cost equation, the R^2 was 0.307, $p<0.0001$. The predicted daily cost for the basic reference case (1 day stay, basic respiratory support only) was £612. The coefficients for advanced respiratory support, circulatory support, and renal support were also statistically significant; the coefficient for neurological support was not however. Advanced respiratory support was found to

add £162 to each day above basic respiratory support; circulatory support added £179. Renal support by itself added £490 above basic respiratory support. Compounded, these differences were greater. Advanced and renal support added £389 above basic respiratory support; and renal, circulatory and advanced respiratory together added £1,190 above basic respiratory support.

4.6 Discussion

Regression analysis has been frequently used in different studies to both identify factors found to contribute to variation in cost (Rutten-van Molken *et al.*, 1998; Rutten-van Molken & Van Doorslaer 1999; Koopmanschap *et al.*, 2001); to predict costs and length of stay in patients (Antonow *et al.*, 2001) and to estimate resource use i.e. patients' TISS score during the first 7 days in the critical care unit (Zimmerman *et al.*, 1993). The dependent variable in the analysis is typically cost (per day or per stay) and the independent variables can be diagnosis, length of stay or other identifiably important factors (Smith & Barnett, 2003). The transformation of data from one scale to another can be used to overcome problems associated with skewness (Briggs & Gray, 1999), and is deemed to be an appropriate correction (Hay, 2005). There are however problems with the transformation of data which are worthy of note. Cantoni & Ronchetti (2006) alude to these, in particular, the difficulties in the interpretability of the model coefficients and the quality of the retransformed parameter estimates is typically poor. Alternative approaches, such as the use of non-parametric bootstrapping which employs the empirical distribution of costs to make inferences about the uncertainty of the sample mean could have been considered (Barber & Thompson, 2000).

4.6.1 Selection of variables for study

The variables available for the exploratory analyses were those routinely collected by the critical care unit staff. Table 4.10 summarises the main findings from the univariate analyses.

Table 4.10: Summary of the univariate and multivariate Analyses

Choice of independent variables	Choice of dependent variable	R^2	F	T	P Value
APACHE II scores	Costs of care in the first 24 hours	0.087	19.347	4.399	<0.0001
Critical care unit length of stay	Average daily costs	0.008	1.517	-1.231	<0.0001
Survival status	Average daily costs	0.152	34.480	-5.872	<0.0001
Daily TISS scores	*Actual* daily costs	0.378	443.782	21.066	<0.0001
Gender	Average daily costs	0.003	0.301		
Male				0.642	0.522
Female				-0.648	0.518
Age	Average daily costs	0.003	0.644	0.803	0.423
APACHE II scores, critical care unit length of stay, survival status, admission status, % of patients receiving advanced respiratory support, post-operative status vs. average daily costs	Average daily costs	0.358			<0.0001
Multivariate analysis of patients' organ support vs. daily costs	*Actual* daily costs	0.307			<0.0001

Each variable will now be discussed in turn.

APACHE II Scores

Based on the findings of this study, patients' APACHE II scores could not be considered a strong predictor of daily cost. The scoring system was primarily intended for prediction of mortality, not for describing critical care patients or predicting costs of care (Dragsted & Qvist, 1992). It was thus not surprising to observe such a poor correlation. An additional problem with APACHE II scores is put best by Birnbaun (1986) - '*the severity of the disease process(es) does not necessarily reflect the level of care required to support the patient....with very ill patients possibly only requiring supporting care whilst minimally ill patients may require profound levels of care*'. APACHE II scores are only recorded within the first 24 hours of admission, which limits its

ability to reflect changes in resource use and cost over time. Finally, a large amount of data is required in order to calculate the APACHE II scores which is a further problem for routine data collection.

Critical Care Unit Length of Stay

Patients' length of stay in the critical care unit has always been a naturally strong predictor of patients' total costs of care, but was not found to be a very good predictor of average daily costs in the univariate analysis.

Patients' Survival Status

There is a belief that it costs twice as much to die in a critical care unit as it does to survive (Sage *et al.*, 1986). The findings in this study suggest that the extent to which non-survivors cost more is certainly less than this. Non-survivors did cost more to treat on a daily basis than the survivors. They did however stay on average, a shorter period of time in the critical care unit than the survivors. The regression analysis however found patients' survival status to be a very poor predictor of average daily costs.

TISS

Patients' TISS points were able to explain about 38% of the variation in daily costs in this study, which was a significant result. The practical and methodological problems of using TISS as a method of cost estimation in a multi-centre setting have already been described (Chapter 3, Section 3.13). The critical care unit at the Royal Hallamshire Hospital like many other critical care units had modified the TISS scoring system to reflect modern clinical practice thus the values obtained are not comparable with those reported in the literature. The version of TISS used in this study contained modified entries for respiratory and renal support.

Gender

Despite epidemiological studies of critical care finding patients to be predominantly male, this was not a trend reflected in the study sample.

Whilst there were males than females, the extent to which a difference existed was not marked. Gender was not considered to play any role in explaining cost differences between patients based on the findings from this study.

Contrary to the findings of Bernard *et al.*, 1993), who studied 19,387 hospital admissions in the United States and found women to spend longer in the critical care unit than men, no significant differences in length of stay or total costs of care were observed in the sample studied.

Age

Although crude mortality is higher in the elderly compared to younger critical care patients (Power, 1999), previous studies have found age not to be a factor that would explain differences in resource use (Katzman McClish *et al.*, 1987; Campion *et al.*, 1981). Approximately 30% of patients in my study were more than 70 years of age and reflect a similar trend to that reported in the literature (Horn, 1997 & Schuster, 1991) with increases in the average age of patients being attributed to rising life expectancy and increases in cardiovascular disease that make critical care necessary (Horn, 1997).

The power of age to predict average daily costs of care was found to be poor; the results for total costs were marginally better but still not a reliable predictor of cost.

Organ Support

Organ support ranked the third best predictor of daily cost after TISS and the multivariate analysis of the other variables, with an R^2 of 0.307. This was an important finding for consideration in the thesis. It was felt that if this variable could be used to predict daily costs and when summed together could be used to estimate total patient costs. These total costs would thus be a function of patients' length of stay and also reflect the care received during that stay.

The advantages to this approach for consideration in a multi-centre setting were as follows:

- The organ support variables were contained within the ACP data set that all critical care units in England and Wales were required to collect on every patient from 1st October 1997;
- Staff working within the critical care units were familiar with the definitions used for the different types of organ support and the data is straightforward and quick to collect;
- The ACP data set cannot be modified by critical care units, in the same way in which TISS is because it forms part of a mandatory Department of Health data set; and
- Being collected on a daily basis, it was sufficiently sensitive to changes in care requirements (and costs) over time.

4.6.2 Costing Methods

The activities of care costing methodology used in this study was effective in allowing the costs of individual patients to be estimated for the purposes of identifying potential cost predictors from the variables studied. Due to the limited availability of patient-level cost data, no such study to date has investigated each of these potential predictors of cost in as much detail.

The limitations of this study include the small sample size upon which these findings are based that raise questions as to the generalisability of these findings both from the perspective of the critical care unit where the study was performed, and from a broader perspective being that of other critical care units in England and Wales. In this study, specifically, the relationship between renal support and daily costs was not tested as no patients received this support (alone). Six types of

organ support[15] were delivered on 92% of days, which left a very small number of days that were spread across the remaining 9 types of organ support[16]. Whilst one can be reassured by the costs produced for the former 6 types of organ support, the relationship between the costs and the latter need to be interpreted with caution because of the small numbers of observations.

The activities of care costing method had the advantage over a 'bottom-up' approach because with the latter, all resources are directly measured at the bedside, whereas with the activities of care method, resource use is grouped together. This means that data collection is less laborious at the bedside, because instead of having to record every single resource item, the nursing and medical staff just had to record that a patient had received a given activity of care.

There are however limitations of this method of costing. First, the configuration of activities assumes an expected resource use for a given activity, rather than an observed resource use. This means that for some patients where an activity took longer to perform or required more staff than expected, their costs will be underestimated. The same reasoning applies to activities taking shorter amount of times and incurring less staff than expected. What was found after having conducted this study was that there was another component to the activities that was missing; that is, the finishing of an activity of care (or termination). For example, when a patient is weaned from mechanical ventilation and the costs incurred with this. If I chose to perform the study again, I would have adapted the method accordingly or at least, produced a series of activities to reflect this.

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15 Basic respiratory support, Advanced respiratory support, Advanced respiratory & circulatory support, Advanced respiratory & neurological support, Advanced respiratory, circulatory & neurological support, Advanced respiratory, circulatory, renal & neurological support.

16 No organ support, Circulatory support, Neurological support, Basic respiratory & circulatory support, Basic respiratory & renal support, Basic respiratory, circulatory & neurological support, Basic respiratory, circulatory & renal support, Advanced respiratory & renal support, Advanced respiratory, circulatory, renal & neurological support.

Secondly, the activities of care only account for only a proportion of the true expenditure of the critical care unit. To apply these estimates to studies seeking to develop HRGs, this represents a problem; that of the funding not reflecting all of the costs.

With respect to testing the generalisability of these findings, further problems emerge. Firstly, the configuration of activities changes from year to year with changes in clinical practice. This can alter the estimates of costs from one study to the next, and care needs to be taken to ensure that such observed differences can be explained (either by a change in the configuration or in the nature of activities of care received by patients). Secondly, the configuration would need adapting to reflect differences in resource use and clinical practice if this method was applied in a multi-centre setting. The amount of time spent maintaining and updating the configuration, based on my experience of performing these tasks, was considerable as was the collection of unit cost data required to estimate the costs of resources used. Coupled with the programming tasks and the amount of time spent by staff at the bed-side recording the activities of care, as and when they were delivered, raised further questions as to the reproducibility of this approach in a multi-centre study. The drug costs were determined from transferring the records made on the drug kardexes over to a database where the unit costs of these were stored; this was also a labour-intensive process.

It would have been useful to have a benchmark against which the activities of care could have been compared to assess the activities' criterion validity. Although the critical care unit collected TISS scores on individual patients, they had modified this measure to reflect the care delivered in the unit. Still, this may have proved helpful in identifying any mismatch between the two systems and perhaps in explaining where some of the nursing time may have been missed.

4.7 Conclusions

This small exploratory study was able to identify the case-mix variables most likely to explain the variation in daily costs between individual patients. This study provided focus and direction to the design of the proposed multi-centre study in terms of identifying important predictors of daily cost.

The reasons for preferring the organ support approach over the TISS scoring system were well explained, however what is worthy of note is the benefits that former approach has over the use of a multivariate model using patients' APACHE II scores etc. described in Section 4.5.2. A simpler costing method that is dependent on a small number of variables is infinitely preferable to one where multiple items of data need to be recorded, particularly at different points during a patient's stay.

For the relationship between daily costs and organ support to be tested in a multi-centre setting, an alternative method of estimating costs has to be considered. The method would need to reflect more closely, the expenditure of the critical care unit but be able to detect variation in resource use between individual patients.

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"When you can measure what you are speaking about and express it in numbers, you know something about it. But when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind"

Lord Kelvin

CHAPTER 5: STUDY METHODS

5.1 Introduction

This chapter describes the design of a multi-centre study of adult critical care units that was needed to collect the necessary case-mix and cost data to propose a set of appropriate HRGs (Chapter 7) and to identify the key cost generating events for critical care patients to inform the economic evaluation of the CESAR trial (Chapter 8).

Section 5.2 describes the aims and objectives of the study and explains how critical care units were recruited and the incentives offered to participants. Multi-Centre Research Ethics Committee approval was achieved for this study (Section 5.6). The different options for capturing the case-mix data were explored before deciding on using specially designed data collection booklets provided in a paper format (Section 5.8). The definitions used to estimate costs are described in Section 5.9 together with the advantages and disadvantages of the cost block method, which was the chosen method. Finally, the data collection processes, method of collection and the arrangements made for data entry and data management are described.

5.2 Study aims, objectives and design

The aim of this study was to generate the necessary data with which to propose a set of appropriate HRGs (Chapter 7) and to identify the key cost generating events for critical care patients to inform the concurrent economic evaluation of the CESAR trial (Chapter 8).

To this end, this study adopted a different design than that described in Chapter 4 based around the collection of monthly expenditure and daily organ support data from a representative sample of adult critical care units. The cost block method (described in Chapter 3) was used to measure expenditure on key areas of resource use during the study period. The 'top-down' method of costing is a retrospective method frequently used for reimbursement purposes, and as such was considered appropriate for devising the HRGs (Gyldmark, 1995). This method of costing has also been used to provide overall estimates of critical care costs in different countries (Jacobs & Noseworthy, 1990; Halpern *et al.*, 1994 & Clermont *et al.*, 1998), as well as in the UK as part of the Critical Care National Cost Block Programme (Dean *et al.*, 2002).

The objective of this multi-centre study was to identify the most appropriate model from which estimates of daily case-mix adjusted costs of care (reflecting the organ support received by patients) could be determined. The results of this analysis had two specific applications: the first being to develop a set of HRGs for adult critical care patients to support reimbursement (Chapter 7) and the second, to produce a set of daily cost weights relating to patients' organ support for use in the CESAR trial (Chapter 8).

A prospective, observational, longitudinal study of a representative sample of adult critical care units located in England, Scotland and Northern Ireland was undertaken. Data were collected over a two-three month period during the second trimester of 2003.

The participating critical care units consisted of a volunteer sample and whilst it was hoped that a geographically representative sample would be recruited, no formal sampling strategies were employed. This was because of the 400 critical care units that were invited to participate in the study, it had only been expected that a very small number would agree to participate. Critical care units are under constant pressure to collect data and participate in studies, so it can be difficult to

encourage them to take on additional work for no financial recompense. The 400 units represented all critical care units in the United Kingdom. A sample involving 40 critical care units was thought achievable however funding for the study was based on an expected recruitment of 6 critical care units.

The Directory of Critical Care (2002) was chosen as the sampling frame and was considered the most effective, given its complete coverage of all NHS hospitals housing critical care services in the UK and the lack of other reliable sources. The Directory comprises over 400 pages of information on general and specialised critical care units and covers the England, Scotland, Wales and the Irish Republic.

5.3 Recruitment strategies

The numbers of volunteer centres depended in the most part on the successfulness of the recruitment strategies employed. A recruitment strategy was devised because the study was considered to be at high risk of not recruiting sufficient numbers of critical care units. This was for three reasons; firstly, the quantity of data collection was large; secondly, there was no funding available to support collection of these data and finally, there was little flexibility in the time scales. The successfulness of this campaign depended on sound organisational planning and effective communication with named individuals working in the critical care units.

5.3.1 Communication

The effectiveness of the communication strategy depended on correctly identifying the most appropriate member of staff to which communications should be directed. It was decided to focus on the medical staff in the preliminary communications about the study. The Clinical Directors / Lead Clinicians of the critical care units were approached because they have the greatest levels of responsibility and

autonomy for decision-making. The option of contacting individuals by e-mail was rejected over postal mail.

A letter was mailed to all adult general critical care units identified from the sampling frame in January 2003, asking for expressions of interest in participating in the study. The letter emphasised the importance of the study for informing proposed changes in government policy, which was felt to be the strongest message to get across to the Clinical Directors and the one that would have the greatest impact when deciding whether or not to participate. A reply slip and a self-addressed envelope were enclosed with the letter explaining that a study information pack would be forwarded to the named person upon receipt of this slip upon return. Interested parties were encouraged to make contact with the University to discuss the study over the telephone or e-mail if they so wished. Within this mailing also contained a contact form where interested critical care units were asked to provide details of the name, job title, telephone number, fax number and e-mail address of the person who would be co-ordinating the study in the unit. Having this information greatly facilitated the task of effective and timely communication during the study.

A positive response to this initial mailing supported the viability of the study. As the nature of the study was of interest to Critical Care Managers, network managers were contacted at the same time as the Clinical Directors.. This two-tiered approach proved to be particularly effective.

5.3.2 Public relations and publicity

Defined by the Institute of Public Relations as '*the deliberate, planned and sustained effort to establish and maintain mutual understanding between an organisation and its public*' (Institute of Public Relations, 1986), public relations was a key element in this study. Four critical care units requested a site visit where the doctors and nurses were given more information about the study and the opportunity to ask

questions. Details of the study were also presented to representatives from two critical care networks and at a well-attended National Critical Care Conference. An article was also published in the Intensive Care Society's Journal to alert the critical care community as to the importance of the impending study and to enhance levels of participation and commitment to data collection (Hibbert *et al.*, 2003) (see Appendix 5.1).

5.3.3 Endorsement

Key policy makers within the Department of Health and the NHS Information Authority publicly supported the study, which helped to boost recruitment levels. Endorsement from key opinion leaders was particularly important as a means of persuading otherwise reluctant critical care units to consider participating. Lead clinicians such as Dr. John Morris, Dr. Bob Winter, Dr. Giles Morgan and the current President of the Intensive Care Society (Dr. Peter Nightingale) supported and encouraged participation in the study.

5.3.4 Branding

It was felt important to establish a corporate image by means of a logo for the study that could be easily identified by the study participants. The logo featured on all of the data collection booklets, the posters to

staff and to the relatives, all questionnaires and correspondence (Appendix 5.2-5.3).

5.3.5 Incentives

Incentives offered to both the networks and the participating critical care units included feedback in terms of a unit-specific, and where applicable, a network-specific report of their data provided for the study. All critical care units received their reports at the end of the study with a copy of the final report produced for the Department of Health.

5.4 Inclusion criteria for centres

The study focused on adult general critical care units, defined as intensive care units (ICUs), combined ICU / high dependency units (HDUs) and combined general care / coronary care units admitting mixed medical / surgical patients predominantly older than 16 years. Cardio thoracic and neurological intensive care units were also included.

5.5 Exclusion criteria for centres

Excluded were specialist liver intensive care units, spinal injuries units, neonatal intensive care units and paediatric intensive care units. Specialist liver intensive care units and spinal injuries units were excluded on the basis that their case-mix and costs would be atypical of those observed in adult general critical care units (our study population) and may skew the results leading to inaccurate conclusions. Those critical care units already participating in an evaluation of the clinical and cost-effectiveness of Pulmonary Artery Catheters led by the Intensive Care National Audit & Research Centre[17] (ICNARC) were not formally approached. This was because it was felt that critical care units would become over-burdened with requests for data. Nevertheless, a small number of these centres expressed an interest in participating and so were included. In addition, those critical care units who had agreed to participate in an evaluation study of the System of

17 ICNARC is an independent charity established in 1994 and coordinates a national, comparative audit of patient outcomes from adult general critical care units in England, Wales and Northern Ireland.

Patient-Related Activities (SOPRA) data set, also led by ICNARC were asked not to consider participating in this study, unless they were able to undertake the two studies in tandem. Data from the ICNARC Case Mix Programme (CMP)[18] were used to study the representativeness of the sample and discussed in more detail in Chapter 6.

5.6 Ethics committee approval

Ethics committee approval was required for the study for the reasons that the patient data would be used for research purposes. An application to Trent Multi-Centre Research Ethics Committee (MREC) was made in September 2002 and approval for the study granted on 16th January 2003 (MREC/02/4/088). Due to the study being eligible for approval under Section D of the Department of Health's 'No local researcher' guidelines', it was not necessary to seek approval from the Local Research Ethics Committees (LRECs). Those LRECs that had participating hospitals listed within their remit were instead notified, in writing, that the study was taking place in their area and sent a copy of the MREC approval letter. Participating centres were asked to notify their respective Research & Development (R&D) Departments of the study and provided with a study folder containing the original MREC application and relevant study documentation with which the study could be registered in accordance with the statutory requirements for research governance.

5.6.1 Patient consent

There are statutory requirements for informed consent of participants in research studies and clinical trials of investigational medicinal products (CTIMPs). The requirements are set out in Schedule 1 to the Clinical

18 The CMP is a comparative audit of patient outcome from critical care. Case mix and outcome data are collected on consecutive admission to participating critical care units located in England, Wales and Northern Ireland and encompass data on patients' co-morbidity, surgical status, reason for admission and outcome.

Trials Regulations. The Regulations transpose the provisions of the European Clinical Trials Directive (EC2001/20) into UK law.

5.6.1.1 Definition of informed consent

Paragraph 3(1) of Part 1 of Schedule 1 to the Regulations, implementing Article 2(j) of the EU Directive, gives the following definition of informed consent: *A person gives informed consent to take part in a clinical trial only if his or her decision is given freely after that person is informed of the nature, significance, implications and risks of the trial*; and is either evidenced in writing, dated and signed, or otherwise marked, by that person so as to indicate his consent, or if the person is unable to sign or to mark a document so as to indicate his consent, is given orally in the presence of at least one witness and recorded in writing.

5.6.1.2 Definition of an incapable adult

Critical care patients are normally unconscious which means that they are unable to give informed consent to their participation in research studies and thus deemed 'incapable'. The term used for this in the Regulations of the EU Directive is *"an adult unable by virtue of physical or mental incapacity to give informed consent"*. For this reason, a surrogate (relative or partner) is usually approached to ask for their assent for participation as this person is considered to be most likely to know what the patient's preferences would be (Edwards *et al.*, 1998)[19] [20].

The study overcame the need to obtain informed consent from individual surrogates by use of a poster that was displayed in the Relatives' waiting area and in the critical care unit (see Appendix 5.4).

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19 The Medicines for Human Use (Clinical Trial Regulations, January 2005)) set out the hierarchy prescribed in the Regulations for determining what type of legal representative should be approached to give informed consent on behalf of an incapable adult prior to inclusion of the subject in the trial. The provisions in England, Wales and Northern Ireland differ from those in Scotland.

20 The conditions and principles listed in Part 5 of Schedule 1 to the Regulations and implement Article 5 of the EU Directive were adhered to in the study.

This was a necessary and important step because critical care units were concerned about the additional workload involved in having to speak to every patient's surrogate to obtain their assent, and having to do this would have negatively affected participation rates. If any of the patients' relatives / partners objected to the use of their relatives' data for the study, they were asked to complete a 'Declaration of Non-Participation' form whereby data relating to their relative would not be used (see Appendix 5.5). Of the patients treated during the study period, none were excluded due to completion of this form.

5.7 Project plan and timescales

A project plan was developed to assist in the correct sequencing of tasks involved in the study. As can be seen from table 5.1, the study ran over a number of months.

Table 5.1: Project plan and timescales

Months	Tasks
September 2002	• Preparation of Ethics Submission • Mailing to adult general critical care units to elicit interest in the study
October 2002	• Ethics Submission considered by Trent Multi-centre Research Ethics Committee (MREC)
December 2002	• Re-submission of study to Trent MREC
January 2003	• Ethics committee approval obtained • Recruitment of adult critical care units and critical care networks
February 2003	• Recruitment of additional centres at national meetings • Recruitment of specialist critical care units • All Local Research Ethics Committees notified with copy of MREC approval letter • Design and production of study materials • Packaging and distribution of materials for the March starters
March 2003	• Start of prospective collection of activity data set • Packaging and distribution of materials for the April starters • Design of spreadsheets for storing the activity data set
April 2003	• Prospective collection of activity data set • Distribution of additional study materials • Entry of activity data returned
May 2003	• Prospective collection of activity data set • Distribution of additional study materials • Entry of activity data returned
June 2003	• Deadline for the return of data collection booklets • Recruitment of personnel to enter the activity data set • Entry of activity data set
July 2003	• Entry of activity data set • Distribution of expenditure questionnaires • Distribution of study methods and unit characteristic questionnaires
August 2003	• Entry of activity data set • Entry of expenditure data • Queries performed on the activity data set
September 2003	• Queries relating to activity data set sent out • Entry of late returns relating to the activity data set • Entry of expenditure data • First reminder letters sent re: outstanding expenditure, study methods and unit characteristic questionnaires
October 2003	• Second reminder letter sent re: outstanding expenditure, study methods and unit characteristic questionnaires • Follow-up of outstanding queries relating to activity data set • Analysis plan produced and approved • Mailing to Finance Departments for outstanding expenditure questionnaires • Design of analysis spreadsheets • Transfer of queried activity data into analysis spreadsheets
November 2003	• Follow-up of outstanding queries • Third reminder letter with duplicate copies of study methods and unit characteristic questionnaires sent to non-responders • Entry of expenditure data • Transfer of queried activity data into analysis spreadsheets
December 2003	• Transfer of queried activity data into analysis spreadsheets • Data analysis
January 2004	• Data analysis
February 2004 – December 2004	• Testing of cost model

5.8 Design of the patient data questionnaires

5.8.1 Method of data collection

There are different modes of administering questionnaires, five of which are described by McColl *et al.*, (2001) and are as follows:

5.8.1.1 Mailed self-completion

The main advantages to mailed self-completion are that they are less costly than conducting interviewers, do not introduce interviewer bias and offer greater anonymity for respondents. The disadvantages however are the lower response rates that tend to be observed when compared to face-to-face interviews and the lack of control over the process in terms of ensuring that respondents complete the questionnaires. Other disadvantages include more errors and delays in getting the questionnaires returned (McColl *et al.*, 2001).

5.8.1.2 Supervised self-completion

Questionnaires administered for supervised self-completion, which is where the study researchers are available to help and explain, can be used for groups (Mc Coll *et al.*, 2001). A pitfall however is the costs of the researchers' time, which would be greater than the costs of mailed self-completion.

5.8.1.3 Face-to-face interviewing

Face-to-face interviewing is preferable for open-ended questions and for studies that have complex instructions or definitions. The benefits of this approach are the high response rates and the opportunity for validation by observation. The pitfalls include the high costs of their undertaking and the possibility that the interviewer may influence the answers given (Mc Coll *et al.*, 2001).

5.8.1.4 Telephone interviewing

Conducting telephone interviews is a lot quicker and cheaper than face-to-face interviews however the mode has generally lower response rates than face-to-face interviews. Furthermore, complex, open-ended questions are thought to be more difficult to pose over the telephone (Mc Coll *et al.*, 2001).

5.8.1.5 Computer-assisted methods

It is possible to develop electronic questionnaires, the answers to which can be directly entered by respondents into a computer. This eliminates the need for data entry by the study researchers (and keeps the costs down) but incurs a high set-up cost (e.g. designing the user-interfaces and database design) and can require extensive piloting (to ensure compatibility with existing software packages etc).

In this study, it was decided to opt for the use of questionnaires mailed for self-completion. As such, data collection booklets were produced for staff working within the critical care units to record the data. There was a blue booklet that covered days 1-21 of a patient's stay and a yellow booklet covering days 22-92. One other method of collecting the data was considered, which was the use of a software package into which staff working in the critical care units could enter the data. This would have had the advantage of eliminating the need for data entry at the coordinating centre. However, the disadvantage of this approach is the compatibility of the software package with the computer systems used in the different hospitals, which can often cause problems and result in delays.

Ten nursing staff from the volunteer sample were selected at random and asked what their preferences were to the method of data collection (e.g. paper format or software package). All expressed a preference for a paper-based questionnaires designed for completion at the patients' bedside..

5.8.2 Content of the questionnaires

Items collected within each booklet with their accompanying definitions are shown (table 5.2).

Table 5.2: Patient data set

Part 1

Data Category	Data Item	Definition	Frequency of data collection	Tick / Number
General	Patient initials	Not defined	At unit admission	N/A
General	Hospital number	Not defined	At unit admission	N/A
General	Local critical care identifier	Not defined	At unit admission	N/A
General	Date of critical care unit admission	Not defined	At unit admission	N/A
General	Time of admission	Not defined	At unit admission	N/A
General	Planned admission	Not defined	At unit admission	Tick
General	Unplanned admission	Not defined	At unit admission	Tick
General	Date of critical care unit discharge	Not defined	At unit discharge	N/A
General	Time of discharge	Not defined	At unit discharge	N/A
Level of care	Level 3 (intensive care)	For patients requiring one or more of the following: • Advanced respiratory system monitoring and support alone. • Two or more organ systems being monitored and supported, one of which may be advanced respiratory support. • Patients with chronic impairment of one or more organ systems sufficient to restrict daily activity (co-morbidity) and who require support for an acute reversible failure of another organ.	Daily	Tick
Level of care	Level 2 (high dependency care)	For patients requiring one of more of the following: • Single organ system monitoring and support, excluding advanced respiratory support. • General observation and monitoring: more detailed observation and the use of monitoring equipment that cannot safely be provided on a general ward. This may include extended post-operative monitoring for high-risk patients.	Daily	Tick

	• Step-down care: patients who no longer need intensive care but who are not well enough to be returned to a general ward.	

Part 2

Data Category	Data Item	Definition	Frequency of data collection	Tick / Number
Organ system support	Basic respiratory support	Indicated by one or more of the following: • More than 50% oxygen by fixed performance mask. • The potential for deterioration to the point of needing advanced respiratory support. • Physiotherapy to clear secretions at least two hourly, whether via tracheostomy, minitracheostomy, or in the absence of an artificial airway. • Patients recently extubated after a prolonged period of intubation and mechanical ventilation • Mask CPAP or non-invasive ventilation. • Patients who are intubated to protect the airway but needing no ventilatory support and who are otherwise stable.	Daily	Tick
Organ system support	Advanced respiratory support	Indicated by: • Mechanical ventilatory support (excluding mask (CPAP) by non-invasive methods e.g. mask ventilation).	Daily	Tick
Organ system support	Basic cardiovascular support	Indicated by one or more of the following: • Treatment of circulatory instability due to hypovolaemia from any cause • Use of a CVP line for basic monitoring or central venous access • Use of an arterial line for basic monitoring of arterial pressure or sampling of arterial blood • An hourly record made of pulse rate, blood pressure and pulse oximetry • Single vasoactive drug used to support arterial pressure, cardiac output or organ perfusion • Intravenous drugs to control cardiac arrhythmias • Non-invasive measurement of cardiac output (e.g. echocardiography, thoracic impedance)	Daily	Tick

Organ system support	Advanced cardiovascular support	Indicated by one or more of the following: • Multiple vasoactive and/or rhythm controlling drugs used to support arterial pressure, cardiac output or organ perfusion. • Patients resuscitated after cardiac arrest where intensive therapy is considered clinically appropriate. • Invasive observation of cardiac output and derived indices (e.g. pulmonary artery catheter, Lithium dilution, pulse contour analyses, oesophageal doppler) • Intra aortic balloon pumping • Insertion of a temporary cardiac pacemaker • Placement of a gastrointestinal tonometer	Daily	Tick
Organ system support	Renal support	Indicated by: • Acute renal replacement therapy (haemodialysis, haemofiltration etc.)	Daily	Tick
Organ system support	Neurological support	Indicated by one or more of the following: • Central nervous system depression, from whatever cause, sufficient to prejudice the airway and protective reflexes. • Invasive neurological monitoring e.g. ICP, jugular bulb sampling.	Daily	Tick
Organ system support	Liver support	Indicated by: • Extracorporeal liver replacement device i.e. MARS (Teraklin, Rostock, Germany), Bioartificial liver or charcoal haemoperfusion	Daily	Tick
Organ system support	ECMO	• Extracorporeal Membrane Oxygenation.	Daily	Tick

The patients' hospital number was requested for the purposes of facilitating the querying process. This number tended to be an alphanumeric code. Individual identifiers such as patients' names and addresses were not recorded. In this way, queries relating to individual patients could be de-anonymised by the critical care unit using their hospital number to access the medical records.

The first part of the questionnaire asked respondents to record the date and time of admission and discharge for individual patients, whether the critical care admission was planned or unplanned, and asked them to state which levels of care patients required during their stay in the critical care unit.

The second part of the questionnaire covered the type of organ support patients received on a daily basis. The organ support variables were extracted from an updated version of the ACP data set, that was (at the time of the study) being modified by a group of critical care opinion leaders belonging to the Critical Care Information Advisory Group (CCIAG) formed by the Department of Health and the NHS Modernisation Agency. This group consisted of critical care doctors, nurses and managers who met at regular intervals to discuss the scope of this dataset and formulated definitions relating to each of the data items within the data set. All of the organ support variables proposed by this Group were included in the study and added to these were two additional organ support fields (liver support and Extracorporeal Membrane Oxygenation (ECMO))[21]. The dataset was selected on the basis that its eventual use would be to replace an existing dataset for routine collection in critical care units.

A study methods questionnaire was also sent to each participating critical care unit to complete. This questionnaire set out to determine how the data collection booklets had been completed, by whom and what steps were taken when they had not been completed (Appendix 5.6).

5.9 Design of the expenditure questionnaires

A number of expenditure questionnaires were produced that sought to estimate expenditure incurred on critical care patients during the same time period as collection of the patient data (see Appendix 5.7 for copies of these questionnaires).

Although costing with the top-down method is comparatively easier to perform than more patient-centred methods because of being less resource-intensive and time consuming, it was important that the components of cost were specified and measured rigorously using standard definitions. This was to ensure that any observed differences

21 Mr. Giles Peek is acknowledged for his help in formulating definitions for liver support.

could be attributed to variation in the estimates (rather than the methods), the costs reproduced and valid comparisons made between different studies (Hibbert & Edbrooke, 2002).

5.9.1 Definitions used

Each questionnaire contained boxes into which the expenditure data were entered and a text box asking for a description of how the expenditure data had been estimated. Precise definitions, based on those developed by a National Working Group on Costing (currently in use as part of the National Cost Block Programme) were adopted to ensure that these data were collected in a standard and consistent manner. The definitions were developed by Group consensus and piloted in two separate studies for ease of completion and comprehension (Edbrooke *et al.*, 1999) (table 5.3).

Table 5.3: Resource items and definitions used in the expenditure sub-study (Dean et al., 2001)

Resource items	Definitions used
Nursing staff	Monthly expenditure on nursing staff was extracted from the budget statements submitted by the critical care units. Bank and agency staff was included.
Drugs and fluids	Expenditure on drugs and fluids incurred by the critical care unit included albumin but excluded nutritional products and blood and blood products.
Disposable equipment	Disposable equipment referred to all equipment used for patient care in the unit (sterile and non-sterile) for single or very limited use.
Consultant medical staff	Salaried costs of each Consultant working on the unit included their basic salary and all overheads, plus merit awards (where applicable), daytime intensity payments, night-time intensity payments and any discretionary points. The total number of sessions worked per month and number of designated sessions for work on the unit, work for outreach, other fixed sessions and number of flexible sessions for teaching, research etc. was also sought. Fixed daytime sessions were defined as those with clinical commitments (such as ward rounds on the unit). Flexible sessions were defined as those without clinical commitments and would include designated sessions for management, administration, teaching or research regardless of whether they were allocated for work related to the unit. Outreach sessions were those dedicated to the care of outreach patients. The costs were determined as follows: Monthly salary / Total number of sessions x (Number of Fixed Clinical Sessions + Number of Sessions for Outreach) + 50% of the flexible sessions
Other medical staff	The average number of hours worked per month in the unit for senior house officers, all SPR1 and SPR2 (registrars), all SPR3, SPR4 and SPR5 (senior registrars) and all staff grades (or equivalent) was used, and to this, the appropriate hourly cost was assigned. The hourly cost was derived from the corresponding salaries + 50% (Band 1A and 2B) to reflect the on-call payments.
Administrative support	Monthly expenditure on administrative staff support was extracted from the budget statements submitted by the critical care units.
Blood and blood products	Expenditure on blood and blood products included expenditure on whole blood and other blood products, but excluded albumin.
Radiology tests	Expenditure on radiology included all x-ray and other radiology tests by the critical care unit. Where salaried costs were not included in the costs of the tests, the salaried cost of the diagnostic radiographers were added separately.
Laboratory services	Expenditure on laboratory services included: bacteriology, virology, clinical chemistry, immunology, haematology, neuropathology and histopathology. Where salaried costs were not included in the costs of the tests, the salaried cost of the laboratory assistants were added separately.
Nutritional products	Expenditure on nutritional products included expenditure on all enteral and parenteral feeds, and special nutritional products that were administered orally.
Specialised bed therapy	The expenditure on specialised bed therapy related to the monthly lease or hire charges incurred by the unit.
PAMS: Physiotherapists	The salaried cost of the physiotherapists normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads).
PAMS: Clinical Pharmacists	Expenditure on Clinical Pharmacists related to services provided by such to the unit. Where a contract was held with the Pharmacy department, the expenditure incurred by the unit was stated. Otherwise, the salaried cost of the clinical pharmacists normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads).
PAMS: Dieticians	The salaried cost of the dieticians normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads).
PAMS: Medical Technical Officers (MTOs)	The salaried cost of the Medical Technical Officers (MTOs) and Assistant MTOs normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads).
PAMS: Information Technologists	The salaried cost of the Information Technologists (database managers) normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads).
PAMS: Clinical and Biomedical Scientists	The salaried cost of the Clinical and Biomedical Scientists normally working for the unit was used (including overheads).

Resource items	Definitions used
PAMS: Speech and Language Therapists	The salaried cost of the speech and language therapist normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads).
PAMS: Psychologists	The salaried cost of Psychologists normally working for the unit was used (including overheads).
PAMS: Occupational Therapists	The salaried cost of the occupational therapist normally working in the unit was used, taking into account the amount of time that they spent in the unit (including overheads) and any materials.
Other: Directorate Accountants	The salaried cost of Accountants normally working for the unit was used (including overheads).
Other: Personnel Officers	The salaried cost of Personnel Officers normally working for the unit was used (including overheads).
Capital Equipment	10% of the total expenditure of the unit was used to estimate the costs of capital equipment.

The coverage of resource use in this study was greater than that included in the National Cost Block Programme. Added to this was the inclusion of Clinical Pharmacists, Dieticians, Clinical and Biomedical Scientists, Speech & language therapists, Psychologists, Occupational therapists, Directorate accountants and personnel officers.

The perspective of the expenditure survey was taken from that of the Critical Care Unit, irrespective of whether the units paid for these resources or not. Collection of hospital overhead costs was not performed. The use of questionnaires limited investigation of the internal validity of the expenditure estimates. As such, annual data from the Critical Care National Cost Block Programme (which reported descriptive statistics relating to some of the daily costs covered in this study) were used later in the thesis for the purposes of external validation. The study used the same definitions for estimating costs as those used by the National Cost Block Programme for the resources that were captured by both studies and therefore formed the most reliable and appropriate source with which to make comparisons. Twenty-one units in our sample (30%) contributed data to the Critical Care National Cost Block Programme for the financial year 2000-2001 (Hibbert *et al.*, 2005).

5.9.2 Advantages of the method used to estimate expenditure

The cost block method had several advantages including good coverage of the key resources; ease of collection (for some items) e.g. the following resource items could be extracted from a critical care unit's budget statement (Nursing staff, disposable equipment, drugs and fluids and administrative staff); consistent use of standard definitions; inclusion of professionals allied to medicine (PAMS), presently excluded from the National Cost Block Programme and finally, the possibility for externally validating the data with that from the Critical Care National Cost Block Programme.

6.9.3 Disadvantages of the method used to estimate expenditure

The method was not without its limitations. Some resources were not included. These were as follows:

- Catering
- Laundry and staff uniforms
- Cleaning
- Portering
- Security
- Chaplaincy
- Equipment maintenance contracts
- Cardiology and renal support from outside of the ICU
- Rates
- Building depreciation
- Building maintenance
- Engineering maintenance
- Decoration
- Water

- Sewerage
- Waste disposal
- Heating & lighting

It was difficult to obtain data for some items (which could have affected the reliability of the estimates) such as other medical staff working on rotating shifts around the Hospitals making it difficult to provide accurate estimates for the time spent in the critical care unit. There was also some ambiguity with some of the definitions. Staff completing the questionnaires for laboratory services felt the definitions could be misinterpreted. There was a problem relating to the actual vs. recorded expenditure for the PAMS. Many of the PAMS returned their expenditure questionnaires stating that there was no cost to the critical care unit, despite a level of service being provided. There is a belief that if a department is not charged for a service provided to it, that a cost is not incurred.

Furthermore, internal validation of the data was difficult for expenditure on those resources not appearing on the critical care unit's budget statement.

By far the weakest part of the study was its inability to capture expenditure on capital equipment. Assumptions had to made about capital equipment expenditure based on data from a small pilot study, where expenditure on capital equipment had been found to represent 5-7% of the total expenditure (Edbrooke *et al.*, 1999). An increase to 10% was made on the basis that some of the pilot units had a large quantity of elderly equipment (>10 years old), which incurred no depreciative cost.

5.9.4 Measurement issues with capital equipment

The Critical Care National Cost Block Programme included a section on capital equipment as shown in table 5.4.

Table 5.4: Capital equipment component of the Critical Care Cost Block Programme

Equipment type	Number within the unit	Number under five years of age	Notes
A full set of monitoring equipment			Each ICU will typically have 1 monitor per bed and one or more at the central station(s). The number required is the total number of full sets of monitoring equipment within the ICU. A full set is the total amount of monitoring equipment needed per bed
Ventilators			This should be the total number of ventilators within the ICU that are used for intermittent positive pressure ventilation. It should include ventilators that are specifically used for patient transportation.
Non-invasive ventilators			The number of ventilators within the ICU that are used in combination with a mask and CPAP circuit.
Renal replacement devices			Renal replacement therapy is undertaken on the ICU using formal dialysis machine, continuous veno-venous haemofiltration or continuous veno-venous haemodialysis. If the equipment was purchased for use exclusively within the ICU, then the number of machines available should be indicated. Some ICUs may have the dialysis undertaken for them within the ICU by specialist renal teams. If this is the case, then the approximate number of dialysis sessions per week should be noted and accompanied by the letter R.
Syringe drivers			Syringe pumps are pumps specifically designed to administer drugs or fluids from a large syringe. It will be common for these pumps to be purchased or leased at different times. Therefore the approximate age required in the table should be an average of the approximate ages.
Infusion pumps			Infusion pumps are defined as pumps designed to administer drugs and fluids from 500ml or 1litre bags. It will be common for these pumps to be purchased or leased at different times. Therefore the approximate age required in the table should be an average of the approximate ages.
Blood gas / chemistry machine			This is a machine designed to measure arterial and venous blood gases. In some cases these machines will also measure other blood chemistry parameters such as serum potassium. They should only be included in the equipment table if they are located within the ICU environment.
Defibrillator			This is the machine normally used to correct ventricular fibrillation. They should only be included in the equipment table if they are located within the ICU environment.

Equipment type	Number within the unit	Number under five years of age	Notes
Fibre-optic bronchoscope and gastroscope			This equipment describes the fibre-optic bronchoscope and gastroscope, the light source and any viewing screens. These constitute one piece of equipment. They should only be included in the equipment table if they are located within the ICU environment.
Ultrasound and echocardiography			Any machine based within the ICU using ultrasound and/or echocardiography techniques
Ventricular assisting devices			This is defined as any machine assisting the ventricle in producing a higher output.

Whilst the coverage of the different types of capital equipment would appear to be complete, there was one obvious omission, that of the humidifiers (needed in conjunction with the ventilators).

The second problem related to the lack of specific definitions relating to the type of equipment. Equipment companies produce a range of models that vary in terms of their features and their price. The assumption underpinning this simple system of 'counting' the different types of equipment was that it would be relatively straightforward to assign a unit cost to these. The unit cost however varies according to the model in use and the purchasing power of the critical care units has not been accounted for. Significant price reductions can be achieved through a critical care network negotiating a favourable price for a number of equipment items bought in a 'job lot'. No rationale was given for distinguishing between the quantity of a given item of equipment and those items under the age of 5 years, which would appear to be an arbitrary cut-off point.

Given these problems, it was decided not to integrate this method of estimating capital equipment expenditure into the survey.

5.10 Design of the unit characteristics questionnaires

The participating critical care units were sent a questionnaire on unit characteristics to complete that consisted of questions relating to geographical location, hospital type, unit type, unit size in terms of staffed bed numbers and the provision of additional services such as outreach and follow-up clinics. A copy of this questionnaire is provided in Appendix 5.8.

5.11 Data collection procedures

5.11.1 Patient data

For pragmatic reasons, there were two waves of prospective data collection. Thirty-three critical care units (47%) commenced prospective data collection on 1st March 2003 for a three-month period and the remaining 37 units (53%) on 1st April 2003 for a two-month period. The reason for this was that a large number of critical care units agreed to participate in the study (but just prior to the start of data collection in March). The data collection booklets were distributed to all of the participating centres prior to the start of the data collection periods. Critical care units were asked to specify levels of anticipated patient throughput for the study period to ensure that an adequate supply of booklets was delivered to them. Eleven thousand data collection booklets were dispatched in total.

All patients cared for in the participating units on 1st March 2003 or 1st April 2003 (depending on when the units started collecting the data), until the 31st May 2003, were included in the study. Those patients admitted to the unit prior to the start of the study were also included. For these patients, their actual date of unit admission was recorded in the data collection booklets but their daily data collection commenced on the 1st March 2003 or 1st April 2003 (as appropriate).

Staff working on the units collected data for consecutive admissions. As far as support for the staff was concerned, a poster listing a series of

frequently asked questions and answers was produced and displayed in each of the participating centres. A help-line telephone number was also disseminated to assist with any queries arising from the study.

Two storage boxes were sent to each critical care unit to keep the empty booklets in and to store the completed booklets.

To ensure that the data collection booklets were returned to the University at regular intervals for entry, critical care units starting data collection on 1st March 2003 were asked to return their completed booklets after the first two weeks of data collection (15th March 2003) and at the end of each month until the end of the study. All of the booklets were manually checked after the first two weeks to ensure that they were being correctly completed. Critical care units starting data collection on 1st April 2003 were asked to return their completed booklets on 28th April 2003 and at the end of the study.

5.11.2 Expenditure data

For critical care units commencing data collection in March, they were asked to provide expenditure data for the (individual) months of March, April and May. Two months of expenditure data were requested from critical care units who started collecting data in April. Participating units were sent these questionnaires to distribute to the relevant departments (located within their hospital) to complete and return to the University of Sheffield.

Each questionnaire was accompanied by a covering letter to the relevant recipient (Head Dietician, Head Pharmacist etc). As this approach was deemed quite risky in the sense that it was not known to whom the questionnaires had been sent to upon their receipt by the named collaborator, another contact form was enclosed with this mailing asking that the collaborator provided details of the person to whom they had sent the questionnaire (name, position, telephone, fax number and e-mail address). They then faxed this contact form back to the University of Sheffield.

A poor response to this initial mailing led us to forward all of the questionnaires that had yet to be returned to the Head of Finance in each of the participating hospitals with a covering letter asking for their co-operation in completing these questionnaires. This proved to be an effective strategy, as the questionnaires were promptly returned.

5.12 Method of collection

5.12.1 Patient data

It was left to the discretion of the participating critical care units as to the time of day when the booklets were completed. It is difficult to know in hindsight whether this was the best approach. Giving the units prescriptive rules as to when and how data should be collected may have improved the consistency of the data, but it is unlikely that units would have responded to such guidance, particularly when they were volunteers and not receiving any form of financial reimbursement for their time spent collecting the data.

A short questionnaire was sent to a named person in each centre after data collection had finished, eliciting how the booklets were completed (see Appendix 5.5). The questionnaire sought to determine whether the booklets were used as a primary tool for recording the data, whether the booklets were completed in a prospective or retrospective manner, the member of staff responsible for collecting the data, the number of staff involved in data collection, the time of the day when data collection took place, reasons given for not completing the booklets / collecting the data and finally, the measures taken to provide data when the booklets were not completed for patients.

5.12.2 Expenditure data

Within each questionnaire contained a box asking respondents to specify the costing method used to estimate the expenditure data if they were not able to adhere to the definitions provided. Where applicable,

they were asked to describe the nature of the resources used (e.g. level of service provided in the case of the professionals allied to medicine).

5.13 Data entry

5.13.1 Patient Data

The data contained within the booklets were manually entered into Microsoft Excel. A better approach to data entry would have been to use a questionnaire design software package, where the data recorded into the booklets by the critical care staff could have been scanned by a computer, which would have considered reduced the burden of data entry.

The accuracy of data entry was ensured by comparing the data collection booklets with the electronic records in 25% of patients, checking for any inconsistencies between the two.

Once all of the data had been entered, the researchers formalised a series of checks on the data set. This was to ensure that a) checks for missing and inconsistent data could be performed in a consistent manner (with minimal bias) b) the results of the checks could be easily documented in a query booklet and c) the integrity of the raw data was maintained. This is discussed in more detail in Chapter 6 (Section 6.3). In summary, patients with identical data (i.e. hospital numbers, date and time of admission and discharge) were identified and queried with the participating centres. A separate record was made of any missing data and units were approached with a request to supply these missing data, e.g. date or time of admission or discharge, admission type (planned or unplanned) and survival status at unit discharge (dead or alive). Inconsistent patient records were also queried with the units, for example, if a patient appeared to have been discharged before they were admitted or if their discharge was recorded on a completely different day to that indicated within the activity spreadsheet. In these

cases (and those of patient duplication), it was requested that each patient's full activity details were re-supplied.

Patients were not permitted to have both basic respiratory and advanced respiratory support on the same day, as whilst it is common for this to occur (when a patient switches from mechanical ventilation to a lesser intensive form of respiratory support) for costing purposes, the higher level of organ support (advanced respiratory support) was recorded.

5.13.2 Expenditure Data

The data captured by the questionnaires and budget statements were transferred into Microsoft Excel. Any data that appeared to be erroneous i.e. annual estimates of expenditure given instead of apportioned amounts relating to the time spent in the critical care, mostly in the case of the PAMS, were excluded from any analysis performed.

5.14 Data protection and confidentiality

The Data Protection Act (1998) was adhered to which protects the right of the individual about what information is obtained, shared, processed or supplied whether via a computer or manual paper records. As data were provided in booklet form, there was no need to consider the transfer of electronic patient records from the critical care units to the University of Sheffield. Patient identifiers were not included in the main database but a unique individual ID included instead (i.e. reversibly anonymised)[22]. There were also firewalls in place to protect the database from access via the worldwide web and the database was password protected. The database was held on a stand alone[23] not

22 Reversibly anonymised: Individual identifiers have been removed or encrypted so those using the data cannot identify individuals. A unique individual ID (or 'key code') may be included. It is therefore possible to reverse the anonymisation of the data either by decrypting the encoded individual identifiers or by linking the data, through the 'key code', to individual identifiers.

23 Data are held on a computer that is not connected to any other computers via a modem or network. Such computers cannot be hacked into externally, and the actual hard drive of the computer would have to be

networked computer and backups[24] of the database performed at weekly intervals with a copy of the backup held at a separate location. The data collection booklets were kept and placed into storage.

5.15 Data management

5.15.1 *Patient Data*

Each hospital had two spreadsheets. The structure and coding of the first spreadsheet, entitled 'Patient ID' is described in table 5.5.

Table 5.5: Structure and coding of the patient ID spreadsheet

Hospital Name
Patient Initials
Hospital Number
Local Critical Care Unit Identifier
Date of unit admission (date/month/year)
Time of unit admission (00:00)
Date of unit discharge (date/month/year)
Time of unit discharge (00:00)
Admission type:
• Planned (1=Yes, 0=No, 2=Missing)
• Unplanned (1=Yes, 0=No, 2=Missing)
Survival status at unit discharge (0=Dead, 1=Alive, 2=Missing, 3=Unknown)

Using the data contained in the Patient ID spreadsheet, patients' length of stay was calculated using the exact dates and times of admission and discharge and an additional variable created called 'patients in for less than 24 hours'. A code (1 or 0) was then assigned to patients according to whether their length of stay was less than 24 hours. Another dummy

stolen for the security of the data to be compromised (Directory of Clinical Databases – data definition manual).

24 Data saved onto back-up disks: Back-up data are saved at regular intervals onto CD, floppy, Zip disk, or other storage device, and are stored securely.

variable was added called 'Complete length of stay data i.e. in the unit for the study period'. Each patient was then coded (1 or 0) according to whether their date and time of admission and discharge fell within the study period, so as to determine the numbers of patients for whom data on their complete episode of care would be missing. All patients still receiving care in the unit beyond 31/05/03 (when the study ended) were given a date and time of discharge of 31/05/03 23:59. The survival status of patients still in the unit at the end of the study period was classified as 'unknown'.

The second spreadsheet entitled 'activity data set' was structured and coded as described in table 5.6.

Table 5.6: Structure and coding of the activity spreadsheet

Hospital number
Date of stay (date/month/year)
Day number (1,2,3 etc)
Level of care data
Level 3 (intensive care) (1=Yes, 0=No)
Level 2 (high dependency care) (1=Yes, 0=No)
Organ support data
Basic respiratory support (1=Yes, 0=No)
Advanced respiratory support (1=Yes, 0=No)
Cardiovascular support (1=Yes, 0=No)
Renal support (1=Yes, 0=No)
Neurological support (1=Yes, 0=No)
Dermatological support (1=Yes, 0=No)
Liver support (1=Yes, 0=No)
Extracorporeal Membrane Oxygenation (ECMO) (1=Yes, 0=No)

5.15.2 Expenditure Data

After the data had been thoroughly checked for any errors incurred through the transfer of data from the questionnaires into the

spreadsheet, these data were transferred into SPSS for Windows, where descriptive analyses could be undertaken.

5.16 Analysis plan

Descriptive statistics were performed on the monthly and average daily expenditure data (means (SD), median (IQR) and minimum and maximum values that were stratified by unit type and size (where appropriate).

5.16.1 Study methods

Using the completed study methods questionnaires, simple frequency tables and pie charts were used to describe the methods of collecting the patient data, methods of booklet completion, numbers of staff involved in booklet completion and the time of day when booklets were completed. A bar chart was used to describe the frequency with which the different measures taken were adopted when the data collection booklets were not completed.

5.16.2 Validity and accuracy of patient data

The validity and accuracy of the patient data were assessed using criteria developed by the Directory of Clinical Databases and a scatter plot was used to explore the relationship between the number of queries generated from the patient data study and the number of patients studied.

5.16.3 Characteristics of the critical care units

The characteristics of the critical care units were determined from the unit characteristics questionnaires and described using simple frequency tables. The Directory of Clinical Databases was used to assess the representativeness of the sample (in terms of geographical coverage). Pie charts were used to describe the numbers of

participating critical care unit by Region and the proportion of critical care units by size.

5.16.4 *Characteristics of patients*

Simple descriptive characteristics were used to analyse the characteristics of patients in terms of their admission status and length of stay. The types and combinations of organs supported were described using frequency statistics.

The relationship between the numbers of days of organ support by both the type of critical care unit and the size of the critical care unit was explored using a chi-squared test (that tested for differences between these characteristics). Differences between groups (denoted by unit type and size) were compared using the Kruskal-Wallis modification (non-parametric) of the analysis of variance (ANOVA) (Godfrey, 1985). Rejection of the null hypothesis was performed where the p values produced from the ANOVA test failed to reach statistical significance ($p>0.05$). The same analytic technique was used to explore both the relationship between the organ support ratios per patient day both by type and size of critical care unit.

5.16.5 *Expenditure data*

The response rate to the expenditure survey was described according to the number and percentage of questionnaires returned on each resource item and of this, the quantity of data suitable for analysis.

Compliance to the expenditure definitions was described as a percentage, and a narrative provided as to the description of the services provided (under each resource item) and the alternative methods used when the provided definitions were not adhered to. Bar charts were used to describe the response rates and the number of responses that accorded to the definitions.

Descriptive statistics relating to the monthly expenditure incurred on each of the resource items were performed and the percentage contribution of each resource item to the total costs of care compared with estimates reported in the published literature. To externally validate the mean daily cost estimates for each of the resource items, comparisons were made using data collected from a larger sample of critical care units participating in the Critical Care National Cost Block Programme. The mean daily costs by type of critical care unit were then compared against NHS Reference Costs. No formal statistics tests were performed for the external validations undertaken.

In order to determine whether the critical care unit who were able to provide expenditure data were markedly different from those who did not provide these data, several comparisons of key characteristics were performed using frequency tables.

Chi-squared tests were used to detect differences in monthly expenditure and average daily expenditure by type and size of critical care unit. Line graphs were used to illustrate the relationship between the monthly and average daily expenditure and critical care unit size.

The results of these analyses will be described in Chapter 6. The development of models and the statistical techniques used (to support the development of HRGs and for the economic evaluation of the CSEAR trial) will be described in Chapters 7 and 8 respectively.

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"It is a capital mistake to theorize before one has data."

Sir Arthur Doyle

CHAPTER 6: RESULTS

SECTION I: PATIENT DATA COLLECTION AND VALIDATION

6.1 Introduction

Chapter 6 describes the data collected in the multi-centre study and the efforts made to validate these data. The Chapter is split into five sub-sections for ease of presentation.

Section I reports on how the patient data were collected and the characteristics of the participating critical care units. An explanation of the checks performed on the data returned follows, and issues relating to the validity and reliability of the data are also discussed. The representativeness of the volunteer sample of units was determined by comparison with the Intensive Care National Audit & Research Centre's (ICNARC) Case-Mix Programme database and data collected by the Audit Commission. Herein after follows a description of the collection of the expenditure data and a discussion of the resultant response rates, adherence to the definitions provided in the questionnaires used and the results obtained. External validation of the expenditure data was achieved using data from the Critical Care National Cost Block Programme and published NHS Reference Costs for adult critical care produced by the Department of Health.

Section II describes the characteristics of the critical care units in the sample.

Section III describes the characteristics of the patients studied (their admission status, length of critical care unit stay, survival status at discharge from the critical care unit, and their type of organ support

received). Some preliminary analyses of the relationship between patients' organ support and the type and size of the critical care unit is also performed.

Section IV describes the collection and validation of the expenditure data.

The relationship between the number of organ support days and the organ support ratio per patient day by type and size of critical care unit is explored in Section V. Four null hypotheses relating to the relationship between a critical care unit's monthly expenditure on nursing staff, drugs and fluids and disposable equipment (and its average daily expenditure) compared to the type and size of the critical care unit are then tested.

6.2 Participation rates

Of the 400 critical care units approached, 84 (21%) units agreed to participate in the study. Of these 84, 14 (17%) critical care units dropped out just prior to the start of data collection, resulting in a sample of 70 units (17.5%) located in 67 hospitals. Patient-level data were collected from these 70 units on 7,304 patients. Expenditure data were also collected (172 months of data in total). Duplicate data were discovered for 61 patients, which when removed, produced a complete sample of 7,243 patients (37,170 patient days) that could be analysed.

6.3 Collection of patient data

6.3.1 Methods of data collection

Data collection booklets were used to record the patient data.

Of the 70 participating critical care units, 65 (93%) completed the study methods questionnaire that sought to elicit the manner in which the booklets had been completed. Data for the non-responders (i.e. those who had not completed the study methods questionnaire) were

represented in the 'Unknown' category in the tables presented. The majority of critical care units used the booklets to prospectively record the patient data. In some units, the relevant patient data was extracted from sources namely other scoring systems in routine use, such as TISS and ICNARC's System of Patient-Related Activity Scoring System (SOPRA). Ten critical care units used data collected for the Augmented Care Period (ACP) Data Set to transfer into the data collection booklets. Due to the quantity of data collected in critical care, it was not surprising to note that multiple methods of data collection were in use. However, it is generally recommended before using 'already collected' data to check how these data were collected (Øvretveit, 1998). It was for this reason that the study methods questionnaire had been sent out to units. The accuracy of the data transferred via extraction from other sources was not however assessed. Table 6.1 summarises the five different methods employed for data collection.

Table 6.1: Method of data collection

Method Of Data Collection	N (%)*
The data collection booklets provided were used as the primary method of data collection	62 (89)
Data was transferred into the booklets after the patient was discharged from the unit i.e. using data from a database	17 (24)
System of patient-related activity data (SOPRA) was used to complete the booklets	4 (6)
Therapeutic Intervention Scoring System (TISS) data was used to complete the booklets	3 (4)
Organ support data was provided retrospectively using ACP data and organ support definitions	10 (14)
Unknown	5 (7)

* Note that many of the respondents indicated multiple methods of data collection and that the figure in parentheses refers to the total sample, i.e. represented as a percentage of 70 (units).

6.3.2 Methods of booklet completion

Although the data collection booklets were designed for facilitating prospective completion at the bedside, the majority of critical care units (64%) recorded these data on a daily basis retrospectively, to reflect the

care delivered over the previous 24 hours (Table 6.2). Only 10 critical care units completed the data collection booklets prospectively.

Table 6.2: Method of booklet completion

Method Of Booklet Completion	N (%)
Prospective completion of booklets at the bedside (ticking activities as and when they occurred)	10 (14)
Retrospective completion at the bedside (ticking activities to reflect the care delivered over the previous 24 hour period)	45 (64)
Retrospective completion away from the bedside (ticking activities to reflect the care delivered as documented in the patients' care records)	6 (9)
Other (i.e. combination of prospective and retrospective data collection methods)	4 (6)
Unknown	5 (7)

6.3.3 Staff responsible for data collection

A number of different types of staff were involved in the task of data collection. In the majority of the critical care units, the bedside nurses were responsible for collecting the data followed by the Medical Staff and Nurse Consultants and Managers (Table 6.3). A comparison was made with data on the job titles of 187 staff members registered as a point of contact for the ICNARC's Case-Mix Programme (CMP) (Harrison *et al.*, 2004). Compared to ICNARC's CMP, our study had a significantly higher proportion of bedside nurses and medical staff collecting data (65.7% compared to 17.6% and 15.7% compared to 1.6% respectively). It was reassuring to note the large numbers of medically qualified individuals involved in data collection because of their better understanding of the patients' condition. The extent to which the quality of data collected varied according to the type of staff responsible for data collection was not however explored.

Table 6.3: Staff responsible for data collection

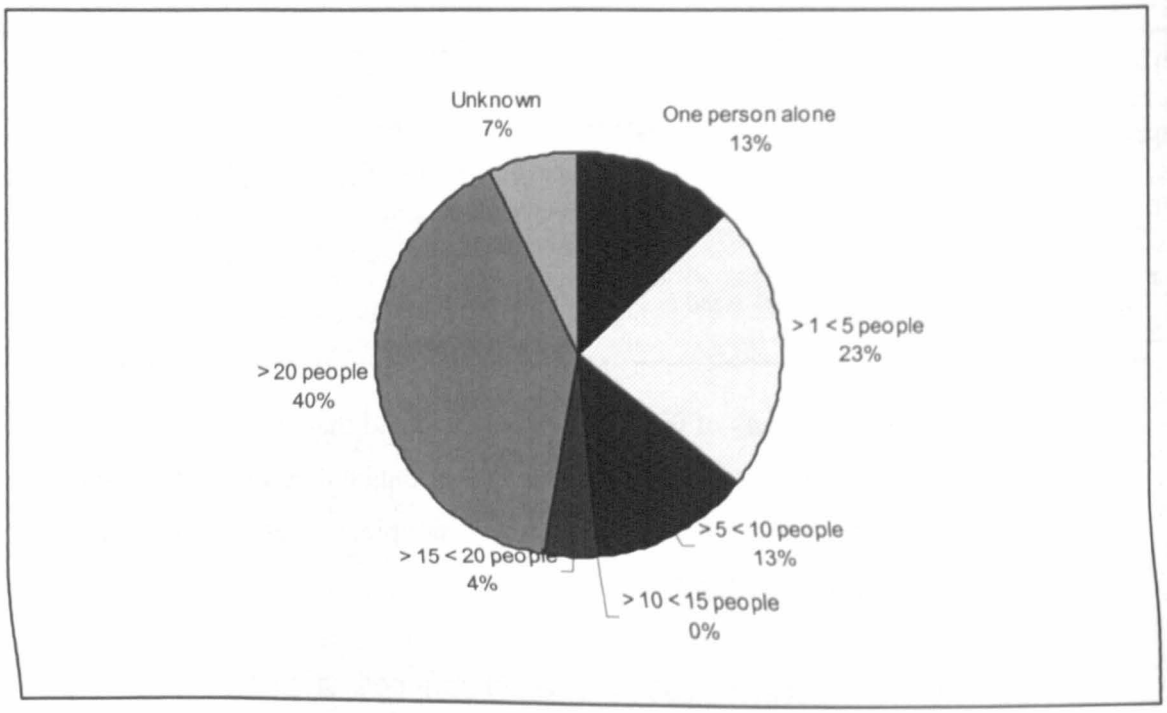
Staff Responsible For Data Collection	N (%)*	Comparison with ICNARC (%)
Bedside nurses looking after the patients	46 (65.7)	33 (17.6)
Medical staff	11 (15.7)	3 (1.6)
Audit staff (including audit clerks)	15 (21.4)	117 (62.6)
Joint audit & clerical staff	N/a	6 (3.2)
Research nurses	5 (7.1)	N/a
Ward clerks	1 (1.4)	23 (12.3)
Other (e.g. nurse consultants, nurse managers and critical care matrons)	8 (11.4)	5 (2.7)
Unknown	5 (7.1)	N/a

* Note that many of the respondents indicated that several groups of staff members were often responsible for data collection and that the figure in parentheses refers to the total sample, i.e. represented as a percentage of 70 (units).

6.3.4 Number of staff involved in data collection

The majority of the critical care units studied had in excess of 20 members of staff involved in completing the data collection booklets. Sixteen critical care units however had between 1 and 5 people dedicated to this task (Figure 6.1).

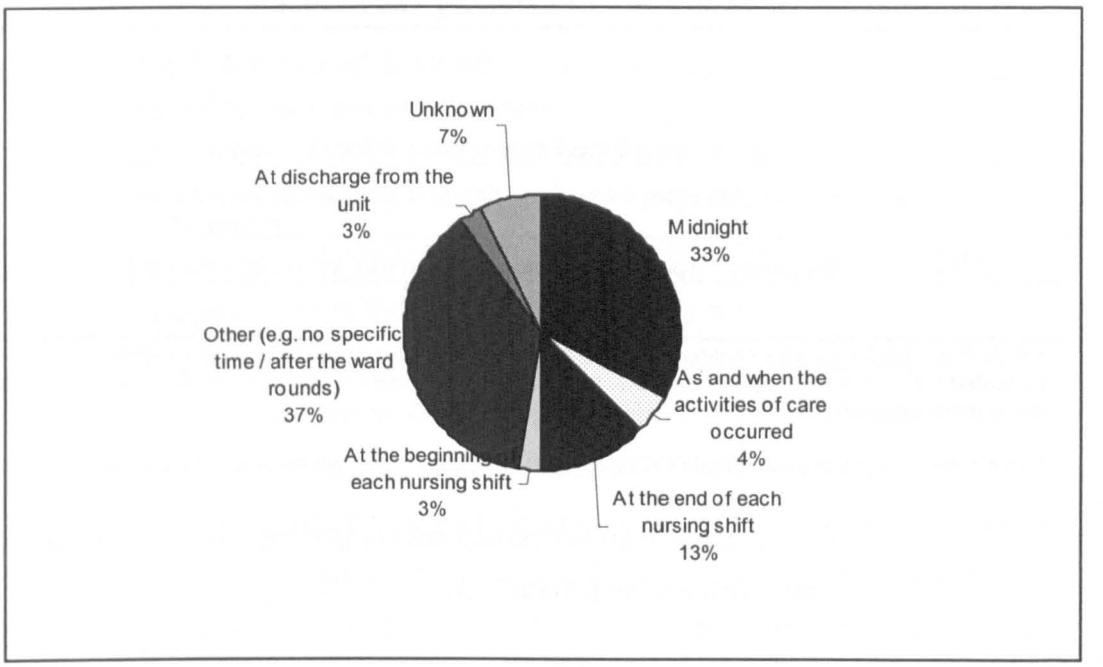
Figure 6.1: Pie chart showing the numbers of staff involved in booklet completion



6.3.5 Time of day when data collection took place

The majority of critical care units completed the data collection booklets as and when they felt it appropriate, such as after the medical ward rounds, or at midnight. Nine critical care units undertook this task at the end of the nursing shift (Figure 6.2).

Figure 6.2: Pie chart showing when the booklets were completed



6.3.7 Measures taken when booklets were not completed

In the majority of cases when the data collection booklets were not completed for the reasons given in table 6.4, staff completed the booklets retrospectively using data from the patients' medical records.

Table 6.4: Reasons given for not completing the booklets

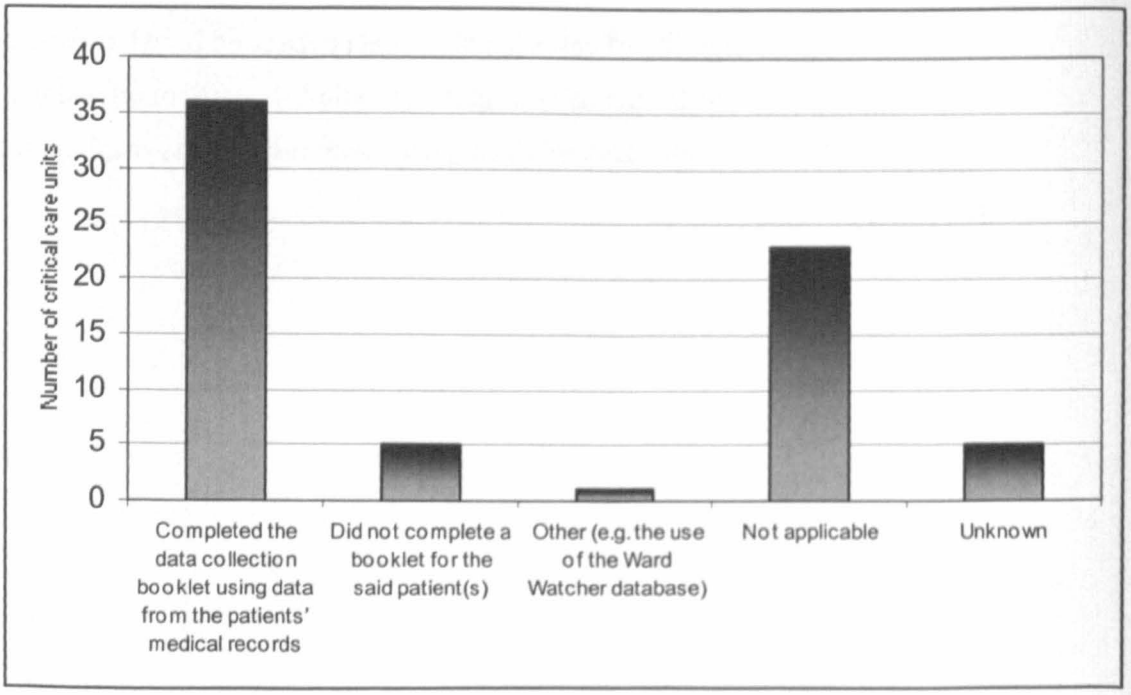
Reasons Given For Not Completing The Booklets	N (%)*
Ran out of data collection booklets	3 (8)
Could not locate data collection booklets	3 (8)
Patients in for such a short period of time that it didn't seem worth it	1 (3)
Unit really busy therefore did not have time and forgot to complete booklet retrospectively	20 (54)
Other (e.g. the person responsible for data collection was absent from the unit)	10 (27)
Unknown	36 (51)

* Note that only 34 responses were given to this question and that multiple reasons were sometimes indicated for not completing the booklets; a total of 37 responses. Therefore, the figures in parentheses are a percentage of this.

†This relates to the overall sample (70 units) and the figure in parentheses is a percentage of this.

Five critical care units reported not completing a booklet for the patients in question (Figure 6.3).

Figure 6.3: Bar chart showing the measures taken when the data collection booklets were not completed



6.4 Data checks

The checks performed on the data set are categorised into those relating to data entry (Section 6.4.1) and data quality (Section 6.4.2).

6.4.1 Data entry

All data documented within the data collection booklets had to be manually input into spreadsheets stored in Microsoft Excel once the booklets were returned to the University of Sheffield. The cross checks performed on all of the data transferred from the data collection booklets and the electronic records containing the entered data, identified data entry errors relating to omissions and inaccuracies. Changes were then made to the electronic records.. Whilst this checking procedure was not formalised in terms of recording the exact number and nature of errors identified, there were only a very small number identified in the 1,811 (25%) records that were checked at random. Checking was performed at the same time as data entry and those individuals involved in entering data were informed that their work would be double-checked prior to the start of data entry. There were 5 individuals involved in data entry (myself, Lizzie Coates, John Campbell, Elena Brooker and James Hibbert). Lizzie and I performed the checking tasks, selecting booklets at random from all of the seventy critical care units.

6.4.2 Data quality

Once the data had been entered into Microsoft Excel, a series of formalised checks were performed on each critical care unit's data, which were briefly described in Section 6.13 and an individualised query form issued to each unit (where appropriate). Sixty-seven critical care units were issued a query form; to which 62 units (93%) responded. Upon receipt of the query form, the data items in question were corrected in each critical care unit's spreadsheet.

Two thousand eight hundred and sixty-eight queries were issued to the participating centres, which represented 4.97% of all of the data received. Only 3 (4.28%) critical care units submitted data that did not generate any queries. Of the 67 critical care units who had been issued with query forms to complete, 49 (73%) units were able to provide data that satisfied the queries raised (see Appendix 6.2).

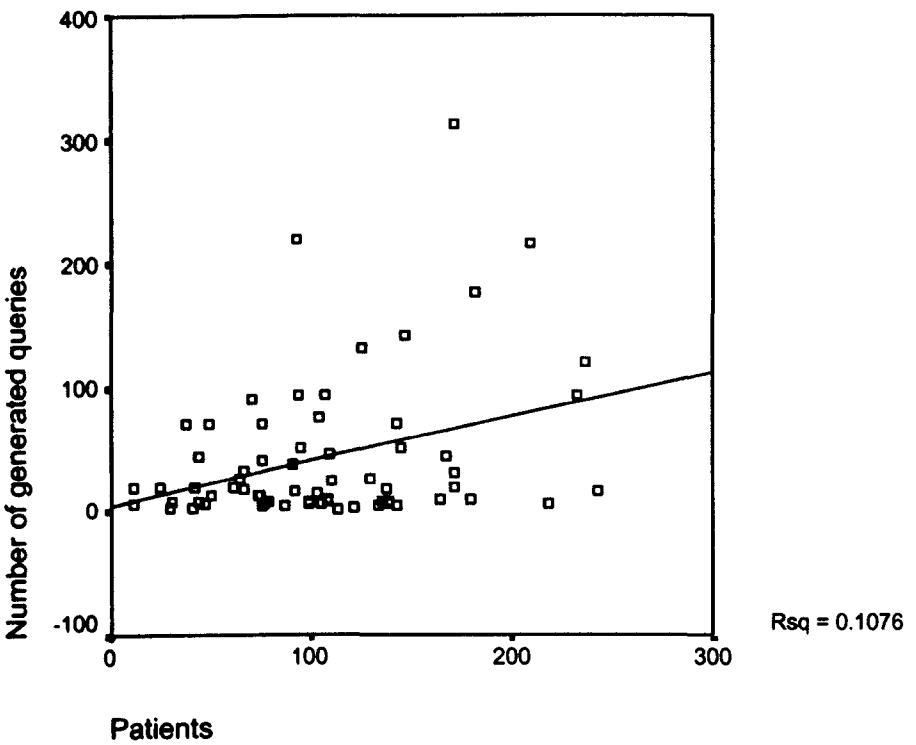
Table 6.5 reports descriptive statistics relating to each type of query data item. Inconsistent (or illogical) data was observed in more than half of the critical care units whereby, for example, patients appeared to have been discharged before they were admitted or if their discharge was recorded on a completely different day to that indicated within their activity spreadsheet.

Table 6.5: Summary of queries

Type of Query	Number of critical care units (%)	Sum of the queries	Mean (SD)	Median (inter-quartile range [min-max])
Number of generated queries	67 (100)	2 868	42.81 (59.66)	18.00 (7.00-51.00 [1.00-312.00])
Number of answered queries	61 (91)	2406	35.91 (57.55)	13.00 (6.00-43.00 [0-312.00])
Inconsistent data	38 (57)	140	2.09 (3.63)	1.00 (0.00-2.00 [0.00-19.00])
Missing date of admission	2 (3)	5	0.07 (0.50)	0.00 (0.00-0.00 [0.00-4.00])
Missing time of admission	32 (48)	142	2.13 (3.72)	0.00 (0.00-2.00 [0.00-19.00])
Missing date of discharge	30 (45)	278	4.15 (13.04)	0.00 (0.00-1.00 [0.00-78.00])
Missing time of discharge	52 (78)	730	10.90 (19.09)	3.00 (1.00-12.00 [0.00-106.00])
Missing type of admission	54 (81)	282	5.72 (6.72)	4.00 (1.00-8.00 [0.00-33.00])
Missing outcome status	63 (94)	1 329	19.84 (27.85)	7.00 (2.00-21.00 [0.00-114.00])

There was a positive linear relationship between the number of patients studied and the number of queries generated: $R^2 = 0.108$, p=0.007 (Figure 6.4).

Figure 6.4: Scatter plot of the relationship between the number of generated queries and the number of patients studied



Six critical care units (9%) did not respond to the request for missing data, which produced a total of 462 (16%) outstanding queries. In this instance, the following changes were made to the dataset:

- Missing date of admission: the first date on which data were collected within the data collection booklet was entered;
- Missing date of discharge: the last date on which data were collected within the data collection booklet was entered;
- Missing time of admission: the earliest possible time, i.e. 0:00 was entered;
- Missing time of discharge: the latest possible time, i.e. 23:59 was entered;
- Missing admission or survival status at unit discharge: these items were coded as missing.

Where data collection had been duplicated, the patient record that closely matched the record that was re-supplied was kept within the dataset and the other record was removed. When inconsistent data were not clarified, the least complete patient record was deleted from the dataset. In some cases, the clarification of some aspects of a patient's episode led to further queries. For example, differences between the survival status recorded in the original data collection booklet and that re-supplied during the query process. In this instance, every effort was made to clarify the characteristics of this patient's critical care episode with the study contact person.

For some patients, both Level 3 and Level 2 care was received during a 24-hour period and so both boxes were ticked in the data collection booklets. In this case, the researchers chose to record the highest level of care in the spreadsheets. All changes were documented in the unit-specific query booklet.

An additional variable called 'Level 1 / 0 / Missing' was created within the data entry spreadsheet for all patients where no data on Level 3 care or Level 2 care was provided. In instances whereby a patient receiving advanced respiratory support and had missing data for their level of care, the researchers recorded that the patient had received Level 3 care (in accordance with the definitions). An additional variable called 'Missing location of care' was created in the spreadsheet for patients where their location of care had not been recorded.

6.5 Completion issues

It was important to know whether the data collected in this study were valid and reliable. Validity is defined as '*the extent to which a measure or piece of data 'reflects' what it is supposed to measure or give information about*' (Øvretveit, 1998). Bohrnstedt (1983) defines reliability as '*the extent to which the variance in an observed [piece of data] is due to random sources or to "noise"*'. Criteria developed by

the Directory of Clinical Databases were used to evaluate the validity and accuracy of the data collected (summarised in Appendix 6.1).

6.5.1 Completeness of recruitment (of eligible patients)

Selection bias can be introduced if a significant proportion of the patients that the study seeks to include are not captured by the study, whereby those included are systematically different from those who are not included in the sample (Black *et al.*, 2003). The two main advantages of encouraging the use of data collection booklets were that it allowed staff to complete them anonymously, in a consistent manner, and the booklets could be used by many people at a low cost. The disadvantages were that a proportion of the booklets may not have been completed fully and it was important to ensure that critical care units had an adequate supply of them with clear instructions for their completion (Øvretveit, 1998). In order to determine the proportion of patients for whom data were collected in the study (i.e. to see how complete the recruitment was), it would have been useful to have compared these data with the critical care unit's admission book. Whilst each critical care unit was asked to estimate their anticipated throughput of patients during the study period, no data was collected on the actual numbers of patients treated during the study from a source other than the data collection booklets.

The Directory of Clinical Databases (DoCDat) hosted by the London School of Hygiene & Tropical Medicine was consulted in order to provide an independent assessment of the study's scope and quality (Black *et al.*, 2003). Their website (www.lshtm.ac.uk/docdat) describes DoCDat as '*an information resource for all those involved in clinical audit, clinical governance, health services management, health services research, research funding, and academic publishing*'.

DoCDat focuses primarily on centralised individual-level databases based either on prospectively or retrospectively collected data. Independent, trained interviewers assess the quality of each database

using a structured questionnaire developed by clinicians, epidemiologists, statisticians and information specialists. The assessment covers general aspects of the database; the data set, such as how many individuals are included etc; outputs i.e. who can analyse the data and how frequently standard audit reports are produced; management of the database, such as who is involved in running it and who funds it; quality of the data including four aspects of the coverage of the data and six aspects exploring the accuracy of the data. According to Black *et al.*, (2003), the instrument has good face and content validity, has no floor / ceiling effects and is acceptable to database custodians.

The 'quality' section of their assessment was used to evaluate the completeness of recruitment for eligible patients in this study, consisting of levels 1 to 4, with Level 1 representing the least rigorous method and Level 4 representing the most rigorous.

Level 1: Unknown or few (>80%)

Level 2: Many (80-90%)

Level 3: Most (90-97%)

Level 4: All or almost all (>97%)

Although no external validation was performed, information was collected on what the critical care unit did when they missed patients (Section 6.3.7). Due to the small number (3.5%) of critical care units who did not complete a booklet for their 'missed' patients, it is assumed that many patients (80-90%) were included in the study as the majority of units used data from the patients' medical records to complete the data collection booklets. As such, the study met Level 2 of the DoCDat criteria for completeness.

6.5.2 Variables included in the study

The rationale given by DoCDat for studying the variables included is that it guides the scope of the kind of analyses that can be conducted

using the data. DoCDat provides concise definitions for these, under the headings of 'identifier[25]', 'admin info[26]', 'condition[27]', 'intervention[28]', 'short-term outcome[29]', 'major, known confounders[30]' and 'long-term outcome[31]'.

The four levels into which studies could be classified were as follows:

- Level 1: Identifier, condition or intervention;
- Level 2: Identifier, condition or intervention, short-term outcome or long-term outcome;
- Level 3: Identifier, condition, intervention, short-term outcome or long-term outcome, major known confounders;
- Level 4: Identifier, condition, intervention, short-term outcome, major known confounders, long-term outcome.

The study met Level 2 as it collected data on patient identifiers, the interventions and patients' short-term outcomes (i.e. survival status at discharge from the critical care unit).

6.5.3 Completeness of data (% variables at least 95% complete)

Data was deemed (by DoCDat[32]) to be complete if the percentage of data on variables collected were at least 95% complete[33]. The rationale

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25 Identifier: Variables by which an individual / episode can be identified, e.g. name, address, postcode, date of birth, NHS number or other unique number

26 Admin info: administrative information such as date of admission into hospital, date of operation, treating clinicians' code, and institutional code

27 Condition: primary diagnosis, e.g. breast cancer or diabetes. This will often be the common circumstance that determines inclusion

28 Intervention: the intervention aimed at treating the condition e.g. surgery or drugs prescribed

29 Short-term outcome: the outcome at the end of that episode of care, e.g. post-operative outcome, status at discharge

30 Major, known confounders: this will vary by condition, but generally would include co-morbidity and age. It could also include socio-demographic variables such as socio-economic status, behavioural variables such as smoking and physiological variables such as height, weight and blood pressure. These variables are vital for producing risk-adjusted outcome analyses

31 Long-term outcome: this will vary according to the condition, but generally would include any follow-up of the patient / episode after the immediate outcome of the intervention (e.g. six months or a year after the first intervention, depending on the severity of the condition

32 Information about DoCDat can be found at http://www.lshtm.ac.uk/docdat

given for looking at this is that difficulties occur when attempting to analyse these data if large amounts of data are missing. Selection bias may be introduced where patients with missing data (excluded from any analysis) are systematically different from those without missing data. Ninety-seven percent of queries were clarified by the participating centres that responded to requests for missing data. It is conceivable that the data would have been more complete had one person within each critical care unit been solely responsible for data collection (however impractical this may have been). The category of concern was that of retrospective completion away from the bedside (ticking activities to reflect the care delivered as documented in the patients' care records). Assuming that the patients' records were complete and comprehensive, this would not have posed a problem, however it is unlikely that notes in the records would translate easily to the structured format of the booklets and thus possible that records for some data items may have been missed.

The four levels into which studies could be classified were as follows:

- Level 1: Unknown or few (<50%)
- Level 2: Many (50-79%)
- Level 3: Most (80-97%)
- Level 4: All or almost all (>97%)

The study met Level 3 with most data being complete (80-97%).

6.6 Accuracy of the data collected

6.6.1 Form in which continuous data (excluding dates) is collected

The first of DoCDat's criteria for accuracy sought to determine the form in which continuous data (excluding dates) had been collected.

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33 The total number of variables at least 95% complete is divided by the total number of variables in the database.

No continuous data were collected in the study so this was not investigated.

6.6.2 Use of explicit definitions for variables

This was defined as '*the percentage of variables which have clear definitions*[34] *laid out in a document as a data manual and is calculated by dividing the number of variables in the database which have been clearly defined by the total number of variables which need to have definitions*' (DoCDat).

The four levels into which studies could be classified were as follows:

- Level 1: None
- Level 2: Some (<50%)
- Level 3: Most (50-97%)
- Level 4: All or almost all (>97%)

All of the variables in this study had clear definitions stipulated for their collection with the exception of planned / unplanned admission which was not analysed. For this reason, the study met level 4 of the criteria.

6.6.3 Use of explicit rules for deciding how variables are recorded

The rationale given for prescriptive guidance on data recording is to ensure that data are recorded in the same way, which increases the reliability of the collected data.

The use of explicit rules was defined as 'the percentage of variables which have clear rules on how to code them...laid on in a document such as a data manual and calculated by dividing the number of variables in the database which have clear rules by the total number of variables which need to have rules' (DoCDat).

34 A definition is a clear description of what the variable means.

The four levels into which studies could be classified were as follows:

- Level 1: None
- Level 2: Some (<50%)
- Level 3: Most (50-97%)
- Level 4: All or almost all (>97%)

The coding of variables was very much simplified in the study, guiding responders to record ticks into boxes for the collection of the organ support data and thus met level 4 of the criteria.

6.6.4 Reliability of coding for conditions and interventions

The reliability of coding for conditions and interventions relates to how standardised the codes are and looks at intra-rater[35] and inter-rater[36] reliability. This is important to determine because it assures the researcher that any observed differences between patients can be attributed to the nature of patient, rather than the way in which the data has been recorded.

The reliability of the tick boxes was perfectly adequate for this study, however the variance in data produced as a result of different staff completing the booklets at different times of the day and the member (type) of staff responsible for completing the booklets in the first instance was of greater concern. Feedback from the staff suggested that the booklets were not unreliable insofar that the data items were not difficult for them to understand. The use of the booklets would not have affected the quality of data collected. What would have been useful to know was the extent to which different types of staff gave the same response to the organ support categories. Tests of inter-rater reliability were not performed as it was only after the data had been collected that the problem of multiple staff engaging in the collection

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35 Intra-rater reliability is when *'the same observer gives the same value at different times, if the thing that he or she observes is the same* (Øvretveit, 1998).

36 Inter-rater reliability is defined as *'the extent to which two or more observers give the same value to the thing that they measure at the same time'* (Øvretveit, 1998).

of the data became apparent. Had it been possible to perform an audit, different members of staff could have been presented with the same patient (on whom data could be collected) and their data compared for concordance (inter-rater reliability). The same member of staff could have been asked to collect the same information at different times of the day (intra-rater reliability). Kappa scores produced from these tests would have provided an effective means of assessing the reliability of the data.

An assumption was made that the scope of organ support variables and their definitions had content validity[37] based on these being devised by a select, expert Group of critical care opinion leaders. The only disadvantage to the collection of the organ support data was the lack of another dataset which could have been used to assess the criterion validity of these data.

The four levels into which studies could be classified were as follows:

- Level 1: Not tested (no inter or intra-rater reliability tests conducted)
- Level 2: Poor (low inter and intra-rater reliability i.e. Kappa <0.5)
- Level 3: Fair inter and intra-rater reliability i.e. Kappa 0.5-0.8)
- Level 4: Good inter and intra-rater reliability (i.e. Kappa >0.8)

As no formal tests of inter-rater and intra-rater reliability were performed, the study fell into the Level 1 category.

37 Content validity is concerned with measuring what one intends to measure (Bohrnstedt, 1983)

6.6.5 Independence of observations of primary outcome[38]

The outcome variables in the study (survival at discharge from the critical care unit) were objective and did not require independent observation.

The four levels into which studies could be classified were as follows:

- Level 1: Outcome not included **or** independence unknown
- Level 2: Observer neither independent nor blinded to intervention
- Level 3: Independent observer not blinded to intervention
- Level 4: Independent observer blinded to intervention **or** not necessary as objective outcome (e.g. death or lab test).

According to the above criteria, the study could be placed in the Level 4 category.

6.6.6 Extent to which data are validated

Misleading results can follow if measures are not taken to ensure the validity of data. The four levels into which studies could be classified were as follows:

Level 1: No audit (no data validation is conducted)

Level 2: Range or consistency checks

- Range checks ensure that data outside of the permitted range are not allowed, for example an age of 150. Range checks may be pre-programmed into data entry programmes and performed automatically at data entry, or performed manually at the data analysis stage.
- Consistency checks can be performed manually or automatically, and involve highlighting areas where the data are inconsistent. For example, a consistency check

[38] Described as any bias associated with the outcome due to the way in which it was reported (DoCDat)

would ensure that an individual having a hysterectomy could not be recorded as male.

- Some databases may go back to the original records to validate the data by retrieving the correct value, for example by sending back a list of queries to those who collect the data.

Level 3: Range and consistency checks

Level 4: Range and consistency checks plus external validation using an alternative source

- External validation involves going back to the original record and comparing the information with that held by the database to ensure that the database records are accurate. This would normally take the form of an audit whereby, for instance, a 1% sample of all database records is compared to the original medical notes.
- Going back to the records to check inconsistencies or range checks by setting up a series of queries does not constitute external validation (DoCDat).

Internal consistency checks of the data set were performed manually and these are described as follows: In order to check whether the level of care had been correctly determined based on the definitions provided, a rule was created whereby Level 2 care should not be ticked if a patient was receiving advanced respiratory support, so for patients with the Level 2 care box ticked, this was changed to Level 3 care. Patients neither could receive both basic and advanced respiratory support during the same day, so the data were changed to reflect this indicating the higher form of organ support (advanced respiratory support). The consistency checks placed the study into the Level 2 category, although the category that include ranges does not strictly apply as no data were collected whereby ranges could be checked.

A discussion of this work takes place towards the end of the Chapter (Section 6.20). Section II will now describe the characteristics of the participating critical care units.

CHAPTER 6: RESULTS

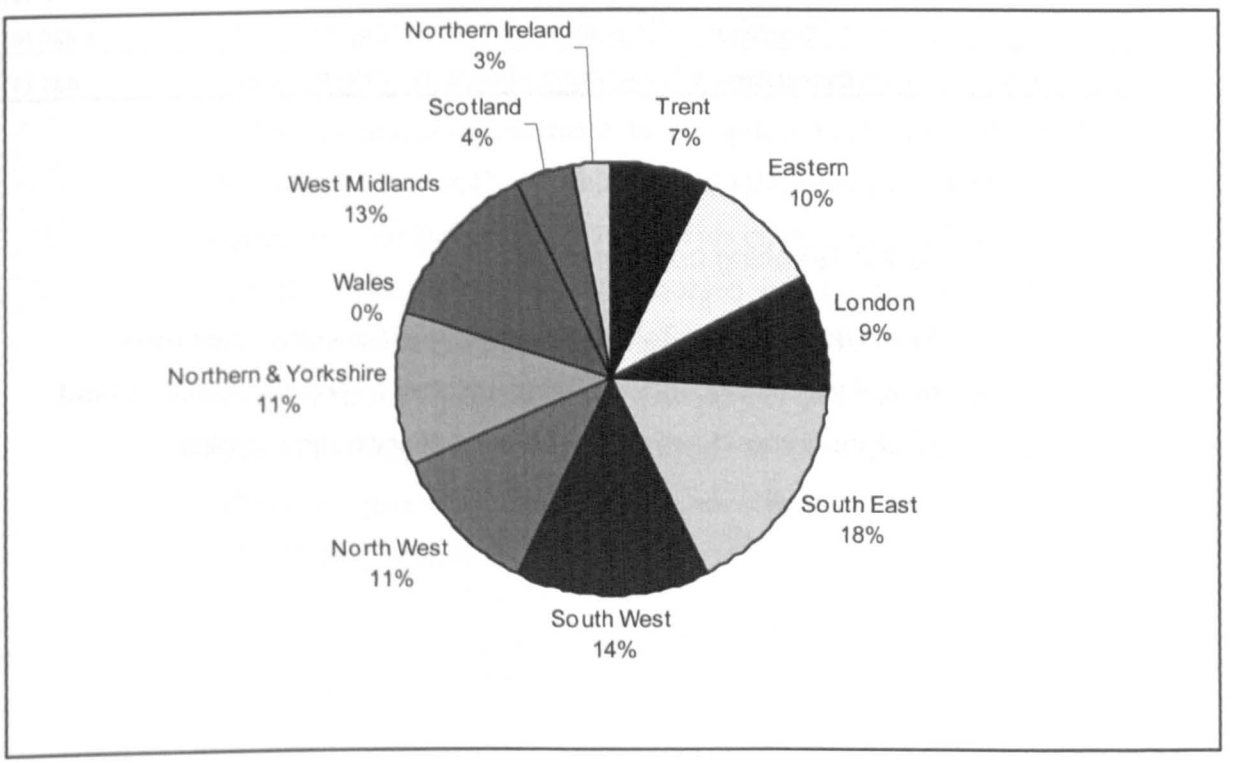
SECTION II: UNIT CHARACTERISTICS

6.7 Unit Characteristics

6.7.1 Geographical coverage

Of the 70 critical care units, 65 (93%) provided data on their unit characteristics. Whilst the sample achieved wide geographical coverage of critical care units in England with smaller numbers from Scotland and Northern Ireland, no critical care units in Wales were represented in the sample (Figure 6.5).

Figure 6.5: Pie chart showing the numbers of critical care units by Region



The three predominant participating regions were the South East, South West and the West Midlands that collectively generated 48% of the patients studied (table 6.6)

Table 6.6 Number of patients and patient days by geographical location

Geographical Location	N (%)	Number of patients studied (%)	Number of patient days included in the analysis (%)
Northern & Yorkshire	8 (11)	745 (10)	3 627 (10)
Trent	5 (7)	488 (7)	2 267 (6)
Eastern	7 (10)	701 (10)	3 971 (11)
London	6 (9)	820 (11)	3 893 (10)
South East	12 (17)	1 158 (16)	6 070 (16)
South West	10 (14)	1 107 (15)	5 377 (14)
West Midlands	9 (13)	1 115 (15)	5 549 (15)
North West	8 (11)	681 (9)	4 361 (12)
Wales	0 (0)	0 (0)	0 (0)
Scotland	3 (4)	349 (5)	1 570 (4)
Northern Ireland	2 (3)	79 (1)	484 (1)

6.7.2 Teaching hospital status

As can be seen from Table 6.7, a quarter of the critical care units studied was located in NHS Trusts that had a Medical School. A third of the units considered themselves as tertiary referral centres.

Table 6.7: Hospital Type

Hospital Type	Number of units (%)	Number of patients studied (%)	Number of patient days included in the analysis (%)
Medical School within the hospital	17 (24)	2 322 (32)	12 627 (34)
Tertiary Referral Centre	25 (36)	2 917 (40)	15 612 (42)
Unknown*	7 (10)	545 (8)	2 954 (8)

* The hospital type was not indicated in two additional responding units.

6.7.3 Types of critical care unit

The majority of critical care units were combined intensive care / high dependency units (HDUs) (46%), followed by adult general intensive care units (ICUs) (24%) and the remaining centres consisted of a mixture of general and surgical HDUs, cardiothoracic units, burns/ plastic surgery units and neurological and neurosurgical ICUs and HDUs. The unit type changed in two hospitals during the study period. One adult general ICU and adult general HDU merged to form a combined adult general ICU / HDU. This change occurred on 29/4/2003. One adult general ICU merged with an adult general HDU to also become a combined adult general ICU/HDU. This changed occurred on 1/4/2003 and the unit descriptors given are for the latter. In three of the hospitals, both the adult general ICU and adult general HDU participated in the study. These are categorised as adult general ICU/HDUs (Table 6.8).

Table 6.8: Types of Critical Care Unit

Unit Type	Number of Units (%)	Number of Patients Studied (%)	Number of Patient Days Included In The Analysis (%)
Adult General Intensive Care Unit	17 (24)	1 373 (19)	8 450 (23)
Adult General High Dependency Unit	2 (3)	177 (2)	686 (2)
Adult General Intensive Care Unit/ High Dependency Unit	32 (46)	3 712 (51)	17 793 (48)
Adult Surgical Intensive Care Unit	0 (0)	0 (0)	0 (0)
Adult Surgical High Dependency Unit	2 (3)	274 (4)	1 164 (3)
Adult Cardiothoracic Intensive Care Unit	2 (3)	378 (5)	1 833 (5)
Adult Coronary Care Unit	0 (0)	0 (0)	0 (0)
Adult Burns / Plastic Surgery Unit	2 (3)	22 (0)	96 (0)
Adult / Paediatric Burns Unit	0 (0)	0 (0)	0 (0)
Adult Neurological Intensive Care Unit / General Intensive Care Unit	2 (3)	152 (2)	887 (2)
Adult Neurological Intensive Care Unit / High Dependency Unit	4 (6)	433 (6)	2 258 (6)
Adult Combined Intensive Care Unit / High Dependency Unit / Coronary Care Unit	2 (3)	176 (2)	649 (2)
Adult Neurosurgical & Neurological Intensive Care Unit / High Dependency Unit	1 (1)	24 (0)	205 (1)
Adult General Intensive Care Unit / Neuro Critical Care Unit	1 (1)	99 (1)	879 (2)
Adult General Intensive Care Unit / High Dependency Unit / Neuro Intensive Care Unit	1 (1)	215 (3)	1 155 (3)
Unknown*	2 (3)	208 (3)	1 115 (3)

*It was possible to clarify the unit type in three of the five non-responding units.

A comparison of our study was made with ICNARC's CMP database[39] and the results were as follows (table 6.9). ICNARC had a higher proportion of ICUs participating in their study and it would appear that a higher number of specialist critical care units and separate high dependency units participated in our study. A similar proportion of combined critical care units (e.g. ICU / HDU) were observed in both studies.

[39] Unpublished data provided by ICNARC Statisticians on 18th May 2005 (sent by e-mail).

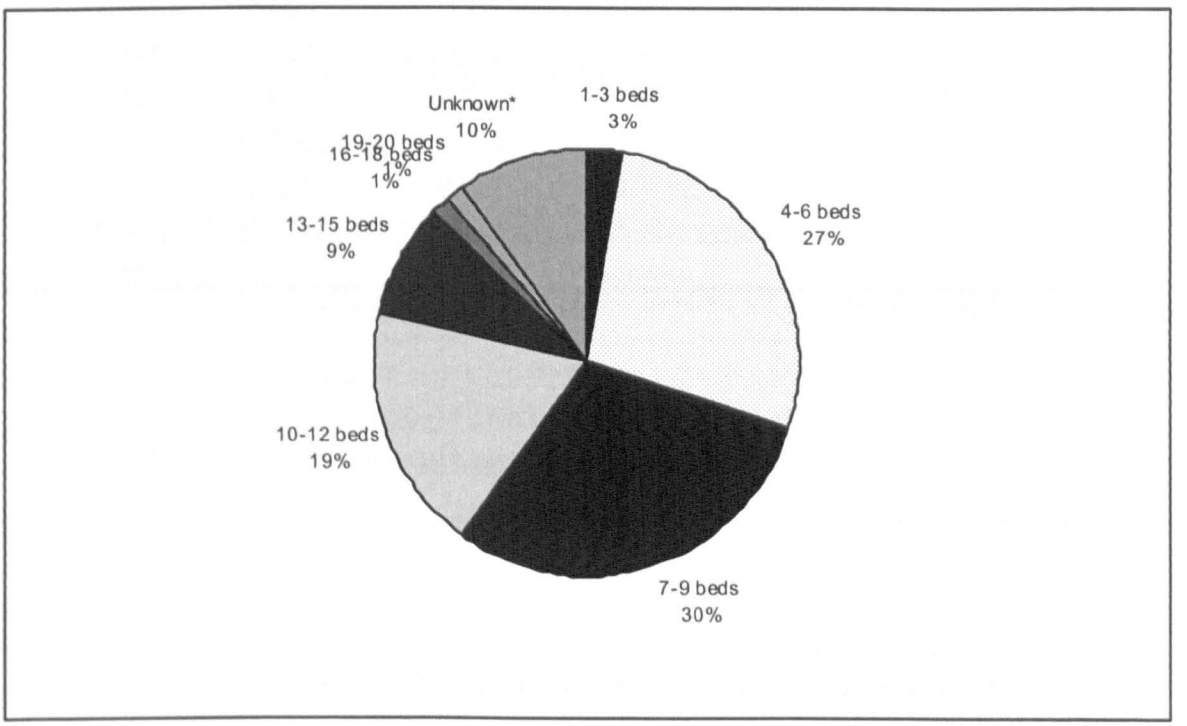
Table 6.9: Comparisons of unit type with the ICNARC CMP database (2005)

Type of Critical Care Unit	ICNARC (%)	Study Population (%)
ICU	71 (42.0)	17 (24.3)
ICU / CCU	3 (1.8)	0 (0.0)
ICU / HDU	87 (51.5)	38 (54.3)
ICU / HDU / CCU	7 (4.1)	2 (2.9)
ICU / HDU / NICU	1 (0.6)	1 (1.4)
Other e.g. HDUs, cardiothoracic ICUs, specialist burns etc.	N/A	12 (17.1)

6.7.4 Number of staffed critical care beds

The number of staffed beds provided by the critical care units ranged from 2 beds to 20 beds, with the majority of units having between 7 to 9 beds (30%) and 4 to 6 beds (27%) (see Figure 6.6). The reason for this wide variation is not known.

Figure 6.6: Pie Chart Showing The Proportion Of Critical Care Units By Size



The median size of critical care units in the ICNARC CMP is 7 (range 3-22) which compares with median values of 5.3 for ICUs and of 6 for combined ICU / HDUs in the Audit Commission Survey (Harrison *et al.*, 2004 & Audit Commission, 1998).

The largest numbers of patients and patient days was collected from critical care units having between 7-9 and 10-12 beds (table 6.10). Comparisons with ICNARC's CMP showed the study sample to have a lower proportion of participating units with 1-3 beds (2.9% compared with 7.6%) and similarly, with units sized between 4-6 beds (27.1% and 54.7% respectively). Our study had a higher proportion of critical care units with 13-15 beds (8.6% compared to 2.9%).

Table 6.10: Numbers of staffed critical care beds

Unit Size (Numbers of staffed beds)	Number of critical care units (%)	Comparison with ICNARC's CMPD[40] (%)	Number of patients studied (%)	Number of patient days included in the analysis (%)
1-3 beds	2 (2.9)	13 (7.6)	47 (1)	151 (0)
4-6 beds	19 (27.1)	93 (54.7)	1 554 (21)	7 344 (20)
7-9 beds	21 (30.0)	38 (22.4)	2 026 (28)	10 857 (29)
10-12 beds	13 (18.6)	19 (11.2)	1 903 (26)	8 965 (24)
13-15 beds	6 (8.6)	5 (2.9)	798 (11)	4 974 (13)
16-18 beds	1 (1.4)	1 (0.6)	240 (3)	1 186 (3)
19-20 beds	1 (1.4)	0 (0.0)	215 (3)	1 155 (3)
> 20 beds	0 (0)	1 (0.6)	0 (0)	0 (0)
Unknown*	7 (10.0)	0	460 (6)	2 538 (7)

* The number of beds was not indicated in two additional responding units.

[40] Data from 170 critical care units was used between December 1995 and January 2005

6.7.5 Provision of additional services

Outreach services

The Intensive Care Society (ICS) (2002) defines Outreach (as applied to critical care services) as "*a multidisciplinary approach to the identification of patients, at risk of developing critical care, and those patients recovering from a period of critical illness, to enable early intervention or transfer (if appropriate) to an area suitable to care for that patient's individual needs.*" Outreach services were provided in 40% of hospitals with a smaller proportion of hospitals offering follow-up clinics and bereavement services (Table 6.11).

According to the ICS (2002), Outreach Services have the following objectives:

- To avert admissions to critical care;
- To facilitate timely admission to critical care and discharge back to the wards;
- To share critical care skills and expertise through an educational partnership;
- To promote continuity of care; and
- To ensure thorough audit and evaluation of Outreach Services.

Table 6.11: Provision of additional services

Additional Services	N (%)
Provision of an outreach service at the time of the study	40 (57)
Provision of a follow-up clinic at the time of the study	24 (34)
Provision of a critical care bereavement service at the time of the study	10 (14)
Unknown	5 (7)

Follow-up Clinics and Bereavement Services

Follow-up clinics are part of the continuum of outreach care (NHS Modernisation Agency, 2003) to 'enable discharges by supporting the continuing recovery of discharged patients...post discharge from hospital, and their relatives and friends' (Department of Health, 2000). As part of a Bereavement service, all recently bereaved relatives are sent a letter of condolence a few weeks after their loss. In this letter are details of people to contact regarding any unresolved issues they may have with their recent critical care experience. If they choose to take up this offer, they are given an appointment to attend the critical care unit to allow for clarification and offered support.

As can be seen from table 6.11, over half of the critical care units operated an outreach service at the time of the study and just over a third were offering follow-up clinics to their patients. Only a small number of units had set up a bereavement service.

6.8 Representativeness of the sample

6.8.1 Representative of Country (i.e. Coverage)

The Directory of Clinical Databases (DoCDat) – data definition manual on data quality was used to assess the extent to which the critical care units studied were representative of the country.

Coverage was defined by DoCDat as 'the extent to which the eligible population (defined by the common circumstance that determines inclusion and the geographical area covered [by the study] can be generalised to the reference population (everyone with the common circumstance in the country from which the data are drawn'.

Four levels of representativeness are given:

Level 1: No evidence or unlikely to be representative

- The sample is unlikely to be representative if those include represent a sub group (e.g. private patients / patients from one ethnic group).

Level 2: Some evidence that eligible population is representative

- Basic comparisons have been made with the reference population (all those in the country with the common circumstance), which show that, for example, incidence rates or the socio-demographic distribution of the eligible population and the total population of the country are similar.

Level 3: Good evidence the eligible population is representative

One or more of the following:

- Comparisons between the eligible population and the reference population show similar characteristics such as demographics or incidence;
- A sampling frame has been used that captures a representative sample.

Level 4: Total population of country included

The Directory of Critical Care (2001) listed 213 (89%) critical care units in England, 16 units in Wales (6.5%) and 11 (4.5%) in Northern Ireland. Our study had 65 critical care units in England (30.5% of this), none in Wales (0%) and 2 in Northern Ireland (18% of this). Comparing our study to the Directory of Critical Care, our sample of 70 critical care units represented 29% of those in England, Wales and Northern Ireland. Of the 70 critical care units studied, 65 (86%) were in England, none in Wales, 2 (3%) were in Northern Ireland. The percentages of units by county suggest that there is some evidence that the sample was geographically representative and as such, would meet Level 2 of the criteria.

6.9 Performance of the study against the DoCDat criteria

The study ratings were compared with the median (interquartile [IQR] ranges from all 154 databases in DoCDat. The mean level achieved by the study across all criteria (with the exception of E as it did not apply) was 2.6. The study exceeded the DoCDat median for 3 categories, equalled it for 2 categories and performed worse than the median in 4 categories (table 6.12).

Table 6.12: Performance of study against DoCDat databases

	Critical Care Study Level				DoCDat databases
	1	2	3	4	Median (IQR)
A. Representative of country					3 (2-4)
B. Completeness of recruitment					3 (1-4)
C. Variables included					3 (2-4)
D. Completeness of variables					2 (1-3)
E. Collection of raw data (N/A)					4 (4-4)
F. Explicit definitions					2 (1-4)
G. Explicit Rules					2.5 (1-4)
H. Reliability of coding					1 (1-4)
I. Independence of observations					4 (2-4)
J. Data validation					3 (3-4)

A discussion of this work takes place towards the end of the Chapter (Section 6.20). Section III will now explore the characteristics of patients and report on some preliminary analyses looking at the relationship between patients' organ support and the type and size of the critical care unit.

CHAPTER 6: RESULTS

SECTION III: CHARACTERISTICS OF PATIENTS AND PRELIMINARY ANALYSES

6.10 Patients' Characteristics

As described in Section 7.1, data were collected on 7,243 critically ill patients. The characteristics of patients in terms of their critical care unit length of stay, survival status at discharge from the critical care unit and type of admission (planned or unplanned) are shown in Table 6.13.

Table 6.13: Patients' descriptive characteristics

Descriptive Characteristics Of The Study Population	N (%)
Total number of patients studied	7,243
Number of patients with complete data (i.e. received treatment in the unit within the time period of the study) (%)	6 498 (90)
Number of patients with a length of stay of less than 24 hours (%)	2 019 (28)
Number of unplanned admissions (%) – where status is known	4 966 (69)
Number of surviving patients – where outcome data is known (%)	83%
Total number of calendar days with data collected	37,170
Mean ± SD Actual Length of stay (actual date and times of admission included for complete patients	4.02 ± 5.88
Median (IQR)	1.97 (0.91-4.39)
Mean ± SD Actual Length of stay (actual date and times of admission included for incomplete patients[41]	13.70 ± 19.90
Median (IQR)	7.34 (2.83-16.76)
Mean ± SD Calendar Length of stay for complete patients	4.64 ± 5.34
Mean ± SD Calendar Length of stay for incomplete patients	9.36 ± 11.74

[41] Patients' critical care unit length of stay was cut at 31/05/03 23:59 for those still receiving care in the critical care unit at the end of the study

6.10.1 Admission status

Thirty-one percent of patients were elective (i.e. planned) admissions.

6.10.2 Patients' length of stay

As the study started at the beginning of a calendar month, there were some patients already receiving care in the critical care unit that had been admitted prior to this date. Critical care units were asked to supply the date and time of admission for their patients so for these patients, complete data on their stay was missing. Comparisons of patients' actual length of stay were possible using published sources provided by ICNARC and the Audit Commission (Harrison *et al.*, 2004; Audit Commission, 1998) as the same methods of length of stay estimation were performed in all studies. The median (interquartile range (IQR)) length of stay was 1.7 (0.8-4.4 days) and 2 (1-5) days in ICNARC's CMP and in any critical care unit[42] respectively. The median length of stay in our study was 1.97 days for patients with complete data and 7.34 days for patient still receiving care in the critical care unit; the former of which is comparable with the CMP and the Audit Commission's findings.

6.10.3 Survival status at discharge from the Critical Care Unit

Mortality rates among patients admitted to the critical care unit are relatively high compared with other areas of medicine (Rubenfeld *et al.*, 1999). More than one of every five patients die on a critical care unit and as many as three out of every five die in some units, according to the Audit Commission (1998). Crude mortality observed at discharge from the critical care unit was 17%, lower than the 21.5% observed by the ICNARC's CMP database of 129,647 admissions to 128 adult general critical care units. The variation in mortality rates between critical care units is thought to be due to case-mix differences (Audit Commission, 1998), however studies using data from

42 Data on 'any critical care unit' were obtained from the Audit Commission Report (1998)

ICNARC's CMP show that some critical care units have higher death rates than expected, even when adjustments are made for case-mix.

6.11 Types of organs supported

6.11.1 Frequency statistics

Table 6.14 shows the number of days where organ support was given to patients. The most frequently given organ support was circulatory support, followed by advanced respiratory and basic respiratory support. By subtracting the days where no organ support was received by patients from the total of 67, 899 organ support days leaving 65,355 days, it was possible to determine the ratio of organ support days over the number of patient days (37,170), which at 1.76 is indicative of multiple organ support.

For this reason, it was felt important to consider the interactions between the organ systems.

Forty-eight combinations of the remaining types of organ support (including days of no organ support) were permissible within the data set. However, only 37 of the 48 combinations were observed during the study period.

Table 6.14: Frequency of days by type of organ support

Type of Organ Support	N (%)
No organ support	2 544 (3.7)
Basic respiratory support	11 125 (16.4)
Advanced respiratory support	19 872 (29.3)
Circulatory support	26 860 (39.6)
Neurological support	3 985 (5.9)
Renal support	3 136 (4.6)
Dermatological support	377 (0.6)
Total	67 899 (100)

Fourteen types and combinations of organ support (29%) reflected the care received by patients in 97.4% of the total number of patient days. Nineteen types and combinations of organ support (40%) increased this percentage by 1.8% to 99.2%. These are denoted in Table 6.15 by an asterix. Advanced respiratory and circulatory support represented the most frequently administered form of organ support with 31.5% of patient days. This was followed by basic respiratory and circulatory support (16.7%).

Table 6.15: Frequency Of Patient Days By Organ Support Type (And Combination)

Number of organ systems	Basic respiratory support	Advanced respiratory support	Circulatory support	Neurological support	Renal support	Dermatological support	N (% of total)
0							2 544 (6.8)
1	X						3 598 (9.7)
1		X					2 822 (7.6)
1			X				3 166 (8.5)
1				X			142 (0.4)
1					X		33 (0.1)
1						X	10 (0.0)
2	X		X				6 212 (16.7)
2	X			X			295 (0.8)
2	X				X		121 (0.3)
2	X					X	13 (0.0)
2		X	X				11 709 (31.5)
2		X		X			390 (1.0)
2		X			X		268 (0.7)
2		X				X	32 (0.1)
2			X	X			119 (0.3)
2			X		X		131 (0.4)
2			X			X	25 (0.1)
2				X	X		0 (0.0)
2				X		X	0 (0.0)
2					X	X	0 (0.0)
3	X		X	X			488 (1.3)
3	X		X		X		337 (0.9)
3	X		X			X	40 (0.1)
3	X			X	X		4 (0.0)
3	X				X	X	0 (0.0)
3	X			X		X	4 (0.0)
3			X	X	X		0 (0.0)
3			X		X	X	3 (0.0)
3			X	X		X	0 (0.0)
3		X	X		X		1 939 (5.2)
3		X	X			X	155 (0.4)
3		X			X	X	2 (0.0)
3		X	X	X			2 212 (6.0)
3		X		X		X	6 (0.0)
3		X		X	X		26 (0.1)
3				X	X	X	0 (0.0)
4	X		X	X	X		6 (0.0)
4	X		X	X		X	2 (0.0)
4	X		X		X	X	5 (0.0)
4	X			X	X	X	0 (0.0)
4		X	X		X	X	20 (0.1)
4		X	X	X	X		231 (0.6)
4		X	X	X		X	50 (0.1)
4		X		X	X	X	0 (0.0)
4			X	X	X	X	0 (0.0)
5	X		X	X	X	X	0 (0.0)
5		X	X	X	X	X	10 (0.0)
TOTAL							37 170 (100)

From the survey of 193 critical care units conducted by the Audit Commission (1998), 103 critical care units that collected information on organ failure reported an average of 12% of patients that had three or more organs supported. In our study, 18% of patients had three or more organs supported, which would suggest that our patients had a greater severity of illness however, it is not clear from the Audit Commission Report what types of organ systems were included in their estimates so it is difficult to make draw any conclusions from this comparison.

6.12 Relationship between the organs supported and the type of critical care unit

6.12.1 Number of organ support days by type of critical care unit

The number of organ support days[43] was stratified by the type of critical care unit (Table 6.16). Significant differences were observed between the different types of critical care units. The adult ICU / HDU / Neuro ICU incurred the highest number of organ support days and the adult burns / plastics unit incurred the least (though the sample upon which these findings were based was comparatively small).

There appeared to be a relationship between the total number of organ support days and the throughput of the critical care unit, which is a function of the size of the critical care unit. For this reason, studying the total number of organ support days in this way is of limited value in terms of understanding whether the type of critical care unit can determine organ support treatment patterns. As such, the number of organ support days was expressed as a ratio (calculated by dividing the monthly number of organ support days over the monthly number of patient days).

43 Expressed as the monthly sum of days of basic respiratory support, advanced respiratory support, circulatory support, renal, neurological and dermatological support

Table 6.16: Number of organ support days by type of Critical Care Unit

Unit Type	Months	Mean (SD)	Median (inter-quartile range)	Minimum – Maximum	Mean Rank
Adult General ICU	41	410 (207)	336 (265-538)	173-1 072	91.96
Adult General / Surgical HDU	8	243 (102)	235 (170-255)	138-471	41.31
Adult Combined ICU / HDU	83	362 (142)	340 (270-435)	36-682	88.21
Adult Cardio thoracic ICU	5	631 (108)	601 (535-742)	503-765	150.60
Adult Burns / Plastics	5	40 (24)	37 (19-63)	7-69	5.60
Adult Neuro / General ICU	6	516 (345)	313 (277-942)	269-997	99.33
Adult Neuro ICU / HDU	12	402 (151)	406 (272-557)	169-587	96.83
Adult ICU / HDU / CCU	6	119 (79)	118 (47-194)	35-201	14.50
Adult ICU / HDU / Neuro ICU	2	1159 (29)	1159 (1 138)	1 138-1 179	171.50
Unknown	4	591 (324)	561 (306-905)	295-945	121.63

Chi-square, df, sig (49.94, 9, p<0.0001)

6.12.2 Organ support ratio per patient day by type of Critical Care Unit

The mean organ support ratios give a meaningful indication of the intensity of organ support in a given type of critical care unit. As one would expect, the adult general / surgical HDUs incur the lowest organ support ratio compared to the other types of critical care unit. The Unknown unit types represent the two teaching hospitals in Leeds (St. James' Hospital and Leeds General Infirmary), in which one would expect to observe a relatively severe case-mix. The differences in the organ support ratios between the different types of critical care units were statistically significant (Table 6.17).

Table 6.17: Organ support ratio per patient day by type of Critical Care Unit

Unit Type	Months	Mean (SD)	Median (inter-quartile range)	Minimum – Maximum	Mean Rank
Adult General ICU	41	1.96 (0.23)	1.99 (1.75-2.08)	1.61-2.71	115.46
Adult General / Surgical HDU	8	1.05 (0.34)	1.19 (0.72-1.28)	0.55-1.50	16.88
Adult Combined ICU / HDU	83	1.68 (0.32)	1.67 (1.50-1.94)	0.73-2.35	75.51
Adult Cardio thoracic ICU	5	1.75 (0.16)	1.68 (1.62-1.91)	1.57-1.97	79.70
Adult Burns / Plastics	5	2.08 (0.91)	2.47 (1.25-2.70)	0.54-2.82	125.00
Adult Neuro / General ICU	6	1.65 (0.47)	1.64 (1.14-2.17)	1.11-2.21	76.83
Adult Neuro ICU / HDU	12	2.04 (0.43)	2.01 (1.68-2.33)	1.43-2.84	117.25
Adult ICU / HDU / CCU	6	1.12 (0.14)	1.12 (0.99-1.26)	0.92-1.30	14.83
Adult ICU / HDU / Neuro ICU	2	2.01 (2.60)	2.01 (1.98)	1.99-2.02	125.00
Unknown	4	2.05 (0.25)	2.04 (1.81-2.29)	1.75-2.35	127.75

Chi-square, df, sig (57.80, 9, p<0.0001)

6.13 Relationship between the organs supported and the size of the Critical Care Unit

6.13.1 Number of organ support days by size of Critical Care Unit

The number of organ support days[44] was then stratified by the number of staffed beds (denoted by size) within the critical care unit (Table 6.18). Significant differences were also observed between the different sizes of critical care units. The adult ICU / HDU / Neuro ICU to incur the highest number of organ support days and the adult burns / plastics unit to incur the least (though the sample upon which these findings were based is comparatively small).

Table 6.18: Number of organ support days by size of Critical Care Unit

Number of staffed beds	Months	Mean (SD)	Median (inter-quartile range)	Minimum – Maximum	Mean Rank
1-3 beds	6	41 (22)	40 (25-62)	7-69	5.67
4-6 beds	40	269 (78)	263 (205-313)	157-560	53.06
7-9 beds	52	358 (101)	338 (292-428)	75-575	89.24
10-12 beds	41	407 (189)	398 (260-572)	35-750	98.34
13-15 beds	14	705 (200)	646 (558-935)	452-1 072	153.14
16-18 beds	3	662 (140)	719 (503)	503-765	152.00
19-20 beds	2	1 159 (29)	1 159 (1 138)	1 138-1 179	171.50
Unknown	14	357 (248)	307 (240-429)	37-945	79.00

Chi-square, df, sig (72.74, 7, p<0.0001)

44 Expressed as the monthly sum of days of basic respiratory support, advanced respiratory support, circulatory support, renal, neurological and dermatological support

6.13.2 Organ support ratio per patient day by size of critical care unit

Study of the organ support ratio per patient day by size of the critical care unit suggested [in the most part] that the number of staffed beds does not have a significant bearing on the intensity of organ support received by patients. However, units with between 13-15 beds did appear to treat sicker patients than the smaller sized critical care units (table 6.19). Further study of the effects of size and intensity of organ support is required using a larger sample.

Table 6.19: Organ support ratio per patient day by size of Critical Care Unit

Number of Staffed Beds	Months	Mean (SD)	Median (inter-quartile range)	Minimum – Maximum	Mean Rank
1-3 beds	6	1.63 (0.77)	1.63 (1.03-2.18)	0.54-2.82	72.83
4-6 beds	40	1.77 (0.40)	1.75 (1.56-2.00)	1.02-2.84	86.03
7-9 beds	52	1.73 (0.37)	1.70 (1.60-1.98)	0.73-2.71	81.79
10-12 beds	41	1.59 (0.43)	1.65 (1.29-1.99)	0.55-2.10	70.82
13-15 beds	14	1.97 (0.21)	2.04 (1.82-2.14)	1.49-2.21	120.43
16-18 beds	3	1.70 (0.14)	1.67 (1.57)	1.57-1.85	70.83
19-20 beds	2	2.01 (2.60)	2.01 (1.99)	1.99-2.02	125.00
Unknown	14	2.04 (0.36)	2.04 (1.78-2.37)	1.41-2.59	121.07

Chi-square, df, sig (19.73, 7, p=0.006)

A discussion of this work takes place towards the end of the Chapter (Section 6.20). Section IV will now describe the collection and validation of the expenditure data.

CHAPTER 6: RESULTS

SECTION IV: COLLECTION AND VALIDATION OF EXPENDITURE DATA

6.14 Collection of expenditure data

6.14.1 Response rates

A lower than expected response rate for the return of the expenditure questionnaires was observed (table 6.20). The first column of table 6.20 describes the nature of each expenditure questionnaire with the second column displaying the response rate showing the percentage of these returned questionnaires of the total of 70 critical care units.

The highest response rate was observed with respect to gathering expenditure data on specialised bed therapy, directorate accountants and dieticians followed by nursing staff, drugs and fluids, disposable equipment and clinical pharmacists. It was much harder to extract data on radiology and laboratory services because of the tests being tracked by Consultant rather than by location (e.g. the critical care unit). Difficulties were also experienced with the provision of expenditure data on junior medical staff because of them working across the hospital as part of the on-call roster and therefore identifying the proportion of their time spent in the critical care unit was problematic.

Access of the budget statements permitted extraction of some of these resources, such as nursing staff, administrative staff, drugs and fluids, disposable equipment, blood and blood products and specialised bed therapy which are denoted by *.

The fourth column entitled 'cleaned data suitable for analysis' shows the percentage of returned questionnaires that could be used in the analysis. Some of the respondents provided expenditure data for the

hospital (as a whole) rather than that relating to the critical care unit (specifically). In this instance, their data were not included. Some critical care units returned the questionnaires stating that they were not able to complete them, which further explains the discrepancy between the response rate and the amount of data that was used in the analysis.

Table 6.20: Response rates to the expenditure survey

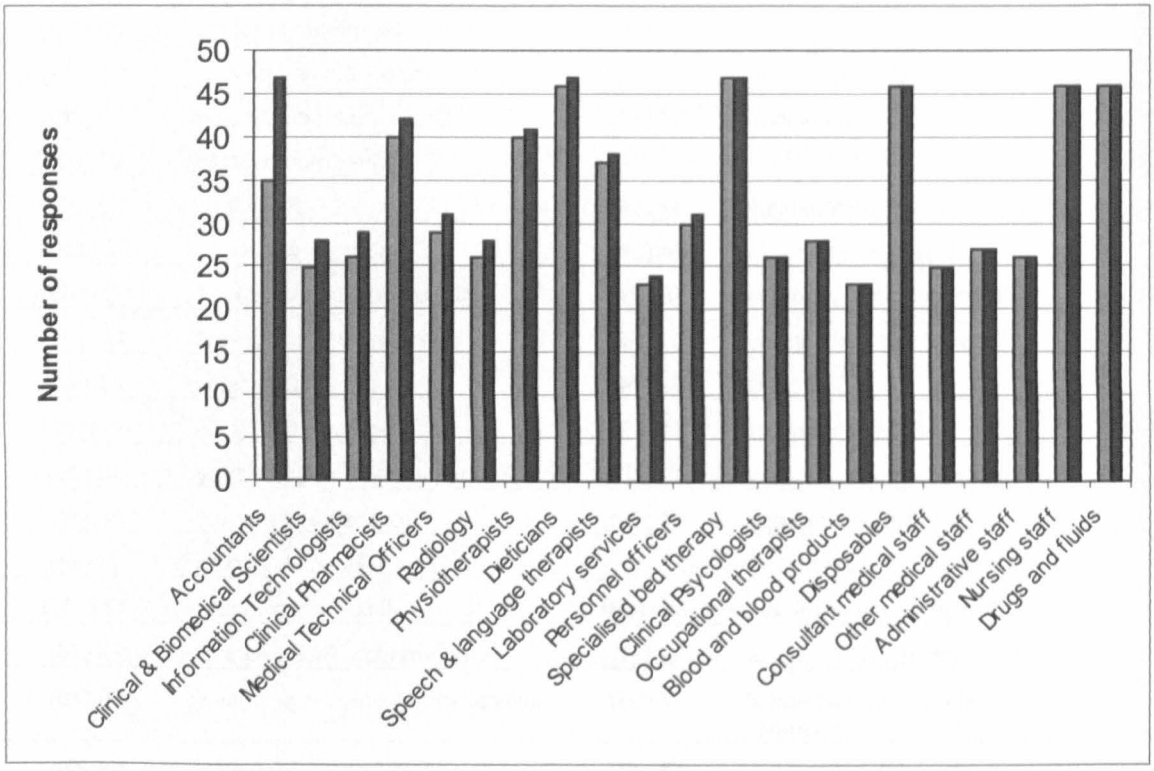
Expenditure questionnaires including budget statements	Critical care unit response rate (%)	Data extraction / resource items	Cleaned data suitable for analysis – number of critical care units (%)	Number of months for analysis
Budget statements	48 (69)	Nursing staff*	46 (96)	109
		Administrative staff*	26 (54)	63
Drugs and fluids	37 (53)	Drugs and fluids*	46 (124)	109
		Nutritional products	29 (78)	75
Disposable equipment	13 (19)	Disposable equipment*	46 (354)	109
Medical staff	33 (47)	Consultant medical staff	25 (76)	61
		Other medical staff	27 (82)	67
Radiology	31 (44)	Radiology	28 (90)	70
Laboratory services	24 (34)	Laboratory services	24 (100)	64
Blood and blood products	15 (21)	Blood and blood products*	23 (153)	59
Specialised bed therapy	39 (56)	Specialised bed therapy*	47 (121)	114
Dieticians	52 (74)	Dieticians	47 (90)	115
Physiotherapists	41 (59)	Physiotherapists	41 (100)	103
Speech and language therapy	49 (70)	Speech and language therapy	38 (78)	100
Occupational therapy	44 (63)	Occupational therapy	28 (64)	69
Medical Technical Officers	33 (47)	Medical Technical Officers	31 (94)	78
Clinical pharmacists	42 (60)	Clinical pharmacists	42 (100)	104
Information Technologists	38 (54)	Information Technologists	29 (76)	74
Clinical and biomedical scientists	37 (53)	Clinical and biomedical scientists	28 (76)	70
Clinical Psychologists	47 (67)	Clinical Psychologists	26 (55)	68
Directorate accountants	47 (67)	Directorate accountants	47 (100)	116
Personnel Officers	32 (46)	Personnel Officers	31 (97)	77

* Extractable data from the budget statements

6.14.2 *Adherence to the definitions for estimating expenditure*

Respondents were asked, when completing the expenditure questionnaires, to provide a description of the resources used and a brief explanation as to how the expenditure data had been estimated (for this resource use). This allowed a comparison of the costing methods used by the respondents against the stipulated definitions (as described in Chapter 5, table 5.3). Figure 6.7 illustrates the number of responses (shown in red) and against those, the number of responses in which the definitions had been adhered to (shown in blue).

Figure 6.7: Response rates to the expenditure survey (red) with the number of responses determined according to the prescribed definitions (blue)



The Directorate Accountants were the worst offenders with 26% of the responders using different methods of estimating the costs than those recommended in the questionnaires. As some of the data were extracted from the budget statements, no deviation from the definitions occurred. Table 6.21 gives more detailed results of this using the information returned by the respondents. The alternative methods used to estimate the critical care unit's expenditure were generic methods such as cost apportionment based on overhead absorption rates and use of reference costs, and resource-specific methods such as the use of Korner Work Units (KWUs), relevant to radiology services alone.

Table 6.21: Description of the resource use and compliance rates

Resource Items	Description of Service Provided	Compliance To definitions (%)	Alternative Methods Used
Nursing staff	- Information extracted from the budget statements so no descriptions given	46 / 46 (100)	- N / A
Administrative staff	- Information extracted from the budget statements so no descriptions given	26 / 26 (100)	- N / A
Drugs and fluids	- Information provided but no descriptions given	46 / 46 (100)	- N / A
Nutritional products	- Information provided but no descriptions given	29 / 29 (100)	- N / A
Disposable equipment	- Information provided but no descriptions given	46 / 46 (100)	- N / A
Consultant medical staff	- Information provided but no descriptions given	25 / 25 (100)	- N / A
Other medical staff	- Information provided but no descriptions given	27 / 27 (100)	- N / A
Radiology	- Costs associated with the performing of radiology examinations e.g. C.T. abdomen, Chest x-rays, C.T. abdomen with and without contrast - Performing of mobile chest x-rays, ultrasounds, cardiac catheterisation and reporting on examinations	26 / 28 (93)	- Salaried costs apportioned to the critical care unit using overheads absorption rate but test results determined according to the definitions provided - Cost of tests calculated using Korner Work Units (KWU) @ £18 per KWU, however salaried costs calculated according to the definitions provided

Resource Items	Description Of Service Provided	Compliance To Definitions (%)	Alternative Methods Used
Laboratory services	- Provision of full pathology support including bacteriology, virology, clinical biochemistry, immunology, haematology and cellular pathology - Provision of histological service to critical care mainly in the reporting of tissue biopsies of various sorts (including lymph node, liver, gall bladder, transplant biopsies etc).	23 / 24 (96)	- Costs based on total laboratory charges apportioned on a percentage basis to various wards served by the laboratory. The percentage basis is arrived at by analysis of total tests for each ward over one year.
Blood and blood products	- Information provided but no descriptions given	23 / 23 (100)	- N / A
Specialised bed therapy	- Rental contracts	47 / 47 (100)	- N / A
Dieticians	- Attendance at daily ward rounds and assessment of patients' nutritional needs that include calculating nutritional requirements, assessing feeding routes, prescribing enteral or parenteral nutrition and monitor feeding - Some audit work - Nutritional screening and assessment - Multi-disciplinary protocol / guidelines development and educational initiatives - Actively involved in teaching - Prescribing total parenteral nutrition (TPN) regimes for individual patients - Provision of advice and care plans for enteral and parenteral feeding	46 / 47 (98)	- Costs apportioned to the critical care unit using overheads absorption rate

Resource Items	Description Of Service Provided	Compliance To Definitions (%)	Alternative Methods Used
Physiotherapy	- Vibration, suction, circulation and mobility related tasks - Acute respiratory work and assessment of rehabilitation needs - Involved in weaning from mechanical ventilation, changing tracheostomies and use of non-invasive ventilation - Attendance at daily ward rounds, critical care unit meetings, case conferences and clinical improvement team meetings. - Involved in setting up equipment, making circuits, keep stock levels up - Teaching sessions - Assessment / management of musculo-skeletal system to maintain / prevent complications of long-term mobility - Early mobilisation including passive movements, posture management and positioning - Specialist assessment and treatment as indicated e.g. in multi-trauma patients	40 / 41 (98)	- Costs apportioned to the critical care unit using overheads absorption rate
Speech & language therapy	- Assessment and therapy of communication and swallowing disorders - Teaching and training sessions for nurses in use of swallowing screening tools - Assessment and management of communication impairment - Liaison with critical care nursing and medical staff and patients' families - Input into the development of tracheostomy guidelines	37 / 38 (97)	- Costs apportioned to the critical care unit using overheads absorption rate
Occupational therapy	- Ad-hoc service to referred critical care unit patients for splinting and provision of small aids e.g. reading stand or prism glass	28 / 28 (100)	

Resource Items	Description Of Service Provided	Compliance To Definitions (%)	Alternative Methods Used
Medical Technical Officers (MTOs)	- Assembly of new ventilators - Ventilator maintenance and reassembly between patients - Technical liaison between ventilator manufacturers, hospital engineering department and the critical care unit - Routine servicing, repair and clinical support to all electro-medical patient connected equipment - Comprehensive repair, maintenance and calibration of all medical devices - Assessment of new medical devices on trial for evaluation prior to purchase - Effective control and application of nitric oxide therapy - Training of medical and nursing staff to competency levels - Active involvement in the transfer of patients for scans - Appraisal, purchase and selection of new equipment - Commissioning and disposal of equipment	29 / 31 (94)	- Costs apportioned to the critical care unit using overheads absorption rate - Apportionment of Reference Costs
Clinical Pharmacists	- Ordering of stock and non-stock items - Clinical check of prescriptions and problem solving - Organisation and providing advice on intravenous nutrition - Ad-hoc input into policies and protocols - Drug kardex monitoring - Monitoring of expenditure on drugs - Advising medical staff on drugs and providing administration advice to nurses - Attending ward rounds with dieticians, doctors and nurses - Reviewing of patients' medication – appropriateness of drug selection, dosage and form. - Produce guidelines for high cost / high use / high risk medicines - Assessment of new drugs and impact on costs to the critical care unit - Production of drug administration guidelines for local use - Audit of drug-related issues	40 / 42 (95)	- Costs apportioned to the critical care unit using overheads absorption rate - Costs apportioned on the basis of pharmacy issues to each ward / location

Resource Items	Description Of Service Provided	Compliance To Definitions (%)	Alternative Methods Used
Information Technologists	- Data collection and entry for the ICNARC Case-Mix Programme Database - Management of the ICNARC database - Production of reports - Training of staff - Maintenance of computer systems - Maintenance of Medicus database	26 / 29 (90)	- Costs apportioned to the critical care unit using overheads absorption rate - Extraction of data from costing system used in Reference Cost return - Total hospital I.T. costs apportioned by the number of computers in each ward / location
Clinical & Biomedical Scientists	- Laboratory analyses of patient samples - Support services associated with pathology - Service of blood gas machine and point of care testing equipment - Maintenance and repair of medical equipment - Provision of echo services - Transcranial Doppler service - Research support - Deep Vein Thrombosis (DVT) assessment - Providing an external quality assurance scheme for the blood glucose meters	25 / 28 (89)	- Pro rata of actual expenditure by number of tests performed - Extraction of data from costing system used in Reference Cost return
Clinical Psychologists	- Provision of psychological service to patients (and relatives) on the critical care unit and at the follow-up clinic	26 / 26 (100)	- N / A

Resource Items	Description Of Service Provided	Compliance To Definitions (%)	Alternative Methods Used
Directorate accountants	- Financial management advice and monitoring - Provision of business advice and support and technical guidance - Assistance with the preparation of business cases and general costing of services and skill-mixes - Preparation of reports on financial position - Preparation of financial forecasts, variance analysis, budget setting, re-charging and checks relating to data integrity - Assistance with service re-design and costing of efficiency plans - Preparation of budget statements, billing costs to outside organisations and investigating variances - Processing of invoices - Raising of purchase orders to suppliers - Fixed assets and stock control - Attending critical care unit management meetings - Training staff in financial and budgetary awareness	35 / 47 (74)	- Costs based on the ICU budget as a percentage of the total divisional budget which is then applied to the monthly costs of the divisional finance function - Costs apportioned to the critical care unit using overheads absorption rate - Costs calculated based on size of budgets managed by the accountant. - HRG allocation of Finance Costs to the critical care unit
Personnel Officers	- Provision of a full range of employment support to the critical care unit team including attendance at interviews, issuing employment contracts, reviewing salary scales, dealing with staff disciplinaries	30 / 31 (97%)	- Costs apportioned to the critical care unit using overheads absorption rate

6.14.3 Distribution of data returned by each critical care unit

Table 6.22 shows for each participating critical care unit, the number of resource use questionnaires that (after cleaning) were suitable for analysis.

Table 6.22: Number of critical care units contributing resource use data for analysis

Hospital Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Aberdeen Royal Infirmary	✓		✓	✓	✓									✓					✓		✓	
Addenbrooke's Hospital				✓							✓		✓				✓				✓	✓
Antrim Area Hospital				✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bristol Royal Infirmary	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓			✓	✓				✓	✓
Broomfield Hospital	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Calderdale Royal Hospital								✓			✓	✓	✓								✓	
Chelsea Westminster Hospital																						
Colchester General Hospital	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Conquest Hospital																						
Cumberland Infirmary, Carlisle	✓		✓	✓	✓		✓	✓			✓	✓	✓	✓		✓	✓	✓			✓	✓
Derriford Hospital	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	
East Surrey Hospital	✓		✓		✓			✓					✓	✓	✓			✓			✓	
Eastbourne District General Hospital	✓	✓	✓	✓	✓	✓	✓				✓			✓			✓	✓	✓			
Freeman Hospital				✓		✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
Frimley Park Hospital	✓	✓	✓		✓						✓	✓	✓	✓						✓	✓	
George Eliot Hospital	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓			✓	✓	
Glenfield Hospital				✓							✓	✓	✓				✓				✓	✓
Good Hope Hospital	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓	✓		✓	✓
Grantham & District Hospital				✓		✓	✓		✓			✓		✓			✓				✓	
Hemel Hempstead General Hospital	✓		✓		✓			✓							✓						✓	
Hope Hospital	✓		✓	✓	✓					✓	✓	✓		✓			✓					
Huddersfield Royal Infirmary											✓	✓	✓									
Hurstwood Park Neurological Centre																						
John Radcliffe Hospital	✓	✓	✓		✓	✓	✓			✓	✓	✓	✓	✓		✓	✓		✓		✓	✓
Leeds General Infirmary	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Leighton Hospital	✓	✓	✓	✓	✓			✓			✓	✓				✓	✓		✓	✓	✓	✓
Lincoln County Hospital	✓	✓	✓	✓	✓						✓						✓				✓	✓
Luton & Dunstable Hospital	✓	✓	✓	✓	✓			✓		✓		✓	✓		✓	✓	✓	✓	✓		✓	✓
Monklands District General Hospital	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓					✓	✓
New Cross Hospital	✓	✓	✓	✓	✓	✓	✓					✓	✓			✓	✓					

Hospital Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
North Devon District Hospital																						
North Manchester General Hospital ICU																						
North Manchester HDU																						
Northwick Park Hospital																						
Pilgrim Hospital																						
Queen Elizabeth Hospital, Birmingham																						
Queen Elizabeth Hospital, Gateshead																						
Queen Elizabeth Hospital, Kings Lynn																						
Queen Elizabeth II Hospital																						
Queen Mary's Hospital, Sidcup																						
Queen Victoria Hospital																						
Radcliffe Infirmary																						
Royal Brompton Hospital																						
Royal Cornwall Hospital																						
Royal Devon & Exeter Hospital																						
Royal Hallamshire Hospital																						
Royal Liverpool University Hospital																						
Royal London Hospital																						
Royal Marsden Hospital																						
Royal National Orthopaedic Hospital																						
Sandwell General Hospital																						
Scunthorpe General Hospital																						
Southampton General Hospital																						
St. James' Hospital																						
St. Peter's Hospital																						
Taunton & Somerset Hospital																						
The Horton Hospital																						
Torbay Hospital																						
Trafford General Hospital																						
Tyrone County Hospital																						
Victoria Infirmary, Glasgow																						
Walsgrave Hospital C2 HDU																						
Walsgrave Hospital C2 ICU																						

Hospital Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Walsgrave Hospital C5 ITU	✓		✓		✓						✓	✓	✓		✓		✓				✓	
Walton Centre for Neurology & Neurosurgery	✓		✓		✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Warrington Hospital	✓	✓	✓		✓	✓	✓				✓	✓				✓						✓
Worcester Royal Infirmary	✓	✓	✓		✓					✓												
Worthing Hospital	✓	✓	✓		✓				✓		✓		✓	✓				✓			✓	
Wycombe General Hospital										✓	✓	✓	✓	✓	✓			✓		✓		
Yeovil District Hospital																						

Key

1 Nursing staff
2 Administrative staff
3 Drugs and fluids
4 Nutritional products
5 Disposable equipment
6 Consultant medical staff
7 Other medical staff
8 Radiology
9 Laboratory services
10 Blood and blood products
11 Specialised bed therapy
12 Dieticians
13 Physiotherapists
14 Speech and language therapy
15 Occupational therapy
16 Medical Technical Officers
17 Clinical pharmacists
18 Information Technologists
19 Clinical and biomedical scientists
20 Clinical Psychologists
21 Directorate accountants
22 Personnel Officers

There were very few critical care units that were able to provide a complete resource use data set; in fact, only Queen Elizabeth Hospital, King's Lynn had a complete data set. St. James' Hospital, Northwick Park Hospital, Leeds General Infirmary, Walton Centre for Neurology and Neurosurgery and Colchester General Hospital were able to provide the majority of data with the exception of two or three resource items. It was not possible to get resource use from any of the following hospitals; Chelsea Westminster Hospital, Hurstwood Park Neurological Centre, Royal Liverpool University Hospital and Yeovil District Hospital.

6.14.4 Problems relating to the completion of the expenditure questionnaires

Feedback received from the critical care units suggested that their inability to complete some of the expenditure questionnaires was due to a number of reasons. Firstly, some hospitals found it difficult to complete the questionnaires on the basis that they did not have any information (at all) on how much their critical care unit had spent on the various resources (i.e. no access to reliable and detailed budget statements). Second, some hospitals had a central 'pot' of funding with which they funded all services but without tracking the quantity of funding spent on each service. Thirdly, a small proportion of hospitals grouped together services such as including neonatal, paediatric and adult critical care (as a whole) that resulted in difficulties when attempting to disaggregate the costs specifically in relation to the adult critical care usage. Finally, a disregard for the specified deadline for the return of questionnaires resulted in a very small number of critical care units returning their questionnaires late. Unfortunately, these data were not included in the analysis.

There were many problems in obtaining some of the expenditure data, particularly for radiology and laboratory services because of difficulties in tracing the usage of these services to the critical care unit (as a location) and the feedback received from these departments was that

the definitions used were ambiguous. As such, these estimates need to be treated with caution. Many of the Professionals Allied to Medicine returned their questionnaires stating that there was no expenditure by the critical care unit, despite a level of service being provided and reported expenditures of zero. We found that there is still a belief that if a department is not charged for a service provided to it, that a cost is not incurred. It is likely therefore that expenditure on these professionals is higher than that reported in this survey. Exclusion of this professional group from the Cost Block Programme was estimated to result in an underestimate of cost of approximately £35 per patient per day.

One of the main causes of the problems with estimating the true cost of a critical care unit lies with the monthly budget statements. Where statements were available in the 46 of the critical care units, expenditure data was reported for nursing staff, drugs and fluids and disposable equipment in the most part. However, there was very limited coverage of the other key service providers, such as the blood bank, physiotherapy and so on, which hindered efforts to compile a comprehensive estimate of the costs without the need for the additional questionnaires. We felt it important to stratify the sample (and costs) by unit type in addition to providing a summary overview of the daily costs because this kind of information is not readily available in published form. No statement or inference of generalisability can be made from these estimates due to the small sample size but it is still useful to observe the variation across the different types of critical care units.

Collection of the data at each study site by the study team may have improved the quantity of data collected from the sample however it may still not have made a significant difference if the data was not available in the first instance. One limitation of this survey was the capture of data relating to capital equipment, which was instead incorporated into the daily costs as a percentage levy. Further work needs to be undertaken in critical care to determine the existence and

maintenance of computerised asset registers, which will facilitate the estimation of costs relating to equipment depreciation and maintenance in the future.

6.14.5 Steps taken to deal with the missing data

Rather than substitute missing data with average values obtained for data received from other similar critical care units, where units were unable to provide these data, instead of imputing zero values into the spreadsheet, they were coded as providing missing data (999).

6.14.6 Results obtained from the expenditure survey

Descriptive statistics for each of the resource items are shown in table 6.23.

Table 6.23: Descriptive statistics relating to the expenditure data

Resource items	Mean (SD) (£)	Median (inter-quartile range [min-max]) (£)	Skewness (std. error)	Kurtosis (std. error)
Nursing staff	128 647 (54 630)	119 179 (91 769-148 896 [41 398 – 304 967)	1.165 (0.231)	1.604 (0.459)
Consultant medical staff	18 174 (7 994)	16 585 (11 608 – 22 959 [4 991 – 38 209])	0.579 (0.306)	-0.187 (0.604)
Other medical staff	21 220 (14 906)	17 445 (7 574 – 33 927 [3 895 – 71 808])	1.204 (0.293)	2.067 (0.578)
Administrative staff	2 810 (2 300)	2 181 (1 116 – 3 457 [560 – 12 886])	2.206 (0.302)	6.099 (0.595)
Drugs and Fluids & Disposable Equipment	42 484 (22 831)	38 018 (28 580 – 55 127 [5 751-101 911])	0.776 (0.231)	0.189 (0.459)
Radiology	4 867 (5 169)	3 088 (1 327 – 5 613 [329-20 067])	1.590 (0.287)	1.604 (0.566)
Laboratory services	8 735 (6 664)	6 747 (4 214 – 11 482 [955 – 30 216])	1.402 (0.299)	2.058 (0.590)
Blood and blood products	7 032 (5 728)	5 370 (3 718 – 8 945 [553 – 22 344])	1.420 (0.311)	1.544 (0.613)
Nutritional products	2 021 (2 445)	1 024 (379 – 2 689 [0 – 12 594])	1.958 (0.277)	4.262 (0.548)
Specialised bed therapy	1 095 (1 544)	347 (0 – 2 154 [0 – 6 583])	1.774 (0.226)	3.058 (0.449)
Dieticians	732 (571)	552 (350 - 960 [0 – 2 500])	1.101 (0.226)	1.103 (0.447)
Physiotherapists	4 650 (4 073)	3 400 (2 400 – 5 671 [328 – 24 355])	2.717 (0.238)	9.628 (0.472)
Speech & language therapy	170 (304)	0 (0 - 222 [0 – 1 486])	2.518 (0.241)	6.790 (0.478)
Occupational therapy	116 (384)	0 (0 - 38 [0 – 2 555])	4.823 (0.289)	25.923 (0.570)
Medical technical officers	2 626 (3 439)	568 (0 – 5 729 [0-12 288])	1.166 (0.272)	0.356 (0.538)
Clinical pharmacists	882 (943)	520 (250 – 1 242 [0 – 3 913])	1.621 (0.237)	2.088 (0.469)
Information technologists	1 160 (1 869)	300 (0 – 1 516 [0 – 6 277])	1.880 (0.279)	2.310 (0.552)
Clinical & biomedical scientists	1 573 (3 010)	130 (0 – 1 604 [0 – 15 818])	3.305 (0.287)	13.054 (0.566)
Clinical Psychologists	67 (249)	0 (0 - 0 [0 – 1 125])	3.785 (0.291)	13.415 (0.574)

Resource items	Mean (SD) (£)	Median (inter-quartile range [min-max]) (£)	Skewness (std. error)	Kurtosis (std. error)
Directorate accountants	698 (1 188)	264 (141 - 607 [0 – 6 404])	3.205 (0.225)	11.037 (0.446)
Personnel officers	565 (915)	292 (0 - 721 [0- 4 587])	3.399 (0.274)	12.937 (0.541)

6.15 Validation of the expenditure data

6.15.1 *Internal validation*

The possibilities for testing the internal validity of the expenditure estimates were limited by the use of questionnaires designed for self-completion in the participating hospitals. The only feasible option available to the study (had more resources been available) would have been to compare the estimates returned by the questionnaires with expenditure data held within the hospitals' finance departments (despite methodological differences between the two different approaches to cost estimation). This would have best been performed through site visits. Direct measurement of the use of resources at the patients' bedside would unquestionably be the best method to validate the estimates produced. The problem with this approach relates to the significant deployment of resources that would have been required.

6.15.2 External validation

Critical Care National Cost Block Programme

External validation of the expenditure data was performed using daily cost data from the Critical Care National Cost Block Programme and NHS Reference Costs produced by the Department of Health for adult critical care.

Data from the Critical Care National Cost Block Programme (which reported descriptive statistics relating to some of the daily costs covered in this survey) were used for the purposes of external

validation (Dean *et al.* 2002) due to concerns about our sample size and the effect this may have had on the resultant cost estimates. Our survey used the same definitions for estimating costs as those used by the National Cost Block Programme for the resources that were captured by both studies, and therefore formed the most reliable and appropriate source with which to compare our findings. Twenty-one units in the sample (30%) contributed data to the National Cost Block Programme for the financial year 2000-2001 and was the best available evidence with which to perform such a validation at the time.

The average daily costs of care were determined by apportioning the monthly expenditure by the number of calendar days observed in each critical care unit from which mean estimates of costs could be estimated.

Table 6.24 compares the costs collected in this survey with those reported by the Critical Care National Cost Block Programme for the financial year 2000-2001 that had a sample of between 69 and 84 critical care units.

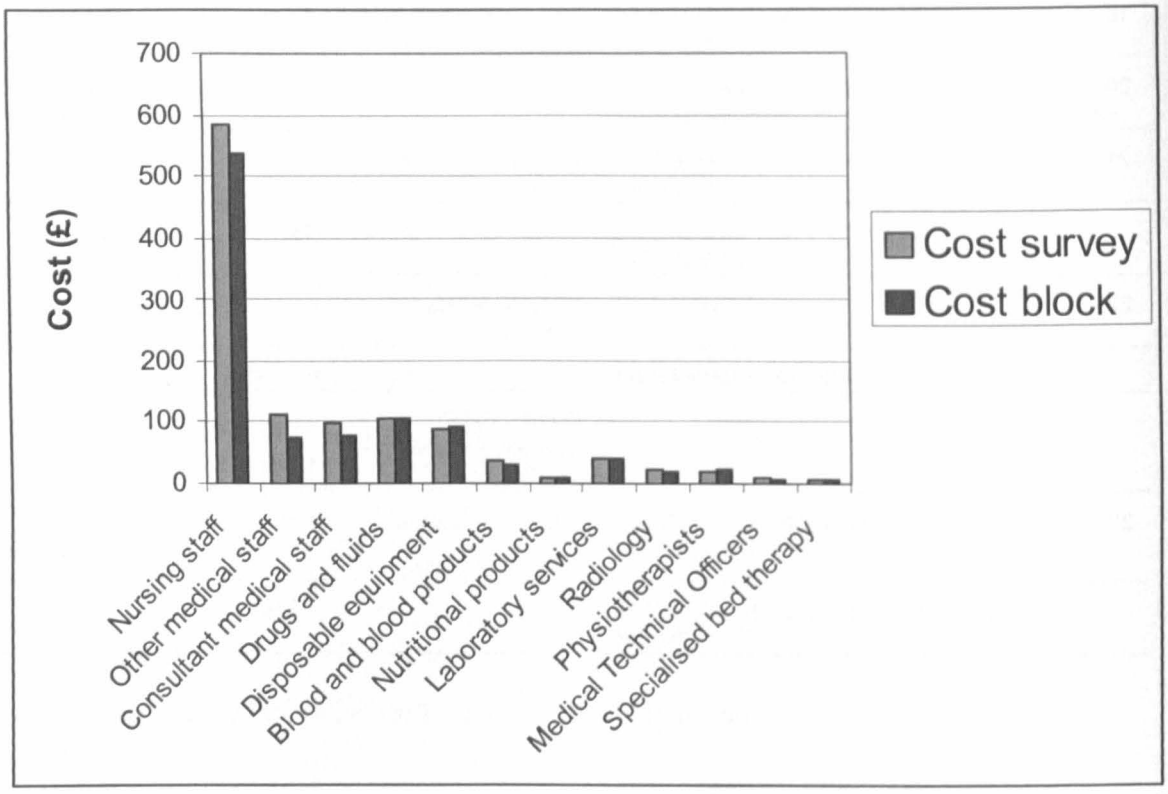
Table 6.24: Comparison of the mean daily cost estimates with the Critical Care National Cost Block Programme

	Resource Category	Resource	Mean cost (£)	Cost block comparisons (2000-2001) n=69-84 units
1	STAFF	Nursing staff	587	539
2	STAFF	Other Medical Staff	111	75
3	STAFF	Consultant Medical Staff	97	79
4	STAFF	Administrative support	12	6
	TOTAL COSTS OF STAFF		**807**	**699**
5	CONSUMABLES	Drugs and Fluids	105	103
6	CONSUMABLES	Disposable Equipment	89	90
7	CONSUMABLES	Blood and blood products	38	31
8	CONSUMABLES	Nutritional products	10	11
	TOTAL COST OF CONSUMABLES		**242**	**234**
9	CLINICAL SUPPORT SERVICES	Laboratory services	42	39
10	CLINICAL SUPPORT SERVICES	Radiology	24	20
	TOTAL COST OF CLINICAL SUPPORT SERVICES		**66**	**59**
11	PROFESSIONALS ALLIED TO MEDICINE	Physiotherapists	21	23
12	PROFESSIONALS ALLIED TO MEDICINE	Medical Technical Officers (MTOs) & Assistant MTOs	10	6
13	PROFESSIONALS ALLIED TO MEDICINE	Clinical and biomedical scientists	9	Not costed
14	PROFESSIONALS ALLIED TO MEDICINE	Information Technologists	6	Not separately identified
15	PROFESSIONALS ALLIED TO MEDICINE	Clinical Pharmacists	6	Not costed
16	PROFESSIONALS ALLIED TO MEDICINE	Dieticians	5	Not costed
17	OTHER	Directorate Accountants	3	Not costed
18	OTHER	Personnel Officers	3	Not costed

	Resource Category	Resource	Mean cost (£)	Cost block comparisons (2000-2001) n=69-84 units
19	PROFESSIONALS ALLIED TO MEDICINE	Speech & Language therapists	1	Not costed
20	PROFESSIONALS ALLIED TO MEDICINE	Psychologists	1	Not costed
21	PROFESSIONALS ALLIED TO MEDICINE	Occupational therapy	1	Not costed
	TOTAL COST OF PROFESSIONALS ALLIED TO MEDICINE		**69**	**29**
22	EQUIPMENT	Specialised bed therapy	6	6
	TOTAL COST OF EQUIPMENT		**6**	**6**
		TOTAL COST (rounded to the nearest £)	1,185	1,027
23	**TOTAL COST OF CAPITAL EQUIPMENT**	Capital Equipment (10% of the total)	119	Not costed or apportioned
	TOTAL COST INCLUDING CAPITAL EQUIPMENT		**1,304**	

Figure 6.8 provides an illustration of this validation exercise.

Figure 6.8: Bar chart comparing the daily cost estimates produced by the study (blue) with data from the Critical Care Cost Block Programme (red)



The Cost Block Programme reported an average daily cost of £1,028 for their sample, which was £274 lower than estimated in the survey (£1,302). The difference in nursing staff costs between the costs in our survey and those reported by the Cost Block Programme can be explained in part by salaried increments and possibly different grade-mix configurations. Our study assigned an hourly cost to the time spent by other medical staff on the critical care units which was derived from the corresponding salaries + 50% (Band 1A and 2B) to reflect the on-call payments. The cost bandings used were based on consultation with personnel officers charged with appointing other medical staff, but are higher than those applied in the Cost Block Programme. The mean daily costs of consumables were very similar to those provided by the Cost Block Programme with marginal differences in cost for the clinical support services. Validation of the cost estimates provided by

the majority of professionals allied to medicine was not possible due to their exclusion from the Cost Block Programme.

Whilst the time period of the study was limited to a two-three month period and the response rate from units varied considerably (due to difficulties in obtaining reliable information and the overlap between the financial years 2002-2003 and 2003-2004), costs were acquired for a wide range of resource inputs into the service, including those provided by professionals allied to medicine – for which data of this sort had not been previously available. External validation of the data using the Critical Care National Cost Block Programme (albeit from a different time period and sample) would suggest that for those estimates where comparisons could be made, they were, at the very least, representative of cost data collected by the Cost Block Programme.

NHS Reference Costs for Critical Care

The NHS Reference Cost document gives details on how the £33 billion of NHS expenditure was used in 2004. Its main purpose is to provide a basis for comparison within (and outside) the NHS between organisations, and down to the level of individual treatments. Whilst it seemed appropriate to attempt to compare the estimates of cost produced in our study with the Reference Costs for Critical Care, there were some difficulties in doing this.

It wasn't clear from the Department of Health's calculations, what exactly was included in the calculation of the Reference Costs. The descriptions given for the unit types were also not sufficiently explicit so as to make direct comparisons; for example, there was no unit type for combined ICU / HDUs. These costs had to be added to the costs of the ICUs and then averaged, in order to make a comparison with the NHS Reference Costs. However, what can be deduced from table 6.25 is that the ICU costs were comparable as were the costs for the Cardiac ICUs, however there were differences in the costs of the HDUs that can

be attributed to the amount of missing data from these types of unit in our study.

Table 6.25: NHS Reference Costs for Critical Care (Department of Health, 2004)

Unit Type	N	National Average Unit Costs (£)	Our study average unit costs (£)
Intensive Therapy Unit / Intensive Care Unit	160	1,328	1,253
Burns Intensive Care Unit	6	1,039	n/a
Neurosurgical Intensive Care Unit	12	1,017	731
Spinal Injuries Intensive Care Unit	2	779	n/a
Renal Intensive Care Unit	1	370	n/a
Cardiac Intensive Care Unit	19	1,025	1,054
Coronary Care Unit	119	457	n/a
High Dependency Unit	109	584	340

A discussion of this work takes place towards the end of this Chapter (Section 6.20). Section V will now describe some analysis of the expenditure data in relation to the type and size of the critical care unit.

CHAPTER 6: RESULTS

SECTION V: ANALYSIS OF THE EXPENDITURE DATA IN RELATION TO THE TYPE AND SIZE OF CRITICAL CARE UNIT

6.16 Introduction

In 2000, a Department of Health report on critical care called attention to the relatively small size of critical care units in the UK, where the average size is 6 beds. According to Jacobs *et al.*, (2004) in Europe, 18% of critical care units have fewer than 6 beds yet the corresponding figure in the UK is 48%. Groeger *et al.*, (1992) report the average size of a critical care unit in the United States to be between 11 and 12 beds. None of these reports however address the role that bed numbers might play in affecting the issue of costs due to economies of scale.

The systematic review by Aletras (1996) identified approximately 100 studies that provide evidence of the existence of economies of scale and scope in hospitals. In the advent of further hospital mergers in so creating much larger critical care units, interest in the effect on cost of achieving greater economies of scale is likely to increase (Baker *et al.*, 2004). For this reason, Section V set out to perform some preliminary analyses of the data collected to see whether any such evidence of the effect of economies of scale was present within the observed sample.

6.17 Study aims

The aims of Section IV were two-fold:

1. To describe the sub-sample of critical care units that were able to provide data on both their expenditure and unit characteristics (size and unit type); and

2. To test four null hypotheses relating to the statistical relationship of a critical care unit's expenditure and type and size of critical care unit.

There was a variable response rate from the expenditure survey where a high number of critical care units were unable to provide a complete data set relating to their monthly expenditure on patients' resource use to permit a full analysis of these data. It was thus decided to focus the analyses described in this Section on expenditure on nursing staff, drugs and fluids and disposable equipment, where these data and data on the type and size (of the critical care units) were available from 46 (66%) critical care units.

6.18 Description of the sub-sample of Critical Care Units

The sub-sample of critical care units was compared to the total sample in terms of their geographical location, the type of hospital they were situated in, and the type and size of critical care unit.

6.18.1 Geographical Location

As can be seen from table 6.26, the number of critical care units in Trent dropped from 5 to only 1. All of the critical care units in Scotland remained in the data set and the majority of units in the West Midlands were also unaffected by the reduced data set.

Table 6.26: Comparison of the geographical location of the sub-sample of critical care units with the total sample

Geographical Location	Number of critical care units in total sample	Number of critical care units in sub-sample (%)
Northern & Yorkshire	8	5 (63)
Trent	5	1 (20)
Eastern	7	6 (86)
London	6	4 (67)
South East	12	8 (67)
South West	10	6 (60)
West Midlands	9	8 (89)
North West	8	5 (63)
Wales	0	0 (0)
Scotland	3	3 (100)
Northern Ireland	2	0 (0)

6.18.2 Hospital Type

Almost half of the critical care units with a medical school located within the hospital was excluded from the data set. It is not known how this would affect the cost estimates produced (table 6.27).

Table 6.27: Comparison of the hospital type of the sub-sample of Critical Care Units with the total sample

Hospital Type	Number of critical care units in total sample	Number of critical care units in sub-sample (% of total)
Medical School within the hospital	17	9 (53)
Tertiary Referral Centre	25	16 (64)
Unknown	7	3 (43)

6.18.3 Type of Critical Care Unit

Comparisons by type of critical care unit showed that the majority of the specialist critical care unit remained within the data set, however the number of combined ICU / HDUs dropped from 38 to 22 (table 6.28).

Table 6.28: Comparison of the types of Critical Care Unit included in the sub-sample with the total sample

Type of Critical Care Unit	ICNARC (% of sample)	Number of critical care units in total sample	Number of critical care units in sub-sample (% of sample)
ICU	71 (42.0)	17	11 (65)
ICU / CCU	3 (1.8)	0	0 (0)
ICU / HDU	87 (51.5)	38	22 (58)
ICU / HDU / CCU	7 (4.1)	2	1 (50)
ICU / HDU / NICU	1 (0.6)	1	1 (100)
Other e.g. HDUs, cardiothoracic ICUs, specialist burns etc and unknown	N/A	12	11 (92)

6.18.4 Size Of Critical Care Unit

Critical care units with 13-15 beds dropped from 6 to 3, a 50% drop. However, the other unit sizes (4-6 beds up to 10-12 beds) were equally affected with between 68% and 77% of units kept within the reduced sample (table 6.29).

Table 6.29: Comparison of the size of Critical Care Unit included in the sub-sample with the total sample

Unit Size (Numbers of staffed beds)	ICNARC (% of sample)	Number of critical care units in total sample	Number of critical care units in sub-sample (% of sample)
1-3 beds	13 (7.6)	2	0 (0)
4-6 beds	93 (54.7)	19	13 (68)
7-9 beds	38 (22.4)	21	16 (76)
10-12 beds	19 (11.2)	13	10 (77)
13-15 beds	5 (2.9)	6	3 (50)
16-18 beds	1 (0.6)	1	1 (100)
19-20 beds	0 (0.0)	1	1 (100)
> 20 beds	1 (0.6)	0	0 (0)
Unknown	0	7	2 (29)

6.19 Statement of hypotheses to be tested

The second aim of Section IV was to test four null hypotheses:

1. A relationship does not exist between a critical care unit's monthly expenditure on nursing staff, drugs and fluids (hereafter referred to as 'expenditure') and the type of critical care unit ($p>0.05$);
2. A relationship does not exist between a critical care unit's average daily expenditure and the type of critical care unit ($p>0.05$);
3. A relationship does not exist between a critical care unit's monthly expenditure and the size of critical care unit ($p>0.05$); and
4. A relationship does not exist between a critical care unit's average daily expenditure and the size of critical care unit ($p>0.05$).

6.20 Results

6.20.1 Hypothesis 1

The first hypothesis set out to negate whether a relationship existed between the type of critical care unit and its monthly expenditure. The number of months contributed by each type of critical care unit is shown in table 6.30.

The sample was dominated by the adult combined ICU / HDUs and the adult general ICUs. Most of the adult general / surgical HDUs were included in the study (88%). No observations were obtained for the adult burns / plastics critical care units.

The mean rank statistics were generated by an ANOVA test that was performed to investigate whether any of the observed differences in expenditure between the different types of critical care unit were statistically significant. The results would suggest that there is a significant difference in expenditure by type of critical care unit ($p<0.0001$).

Table 6.30: Monthly expenditure by type of Critical Care Unit

Unit Type	Months (% of total sample)	Mean (SD) (£)	Median (inter-quartile range) (£)	Minimum – Maximum (£)	Mean Rank
Adult General ICU	26 (63)	166 277 (64 396)	155 006	71 664 – 356 262	52.58
Adult General / Surgical HDU	7 (88)	60 098 (14 346)	54 002	48 977 – 86 353	4.71
Adult Combined ICU / HDU	55 (66)	167 940 (45 444)	166 706	92 550 – 261 748	57.27
Adult Cardio thoracic ICU	3 (60)	380 473 (21 361)	381 028	358 842 – 401 553	108.00
Adult Burns / Plastics	0 (0)				
Adult Neuro / General ICU	5 (83)	170 268 (77 734)	144 979	112 326 – 301 724	50.00
Adult Neuro ICU / HDU	5 (42)	185 714 (33 718)	203 614	145 974 – 220 897	7.50
Adult ICU / HDU / CCU	2 (33)	71 626 (5 293)	71 626	67 883 – 75 368	69.80
Adult ICU / HDU / Neuro ICU	2 (100)	343 422 (11 491)	343 422	335 296 – 351 547	104.00
Unknown	4 (100)	230 324 (92 669)	228 559	148 712 – 315 467	74.75

Chi-square, df, sig (38.69, 8, p<0.0001)

6.20.2 Hypothesis 2

The second hypothesis related to the average daily expenditure by type of critical care and the results of this analysis are shown in table 6.31. The results of this analysis were slightly easier to interpret than those shown in table 6.30, as the monthly expenditure had been apportioned by the number of patient days. The results followed a logical pattern, in that the adult general ICUs were shown to incur higher daily costs than the adult general / surgical HDUs (the difference in cost being due to the lower nurse to patient ratio in the High Dependency Units and patients with a lesser severity of illness). Significant differences in average daily costs, as with the monthly expenditures, were observed by unit type ($p<0.0001$).

Table 6.31: Average daily expenditure by type of Critical Care Unit

Unit type	Months (% of total sample)	Mean (SD) (£)	Median (inter-quartile range) (£)	Minimum – Maximum (£)	Mean Rank
Adult General ICU	26 (63)	1 049 (338)	1 063 (710-1 359)	538 – 1 878	79.58
Adult General / Surgical HDU	7 (88)	284 (103)	241 (205 – 403)	199 - 457	4.43
Adult Combined ICU / HDU	55 (66)	751 (205)	708 (621 – 828)	477 – 1 503	52.85
Adult Cardio thoracic ICU	3 (60)	1 030 (387)	836 (780)	780 – 1 476	82.33
Adult Burns / Plastics	0 (0)				
Adult Neuro / General ICU	5 (83)	637 (62)	654 (578 – 686)	545 - 712	37.00
Adult Neuro ICU / HDU	5 (42)	640 (154)	642 (401)	493 - 853	38.60
Adult ICU / HDU / CCU	2 (33)	406 (7)	406 (493 – 785)	401 - 411	7.00
Adult ICU / HDU / Neuro ICU	2 (100)	595 (3)	595 (593)	593 - 597	22.50
Unknown	4 (100)	844 (53)	847 (792 - 893)	785 - 897	76.00

Chi-square, df, sig (47.59, 8, p <0.0001)

6.20.3 Hypothesis 3

The third hypothesis focused on the relationship between the size of the critical care unit (i.e. number of staffed beds) and its monthly expenditure. As shown in table 6.32, there was a trend towards a higher level of expenditure as the size of the critical care unit increased, with the exception of units sized between 19-20 beds, but this was most likely due to the very small number of observations. The results from the ANOVA test confirmed that a relationship does appear to exist between the size of a critical care unit and its monthly expenditure ($p<0.0001$).

To visualise this relationship, data on the monthly expenditure and the number of staffed beds (size) were plotted. Data provided in the 'unknown' category were excluded (Figure 6.9).

Figure 6.9: Line graph showing the monthly expenditure by the number of staffed beds

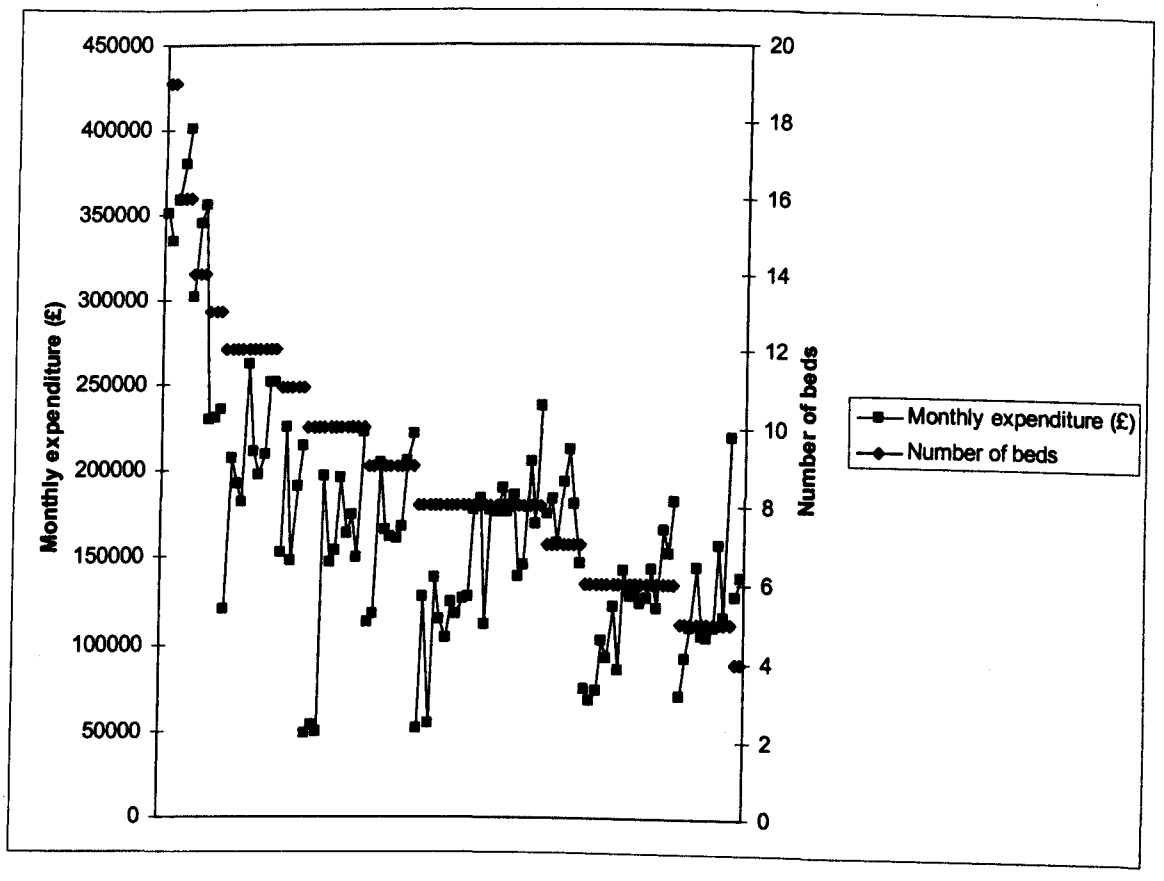


Table 6.32: Monthly expenditure by size of Critical Care Unit

Number of staffed beds	Months (% of total sample)	Mean (SD) (£)	Median (inter-quartile range) (£)	Minimum – Maximum (£)	Mean Rank
1-3 beds	0 (0)				
4-6 beds	29 (73)	121 838 (34 462)	122 076 (97 340 – 142 839)	67 883 – 219 434	29.79
7-9 beds	39 (75)	156 727 (41 542)	164 661 (126 308 – 183 772)	52 167 – 236 846	52.31
10-12 beds	26 (63)	175 382 (57 624)	191 279 (148 595 – 211 338)	48 977 – 261 748	64.15
13-15 beds	6 (43)	283 023 (59 203)	268 686 (229 878 – 347 978)	229 177 – 356 262	98.67
16-18 beds	3 (100)	380 474 (21 361)	381 028 (358 842)	358 842 - 401 553	108.00
19-20 beds	2 (100)	343 421 (11 491)	343 422 (335 296)	335 296 – 351 547	104.00
Unknown	4 (29)	230 324 (92 669)	228 559 (149 433 – 312 981)	148 712 – 315 467	74.75

Chi-square, df, sig (47.16, 6, p<0.0001)

6.20.4 Hypothesis 4

The fourth hypothesis tested the assumption that a relationship does not exist between a critical care unit's average daily expenditure and the size of critical care unit ($p>0.05$). The p value of 0.294 would suggest that in this case, there does not appear to be a definitive trend or statistical relationship between these two variables. The variable sample size by staffed bed category could have been a contributing factor, with a very small number of observations in the 16-18 beds category (table 6.33).

Data on the average daily expenditure and the number of staffed beds were plotted using the same sample of 44 critical care units (105 months) (Figure 6.10).

Figure 6.10: Line graph showing the average daily expenditure by the number of staffed beds

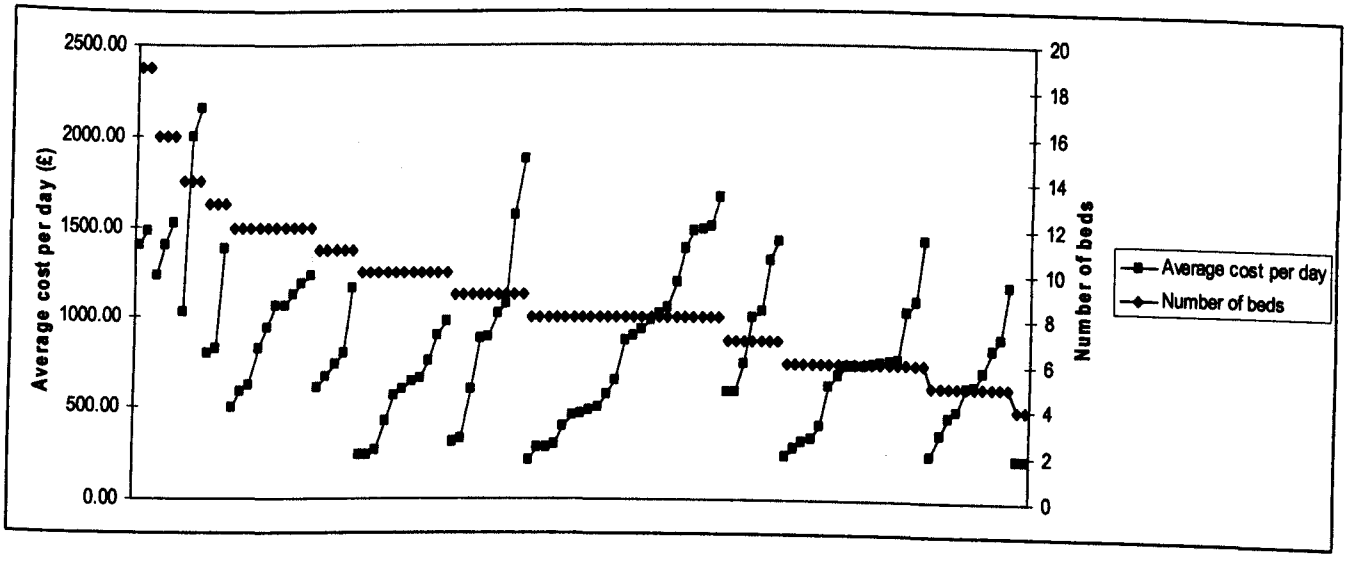


Table 6.33: Average daily expenditure by size of Critical Care Unit

Number of staffed beds	Months (% of total sample)	Mean (SD) (£)	Median (inter-quartile range) (£)	Minimum – Maximum (£)	Mean Rank
1-3 beds	0 (0)				
4-6 beds	29 (73)	821.22 (332)	712 (615 – 1 119)	401- 1 478	56.90
7-9 beds	39 (75)	773 (301)	724 (612 – 855)	241 – 1 878	54.21
10-12 beds	26 (63)	717 (293)	649 (559 – 900)	199 – 1 345	49.08
13-15 beds	6 (43)	862 (332)	676 (636 – 1 224)	621 – 1 392	59.83
16-18 beds	3 (100)	1 031 (387)	836 (780)	780 – 1 476	82.33
19-20 beds	2 (100)	595 (3)	595 (593)	593 - 597	22.50
Unknown	4 (29)	844 (53)	847 (792 – 893)	785 - 897	76.00

Chi-square, df, sig (7.31, 6, p=0.294)

6.21 Discussion

Chapter 6 set out to describe the data collected in the multi-centre study and the efforts made to validate these data. The response rate was sufficiently high so as to generate a reasonably large sample of patient data and exceeded that expected, given the absence of any financial incentive to participate in the study. However, of the 400 listed critical care units, only 17.5% was captured by the volunteer sample. Not having any critical care units from Wales was a disappointment. One of the unresolved issues with the study was a source of variability relating to the differences between those critical care units who participated in the study and those who do not. According to Sculpher *et al.*, (2004), this is a special form of variability by location and implies that data collected in those centres may not be a realistic prediction of what might emerge should the same data have been collected in the non-participating centres.

The data collection booklets proved a useful and reliable means of collecting the patient-level data and a very high percentage of critical care units used the booklets to record the data. Different members of staff were involved in data collection that may have resulted in some variation in terms of the accuracy and reliability of the data. This was not investigated in the study, which is a potential weakness of the research. Had sufficient funds been available subject to it being feasible, it would have been a good idea to organize a training course for all of the data collectors to take them through the data collection booklets and the organ support definitions. The posters attempted to address obvious issues and problems that might arise during the study period.

The use of the booklets generated a considerable amount of data entry, which was a burdensome and costly task to undertake. Electronic means of data capture in the adult critical care setting have been used in other studies with varying degrees of success, so although this option

would appeal under normal circumstances, in practice, it is unlikely to have proved as acceptable to the data collectors as the booklets. If the study were to be repeated, it would have been better to explore the possibility of designing the booklets in such a way that the data could have been scanned into a computer rather than to rely so much on manual data entry. Double-checking of the electronic records with the data collection booklets were randomly performed in 25% of cases, which was considered an acceptable threshold (albeit an arbitrary threshold) for identifying errors of transmission. Due to the very small number of errors identified, these were not formally recorded and evaluated which is another weakness of the research. In order to compensate for this, exhaustive electronic checks of the data were undertaken so as to minimise inconsistencies and duplications within the data set that had stemmed primarily from the critical care units.

The high response rate to the issued queries (93%) meant that one could be reasonably confident that the data were of an acceptable quality, as far as accuracies relating to the date and time of admission and discharge, survival status and type of admission were concerned. It was not possible to determine the accuracy and completeness of the organ support data, without having audited a random sample of patient records. This type of audit was considered, however, data was not routinely recorded on patients' daily organ support profiles in their medical records or in databases held by the critical care units, which meant that there was nothing against which the data contained in the booklets could be compared or validated. In the absence of any possible means of validation, one had to assume that the organ support data were correct, accurate and complete. The internal consistency checks relating to basic and advanced respiratory support were the best that one could hope to achieve as far as checking the organ support data.

The study performed very well when compared to the DoCDat databases. It produced the same median values as these databases as far as its reliability of coding and independence of observations and

exceeded the median values in the following areas (completeness of variables, having explicit definitions and explicit rules). The only areas that were identified as scoring worse were the representativeness of country, completeness of recruitment and variables included in the study. In the absence of other criteria, the DoCDat criteria served as an effective means of describing key aspects of the study from a quality perspective, however there were aspects of the criteria that did not strictly apply such as the collection of raw data and the variables included category.

The patients included in the study were similar in terms of their critical care unit length of stay to those captured within the ICNARC CMP database and published sources. Crude mortality was slightly lower than that reported by ICNARC. Differences in case-mix were mooted as a possible explanation for this. However, differences in admission policies (to the critical care unit) could also have been an explanatory factor.

Although the number of organ support days varied by type of critical care unit, this analysis was not particularly useful or informative. What proved to be of greater interest was the relationship between the organ support ratios per patient day by type of critical care unit that yielded findings that one would expect to see, in as much that high dependency units had a lower organ support ratio per patient day than the intensive care units. These findings were statistically significant.

The number of organ support days increased according to the size of the critical care units, which is a finding that one would expect to see. As far as whether larger-sized units would treat sicker patients (expressed as the organ support ratio per patient day), the findings were inconclusive. This is where a larger sample of critical care units in the size categories 1-3 beds and >13 beds would have been useful.

A lower than expected response rate for the return of the expenditure questionnaires proved not to affect the generalisability of the estimates obtained following the external validation performed using data from

the Critical Care National Cost Block Programme and the Department of Health's NHS Reference Costs. The steps taken to deal with the missing data could have been further explored. It was decided to code these as 'missing' rather than substitute the gaps with mean estimates from the sample. Given that the aim of the study is to generate data with which to develop a cost model using the most complete and reliable data available, it was appropriate not to substitute the missing values in this way for fear of introducing additional confounders in the models. In doing so however, the analyses performed in Section IV were only able to use expenditure data on nursing staff, drugs and fluids and disposable equipment rather than data on the overall costs of the adult critical care unit (which would have included more resource items that these three).

The reduction in the sample of critical care units able to provide both patient and expenditure data provoked some concern as to how representative the sub-sample was of the overall sample of units. The number of remaining critical care units in the Trent Region went from 5 to 1, almost half of the critical care units with a medical school were excluded but the majority of specialist critical care units remained within the sample. Unfortunately, the larger sized units were most affected. Critical care units with 13-15 beds dropped from 6 to 3. It is difficult to ascertain how losing some of the critical care units from the sample may have affected the results of the analyses performed.

Section IV set out to test 4 hypotheses. These findings were of interest in as much that the expenditure of a critical care unit and its average cost per day was found to vary significantly according to the type of critical care unit. Similar findings were observed as far as the size of the critical care unit and its expenditure. Although the latter analysis of size is an obvious finding, the relationship between unit type and expenditure has not been previously investigated or reported.

The analyses performed in Section V did not generate substantive evidence of excessive scale economies in the sample studied, however

a reduction in per diem costs was evident in the first three bed size categories with an increase in cost observed in units operating at a capacity of greater than 13 beds. Bertolini *et al.*, (2003) found from a study of 80 Italian critical care units that labour costs per patient decrease almost linearly as the number of beds increases up to about 8, and it remains nearly constant above about 12 beds. The conclusion from this work was that ICUs with less than 12 beds were not cost-effective. This is certainly an area where further research is warranted using data from a larger sample of critical care units.

In conclusion, the results of this study generated a valuable, high quality dataset that has been fully described in this Chapter. Chapters 7 and 8 will endeavour to use the data set to inform the development of HRGs and the economic evaluation of the CESAR trial.

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'An intelligent being cannot treat every object it sees as a unique entity unlike anything else in the universe. It has to put objects in categories so that it may apply its hard-won knowledge about similar objects encountered in the past, to the object at hand'

Steven Pinker (1997)

CHAPTER 7: DEVELOPMENT OF PROPOSED HEALTH CARE RESOURCE GROUPS FOR ADULT CRITICAL CARE PATIENTS

7.1 Introduction

The previous chapter described a sub-sample of 46 critical care units that generated high quality data on both unit expenditure and patients' daily organ support. This chapter set out to use these data to develop a set of proposed Healthcare Resource Groups (HRGs) to support the Department of Health's policy '*Reforming NHS Financial Flows: Introducing Payment By Results*' (2002).

A background to the development of the American Diagnosis-Related Groups (DRGs) is provided in Section 7.2 and some of the concerns surrounding the use of DRGs for adult critical care patients are introduced. Healthcare Resource Groups, the British equivalent to the DRGs, are then described. HRGs are '*groups of patient episodes or treatments for the purpose of supporting both internal management and external contracting*' (Morris, 1995). They use the ICD-10 (International Classification of Diseases diagnostic codes version 10) and OPCS-4 (Office of Population Censuses and Surveys Tabular list of Classification of Surgical Operations and Procedures Fourth Revision) procedure codes as the basis of grouping, together with information on age and discharge status.

Section 7.3 then describes the context within which HRGs are needed and sets out the aims of the '*Payment By Results*' policy.

Section 7.4 describes the findings from the survey conducted by Morris (1995) who was charged with eliciting the opinions of a sample of clinicians on possible options for HRG development in adult critical care. Note that this was the same survey described in Chapter 4. The criteria set by the NHS Information Authority (NHSIA) (2002) against which the HRGs should be developed are detailed, where activities within groups should be similar both clinically and in terms of the resources used, groups should be based on routinely available data and the number of groups should be manageable. This, coupled with the original DRG criteria proposed by Hornbrook (1982) established the prerequisites for the HRGs.

All of the factors identified as possible 'groupers' from the Morris Survey were then critiqued in turn (Section 7.4.1).

The aims of this Chapter were thus to identify an appropriate model from which estimates of daily case-mix adjusted costs of care could be determined and to use this model to develop a set of HRGs that met the aforementioned criteria.

Section 7.5 describes the statistical methods used to derive the daily case-mix adjusted cost estimates. Random-effects models were deemed appropriate on the basis of Breusch-Pagan and Hausman specification tests of the data set.

Nine models in total were developed. The first model described in Section 7.6.1, was a maximum-likelihood random-effects model that excluded the constant term and used the critical care unit's monthly expenditure on nursing staff, drugs and fluids and disposable equipment as the model's dependent variable and the number of days of basic respiratory support, advanced respiratory support and so on, as the independent variables. In this model, the interactions between the six different organ systems were not explored in this model. The coefficients produced by the model were then used to estimate the total costs of 7,243 patients in the dataset and a cluster analysis was performed using the total number of organs supported as the grouping

variable and patients' length of stay and total costs of care as the clustering variables. Twenty HRGs resulted from the cluster analysis. The limitations of the random-effects model were discussed together with the problems associated with having clusters based on length of stay (i.e. introducing the risk of perverse incentives).

Additional models were then explored in Section 7.8, based on the types and combinations of organ support (Section 7.8.1) and the total number of organs supported (on a daily basis) (Section 7.8.5). The results of the different models are presented and discussed. The model deemed to be the most suitable for estimating case-mix adjusted daily costs was the last model (Model 9) that offered a simpler way of costing patients than the previous models. Rather than performing a cluster analysis using total patient costs estimated using the coefficients from Model 9, it was decided that the estimates / weights themselves were of greater interest and use than having a defined set of HRGs.

The model is then evaluated in two ways; firstly, by its ability to predict the expenditure observed in the 46 critical care units using the case-mix adjusted costs and secondly, by assessing through a pilot study, its acceptability to users judged in a number of ways relating to the criteria proposed by Hornbrook (1982) and the NHSIA (2002). Chapter 7 concludes with a discussion of these findings.

7.2 Background

Case-mix classification systems provide a means of defining the product of a hospital. The need for case-mix adjustment stems from the fact that each individual patient differs from others in terms of the services delivered (to that patient) and consequently the resources consumed. Maniadakis *et al.*, (1999) explain that '*every individual case constitutes an intermediate output on its own and as such it is important to aggregate cases into groups in a manner that reflects differences in resource requirements such as cluster analysis against*

which weights are attached. Thus, one needs a method of grouping cases into similar groups and a method of estimating the weights'.

The concept of Diagnosis-Related Groups (DRGs) originated from a patient classification system developed at Yale University in the 1960s. The original aim of this system had been to identify unusual patients with exceptionally long lengths of stay (Fetter, 1986). As the expenditure on acute hospital care dramatically increased in the United States (U.S.) – from $13.9 billion in 1965 to $99.6 billion in 1980 (Gibson & Waldo, 1981), the use of DRGs then changed from a way of describing patients and their characteristics, to a means of fee-setting, introduced by the federal and state governments in an attempt to curtail these spiralling costs and standardize hospital reimbursement. In this way, a fee for service payment was provided for each hospital inpatient, based on the primary surgical or medical condition for which the patient was treated (Freyaldenhoven & Campbell, 1996). Case-mix adjusted output-based funding also provides specific benchmarks for hospital inpatient services, against which managers and clinicians can compare their practice (Jackson, 1995).

Whilst case-mix groupings can be formed in a variety of different ways (Plomann & Shaffer, 1983 & Thompson *et al.*, 1975), DRGs have revolved around patient attributes and treatment processes, developed using AUTOGRP (AUTOmatic GrouPing System) – a type of cluster analysis software. A patient's primary and secondary diagnoses and surgical procedures play a key part in assigning patients to a given DRG. Length of stay tends to be used as the proxy for resource consumption rather than costs or charges (Grimaldi & Micheletti, 1983).

Healthcare Resource Groups (HRGs) are the British equivalent to the American DRG system and were developed in the early 1990s by the NHS Information Authority (NHSIA) in conjunction with the Royal Colleges (Appleby & Thomas, 2000). HRGs have been described in broad terms as '*groups of patient episodes or treatments for the*

purpose of supporting both internal management and external contracting' (Morris, 1995). A more specific definition is however provided by Sanderson (1991) who describes the groupings as '*similar to DRGs (and in a number of cases are actually the same as DRGs) in that they are based upon readily available items of information (diagnosis, procedures, age, discharge status and specialty). They number just over 500 and are intended to be resource homogeneous in terms of length of stay. The key difference is that for surgical DRGs the grouping is largely driven by the procedure rather than the primary diagnosis.*'

Both the DRG and HRG systems use coded operative procedures or discharge diagnoses as primary descriptors of the resultant groups. Age and hospital complications form secondary descriptors although English HRGs have greater flexibility in some areas and need not be entirely linked to disease. Existing HRGs for other areas of medicine, which are linked primarily to diagnosis, occur only where the mean discharge data does not provide adequate medical procedure information.

Although the DRG classification is becoming progressively more effective, it fails to measure many types of variations in patients' needs for care which is an important consideration for adult critical care patients (Beaver *et al.*, 1998). HRGs have been developed for many different types of diagnoses with the exception of adult critical care. With the advent of the '*Payment by Results*' policy (2002), a way of classifying critical care patients was urgently needed.

7.3 Prospective vs. retrospective reimbursement systems

Traditional DRG-based payment methodology employs prospective reimbursement systems that result in a mix of profitable and non-profitable cases with the total payment of all patients within a DRG expected to "average out" so that payment for a pool of discharges is at

or near the cost of providing care (Cooper & Linde-Zwirble, 2004). Whilst these systems are thought to provide incentives for efficiency and avoid adverse patient selection, they can generate problems due to creaming, skimping and dumping (Biorn *et al.*, 2003). Neonatal, paediatric and adult intensive care, trauma and burns patients (Pasternak *et al.*, 1986; Bekes *et al.*, 1988; Sharkley *et al.*, 1991; Froehlich & Jarvis, 1991; Joy & Yurt, 1990) treat small numbers of very high cost patients that can however skew the distribution of expenditure and result in a financial shortfall. There are a number of studies in neonatal intensive care that have demonstrated the inadequacies of prospective pricing systems using DRG systems (Berki & Schneier, 1987; Lictig *et al.*, 1989; Phibbs *et al.*, 1986; Poland *et al.*, 1985; Resnick *et al.*, 1986) and this is thought to be due to systems not taking into account much of the variability in cost (Khoshnood *et al.*, 1996). Issues relating to outlier patients receiving care in large teaching hospitals (Berki & Schneier, 1987), variation in case-mix severity (Phibbs *et al.*, 1986) and underestimates in the number of days required for treatment (Poland *et al.*, 1985) have been identified as problematic. The general consensus does appear to reflect the views of Sics & Congdon (1988) in so stating that '*funding for neonatal care should be based on demonstrated costs*' (p.306). Prospective reimbursement systems are clearly better suited to a more homogeneous case-mix that fit better to an average cost per patient cost model (with minimal cost variation). Jackson (1995) explains how systems like these can encourage the systematic referral of more complex cases to tertiary referral hospitals, thus shifting the burden of resource use elsewhere.

To reduce the financial risk to hospitals in providing intensive care under a case-mix adjusted reimbursement system, it was decided in this study to develop a retrospective as opposed to prospective method of reimbursement. In this way, the focus of cost would become that of a per diem cost rather than an *a priori*-determined total cost per case. There was evidence from the literature that supported this approach; in Germany a prospective payment system (G-DRG) based on the

Australian refined diagnosis-related groups (AR-DRG) found a high proportion of intensive care to be systematically under-funded (Hindle, 1995) and the k-means cluster analysis as performed by Neilson *et al.*, (2004) identified homogeneous groups based on length of stay could create perverse incentives for critical care units to keep patients in the units for longer periods so as to re-coup the higher reimbursement tariff for the longer length of stay.

7.4 Policy context

The Department of Health introduced the '*Reforming NHS Financial Flows: Introducing Payment by Results*' policy in 2002 that clarified their vision for a new reimbursement system for adult critical care units to support the post-NHS Plan reforms.

The aims of '*Payment By Results*' were:

- To pay NHS Trusts and other providers fairly and transparently for services delivered;
- To reward efficiency and quality in providing services;
- To support greater patient choice and more responsive services; and
- To enable commissioners to concentrate on quality and quantity rather than on price (Department of Health, 2002).

Within the '*Payment By Results*' system, Primary Care Trusts would contract with healthcare providers of their choice based on flexible, as opposed to 'block' contracts, which ensure that the providers are only paid according to the work they complete, using a standard price tariff adjusted for case-mix on the basis of HRGs.

The Payment by Results Consultation: Preparing for 2005 (Department of Health, August 2003) recognized that the approach to funding critical care was a key issue. In particular, it was necessary to guarantee

adequate funding to ensure that critical care capacity was available when needed.

Payment By Results was deemed to have particular benefits for adult critical care.

- A reimbursement system based on case-mix-weighted activity[45] and a national price would ensure that critical care units were funded for the activity they undertook and the complexity of the case-mix. Also, commissioners and providers would need to reach a better understanding of prospective activity levels, and so planning and monitoring of activity within critical care is given greater attention than in the past.
- As far as incentives were concerned, 'Payment by Results' would help to ensure that incentives are in place to enable appropriate discharge from the Intensive Care Unit and High Dependency Unit to the ward, thereby improving the use of resources.

In order for this to work successfully, the HRGs would need to be defined in a clinically meaningful manner and be amenable to a multi-centre evaluation, where the variation in cost within each group was minimal and the variation in expenditure between hospitals was captured.

7.5 Possible groupings for critical care patients

Despite significant theoretical and practical difficulties, in March 1994, a meeting was held between representatives of the Intensive Care Society (ICS) and the NHSIA during which they concluded that the concept of classifying critical care episodes into HRGs merited further evaluation. Dr. John Morris, a Consultant in Critical Care from the William Harvey Hospital in Ashford then embarked on an 11-week

[45] Case-mix adjusted payment means that providers are not just paid for the number of patients they treat in each specialty, but also for the complexity or severity of the mix of patients they treat.

project where he visited 21 adult critical care units to elicit clinical opinions on the options for HRGs in critical care patients, which he did through a series of semi-structured interviews with the lead Consultants.

The question that Dr. Morris set out to address was whether a similar approach - the conventional method of using diagnosis for HRG classification - could be used for counting and classifying episodes of adult critical care?

Whilst the survey was based on clinical opinion, when the DRG system was implemented in the U.S., it was acknowledged that whatever system was adopted, it needed to be respected by the clinicians in order to be accepted.

The results from the semi-structured interviews suggested eight factors that could be used to define HRGs or iso-resource groups for the critical care unit. Iso-resource groups are not defined on the basis of expected resource use but on the ability to discriminate between costs of treatment (Bardsley, 1987)

7.4.1 Possible factors for HRG Classification

Use of diagnostic codes

Morris (1995) raised the first problem with the use of diagnostic codes for HRGs as being that of terminology, specifically, the absence of clear definitions. He found during his site visits that the coded diagnosis on hospital systems related to the coding clerk's interpretation of a hospital discharge summary or perusal of hand-written case notes. Feedback from the critical care units suggested that the hospital discharge diagnosis might not be identical to the reason for admission to the critical care unit, which is the more significant of the two for predicting resource use. Clinical opinion suggested more confidence in using the reason for admission as a grouping component compared to other diagnostic descriptors, although this was a narrative (subjective) data field.

Emergency or elective admission

Most admissions to the critical care unit present as emergencies, with the remainder forming a recognisable group of planned admissions following either elective major surgery or surgery in the presence of co-existing disease as a known risk factor. Most clinicians interviewed felt that this component of elective surgical work would give rise to predictable resource use and as such, this factor could be used as a descriptor for HRGs. The problem however is the high number of emergency admissions, for whom this level of predictability (of resource use) would not necessarily be observed.

Critical care unit mortality

The survey suggested fairly strong support for the inclusion of mortality as a component of iso-resource grouping, however non-survival from an episode of intensive care may seem more of an outcome statistic than a factor for predicting homogeneous clinical groups with similar resource consumption.

Clinical procedures

Healthcare Resource Groups for many of the surgical specialties rely heavily on an OPCS procedure code as a primary descriptor. It could be argued that if critical care unit resource consumption is strongly related to specific procedures such as invasive monitoring and inotrope infusions etc., then if these coded interventions were routinely collected in information systems, they could be used to partition the caseload into HRGs. Whilst being an attractive option, it lacks the availability of standardised computer codes for intensive care procedures. Morris (1995) felt it unlikely that the critical care procedure codes could be used alone in that it is unlikely they would correlate uniformly with the major resource factor of nursing.

Severity of Illness

Information gathered through the semi-structured interviews uncovered a common view that the observance of abnormal physiology provides

better information for classifying patients compared to other factors such as diagnoses or intervention scoring. The APACHE II score was thus proposed, however, the performance of APACHE II in predictions of cost has not been strong (Coulton *et al.*, 1985). There are many articles that describe different severity measures in terms of their potential usefulness in cost monitoring, however because of methodological differences among the studies, it remains difficult to draw conclusions about their relative performance in terms of identifying the best scoring system (Cretin & Worthman, 1986 & Rosko, 1998). It is conceivable therefore that these scores could be used to assign patients to iso-resource groups on the basis that the more ill the patient then the greater the resources consumed, yet it is debatable whether a single measurement would allow for variations in sickness during a critical care unit stay. Morris (1995) suggested that there could be a correlation between a patient's severity score in the first 24 hours of their critical care unit stay and their total resource use (during their stay), but this is complicated by patients with high day one scores falling into both early or late death categories. A patient with a high score may respond rapidly and survive to leave the critical care unit but another with the same initial score may develop multi-organ failure and stay in the critical care unit for a longer period (and consume more resources).

The clinicians consulted were however, mostly in favour of the inclusion of severity of illness scores for this purpose.

Length of Stay

Patients' length of stay has traditionally been viewed as a convenient variable for estimating and comparing the resources used in hospital care and for validating HRGs. The assumption is made that both fixed and variable costs are evenly spread on a day-to-day basis and this may also seem appropriate for intensive care where nursing costs are known to contribute a high and stable proportion of the fixed daily costs. However, daily costs of critical care are thought to vary significantly. The Clinicians interviewed were supportive of using patient's length of

stay as a possible HRG descriptor and Morris (1995) alluded to the fact that HRGs could indeed be defined using length of stay in combination with other clinical factors.

Patient Dependency

Existing patient dependency scoring systems were explored as a possible means of classifying patients, however according to Morris (1995) '*there are considerable theoretical and practical problems*'. This was due to the fact that there is no single system that is acceptable for this purpose at present. The allocation of scores had proved to be either '*extremely labour intensive and poorly completed*' or '*highly subjective despite some innovative local improvements*' leading Dr. Morris to conclude that purchasers would question the allocation of patient episodes to expensive HRGs using such arbitrary data.

TISS Scores

There was considerable support for the use of a TISS type score as a variable for devising HRGs, however TISS was not routinely collected for purposes other than research and/or audit studies.

7.4.2 Prerequisites to the HRGs

When deciding how many HRGs to have for a given patient population, a trade-off has to be made between achieving homogeneity and manageability. The number of groups has to be sufficiently large in number so as to be sensitive to differences in resource use but not '*managerially cumbersome*' i.e. excessive in number (Grimaldi & Micheletti, 1983). Chapter 4 described an exploratory evaluation of the above factors and concluded that patients' daily organ support had many appealing features as a possible method of HRG classification. The criteria set by the NHS Information Authority against which the HRGs should be developed were as follows:

- Activities within groups should be similar both clinically and in terms of the resources used);

- Groups should be based on routinely available data; and
- The number of groups should be manageable (NHS Information Authority, 2002).

It was also felt important that the case-mix classification or measure adhered to criteria proposed by Hornbrook (1982) that had been used in the U.S. for the DRG system:

- Reliability
  - Consistent, not susceptible to random errors
- Validity
  - Content – representative and comprehensive
  - Predictive – ability to predict some hypothesised outcome
  - Construct – ability to explain differences in a way that is theoretically coherent
- Sensitivity
  - Discriminates between hospitals
- Cost-effectiveness
  - Least cost method of measurement without significantly compromising performance
- Flexibility
  - Can be used for a variety of purposes
- Acceptability
  - Measure is accepted by all users

7.4.3 Study aims

In summary, the aims of this Chapter were to:

- Identify an appropriate model from which estimates of daily case-mix adjusted costs of care could be determined; and
- Propose a set of HRGs that met both these criteria.

7.5 Statistical methods for daily case-mix adjusted cost estimates

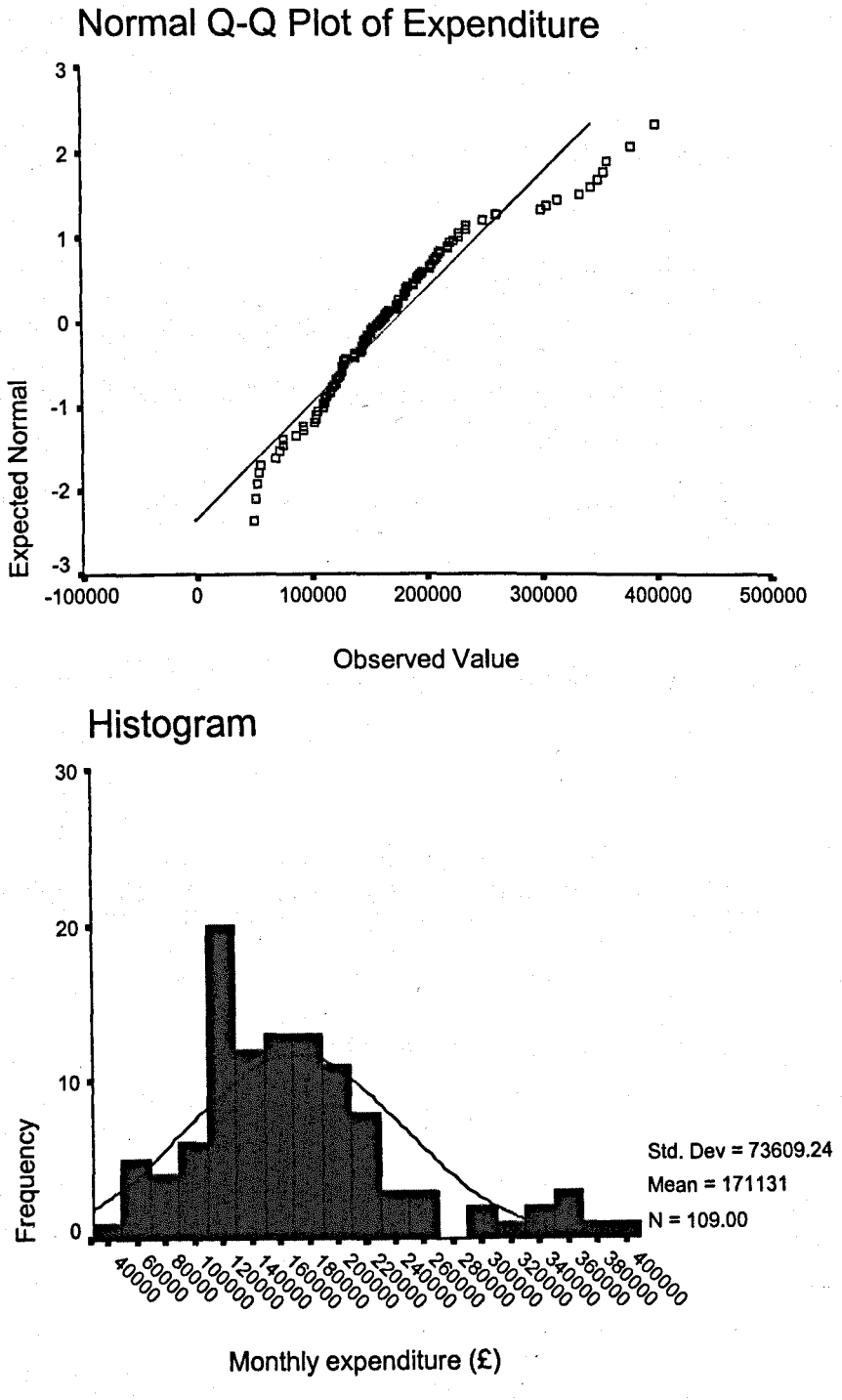
The HRG development consisted of two tasks; the first task was to use a statistical method to derive daily costs of care that related to patients' organ support (i.e. the resultant coefficients) using the expenditure and organ support data entered into the model. After having assigned daily costs to patients' organ support data collected in the multi-centre study, the second task was to explore ways in which the HRGs could be developed.

The data set consisted of longitudinal monthly expenditure and organ support data from the sub-sample of 46 adult critical care units described in Chapter 6. Only those critical care units that supplied data on their expenditure, case-mix and unit characteristics were included. The frequency of organ support data by type and combination of organ support was described (Table 6.15).

Transformation of the dependent cost variable is often used to solve the problems of heteroscedasticity and skewness in linear ordinary least square regression (Kilian *et al.*, 2002). However, logarithmic transformation or some other power transformation creates a number of additional complexities that are often inappropriately ignored (Hay, 2005) such as the interpretabilities of the model coefficients and the fact that the transformed data will have only an approximate normal distribution (Cantoni & Ronchetti, 2006).

Transformation of the expenditure data was not necessary in this study however as these data were normally distributed (Figure 7.1) (Kolmogorov-Smirnov statistic = 0.094, p=0.018). Descriptive statistics were used to describe the dependent and independent variables used in the model.

Figure 7.1: Histogram of monthly expenditure



Prior to exploring different types of regression techniques, ordinary least-squared (OLS) multiple regression analysis was considered. Multiple linear regression '*attempts to predict or estimate the value of a single continuous response variable from the known values of two or more continuous or categorical explanatory variables*' (Lang & Secic, 1997). Statistical inference in this analysis, as described by Kleinbaum *et al.*, (1998) was based on estimation of the cost function i.e. estimating daily costs of care based on organ support. First, a mathematical model was specified that described how a critical care unit's monthly expenditure on nursing staff, drugs and fluids and disposable equipment was related to the organ system support received by its patients. Here, the model provided estimates of an unknown daily cost for the sum of these three main resources for different types and combinations of organ support.

Standard regression analysis however assumes that all observations in the sample are independent (Heyse *et al.*, 2001), yet, due to the clustered nature of the data set (with each critical care unit contributing a different number of months' data to the model), the observations were not independent of one another. Without adjustment for clustering, standard OLS can produce inefficient parameter estimates and incorrect standard errors (Sculpher *et al.*, 2004 & Merlo *et al.*, 2005). The different approaches available for dealing with this problem include aggregate-level analysis where information is aggregated to the highest level, the use of generalised estimating equations (GEE) which is a more sophisticated alternative statistical technique, and performing separate analyses for each clustered data set but this clearly reduces the number of observations in the analysis (Gilthorpe *et al.*, 2000).

A multi-level regression analysis (MLRA) (alternatively referred to as a hierarchial linear or random coefficient model – see Carey, 2000) was employed, which is suitable for the analysis of data with some underlying hierarchial structure (Beacon & Thompson, 1996). MLRA assumes the clustered observations (months) are broadly similar, with

differences between the critical care units due to either random variation or discernible external influences (Gilthorpe *et al.*, 2000 & Merlo *et al.*, 2005).

Jones (2000) illustrates the basic structure of a multilevel model by considering a simple linear model consisting of two levels which represents months of patient data ($i = 1,\ldots,n$) nested within critical care units ($j = 1,\ldots,m$). yij represents the outcome of interest which is related to a vector of explanatory variables x in the following manner:

$$Yij = xij\beta + \mu j + \varepsilon ij.$$

One assumes that the random error term of months of patient data i in critical care unit j, εij, has zero mean and constant variance $\sigma\varepsilon^2$. The effects of critical care units are estimated through μj which is assumed random and again has a mean of zero and constant variance $\sigma\mu^2$.

The literature on Panel data techniques places emphasis on the relative merits of treating higher level units (in this case, the critical care units) as random or fixed effects. In the above model, the individual effects (μj) are specified as random effects, but they could be specified as fixed effects, to be estimated together with β.

Breusch-Pagan and Hausman specification tests were used to assess the appropriateness of applying a random as opposed to a fixed-effects model.

Fixed effects models assume random variation within each critical care unit but not potential heterogeneity between critical care units so the confidence interval is artificially narrow. A random effects model includes both sources of variation, the between and within study variance. The underlying effects are assumed to vary at random (Sutton *et al.*, 2000).

Based on the results of these tests, random-effect models were developed using the critical care units' monthly expenditure as the dependent variable and the number of days of each type and

combination of organ support as the independent (or explanatory) variables. Random-effects models overcome this problem of correlated data and are typically advised (Liang & Zeger, 1986). All analyses were performed using Stata Version 8.0 (Stata Corporation, College Station, TX).

This choice of analysis had three main objectives:

- To recognize the hierarchial and clustered structure of the data (Drummond *et al.*, 2005 & Thompson *et al.*, 2006);
- To characterize the relationship between expenditure (Y) and the number of days of different types of organ system support ($X_1, X_2 \ldots X_k$); and
- To produce a quantitative formula to predict the expenditure of a critical care unit (Y) as a function of the number of days of the different types of organ system support ($X_1, X_2 \ldots X_k$).

7.6 Types of models developed for the case-mix adjusted cost estimates

7.6.1 Random-effects model of monthly expenditure and days of organ support received

The first model developed was a maximum-likelihood random-effects model. To prepare the data for the model, the number of days where each type of organ support was given was summed for each critical care unit on a monthly basis (so, the monthly number of days of basic respiratory support, advanced respiratory support etc). The spreadsheet was structured in such a way that the model treated the organ systems as independent of one another, not allowing for any interactions between the different organ systems. The organ systems included in this model were: basic respiratory support, advanced respiratory support, circulatory support, renal support, neurological support and dermatological support. The model used the monthly critical care unit's

expenditure on nursing staff, drugs and fluids and disposable equipment as the dependent variable and the monthly sum of the days of different types of organ support (namely basic respiratory support, advanced respiratory support, circulatory support, renal support and dermatological support) as the explanatory (independent) variables.

In order to get the cost coefficients down to a daily level so as to derive estimates of daily cost from the monthly expenditure, the constant term (intercept) was excluded from the model. Table 7.1 presents the results of this model.

Table 7.1: Results of the random-effects model (Model 1)

Type of organ support	Coefficients (£)	Standard Errors	z	P>[Z]	95% confidence intervals (£)
Basic respiratory support	456	127.64	3.57	0.000	205.76-706.10
Advanced respiratory support	576	124.95	4.61	0.000	330.83-820.61
Circulatory support	220	112.16	1.96	0.050	0.26-439.91
Renal support	528	298.63	1.77	0.077	-57.43 – 1,113.17
Neurological support	51	164.02	0.31	0.757	-270.77 – 372.18
Dermatological support	270	917.85	0.29	0.769	-1,528.94 – 2,068.96

If one considers the coefficients produced for each type of organ support, the results shown in Table 7.1 appeared to follow a logical sequence; insofar that basic respiratory support was less costly than advanced respiratory support (hence reflecting the findings of the exploratory analyses described in Chapter 4).

Given that only the costs of nursing staff, drugs and fluids and disposable equipment were included in the model, it was necessary to

add the remaining resources to the modelled estimates of cost in order to estimate a complete daily cost. For this reason, the non-modelled costs of care (£522.50) that formed the 'overhead' component of the daily cost were added to the modelled cost estimates and total costs of care could then be calculated for the 7,243 patients in the total sample. Total costs were determined based on the number of days of each type of organ support received.

8.7 Types of models developed for the HRGs

Now that the first task of daily cost estimation based on the type of organ support received had been completed, the next task was to identify the best way of 'grouping' the patients. OLS regression models were developed to determine the extent to which the total number of organs supported during a patient's stay could explain the variation in length of stay and total costs of care. Four different statistical models in total were developed – two of which included outliers (Models 1 and 3). In each, the independent variables represented the total number of organs supported during the patients' stay, coded as dummy variables (1 or 0) and the dependent variables were either length of stay (in Models 1 and 2) or total costs of care (in Models 3 and 4).

Model 1 (Length of Stay) Outliers Included

- Dependent variable (Length of critical care unit stay)
- Independent variables (No organs supported; One organ supported; Two organs supported; Three organs supported; Four organs supported; Five organs supported; Six organs supported).

Model 2 (Length of Stay) Outliers Excluded

- Dependent variable (Length of critical care unit stay)
- Independent variables (No organs supported; One organ supported; Two organs supported; Three organs

supported; Four organs supported; Five organs supported; Six organs supported).

Model 3 (Total Costs) Outliers Included

- Dependent variable (Total costs of care)
- Independent variables (No organs supported; One organ supported; Two organs supported; Three organs supported; Four organs supported; Five organs supported; Six organs supported).

Model 4 (Total Costs) Outliers Excluded

- Dependent variable (Total costs of care)
- Independent variables (No organs supported; One organ supported; Two organs supported; Three organs supported; Four organs supported; Five organs supported; Six organs supported).

One hundred and forty-nine patients (2% of the total sample) were identified as 'outliers' (by falling outside of 3 standard deviations) in the regression model. These outliers were patients with very long lengths of stay or high total costs of care (usually both). The models were run in two ways: by including the 'outliers' and excluding them to see what effect they had on the results. The statistic of interest with these models was the R^2 value as what was needed was a way of 'grouping' patients that most closely reflected their total costs of care.

As can be seen from table 7.2, the exclusion of outliers improved the model fit, with higher resulting explanatory power. All four models were statistically significant, and model 4 yielded the highest R^2 value (0.349), which was still better (statistically) than patients' length of stay when the outliers were included in the model. The R^2 values were used as a means of guiding the focus of more detailed analysis towards the model most likely to explain the highest amount of variation in cost. Further analysis of the resulting beta coefficients (and appropriate face validity checks) followed once this model had been identified.

Table 7.2: Results of the OLS models

Dependent Variables	Independent variables	Inclusion of outliners	Model criteria	R^2 VALUE	P value
Model 1: Critical Care Unit Length of Stay	No organs supported (yes or no) One organ supported (yes or no) Two organs supported (yes or no) Three organs supported (yes or no) Four organs supported (yes or no) Five organs supported (yes or no) Six organs supported (yes or no)	Yes	Enter	0.192	P<0.0001
Model 2: Critical Care Unit Length of Stay	No organs supported (yes or no) One organ supported (yes or no) Two organs supported (yes or no) Three organs supported (yes or no) Four organs supported (yes or no) Five organs supported (yes or no) Six organs supported (yes or no)	No	Enter	0.247	P<0.0001
Model 3: Total Costs of Care	No organs supported (yes or no) One organ supported (yes or no) Two organs supported (yes or no) Three organs supported (yes or no) Four organs supported (yes or no) Five organs supported (yes or no) Six organs supported (yes or no)	Yes	Enter	0.252	P<0.0001

Dependent Variables	Independent variables	Inclusion of outliners	Model criteria	R^2 value	P value
Model 4: Total Costs of Care	No organs supported (yes or no)	No	Enter	0.349	P<0.0001
	One organ supported (yes or no)				
	Two organs supported (yes or no)				
	Three organs supported (yes or no)				
	Four organs supported (yes or no)				
	Five organs supported (yes or no)				
	Six organs supported (yes or no)				

K-means clustering had been used before in a study from Germany that had attempted to propose some DRGs for their critically ill patients using patients' length of stay (Neilson *et al.*, 2004). For this reason, the same technique was considered here as a way in which HRGs could be developed for the UK. *K*-means clustering attempts to identify homogeneous groups of cases based on selected characteristics using an algorithm that can handle large numbers of cases (SPSS, Version 10). Cluster variability is measured with respect to the mean values for the classifying variables. Two variables were used to define the clusters (critical care unit length of stay and total costs of care) and the distances (dissimilarities) between the clusters were measured in multi-dimensional space (e.g. Euclidean distances). In this way, all of the clusters were statistically different from one another ($p<0.0001$) using ANOVA tests. The patients identified as 'outliers' were excluded from the cluster analysis.

One of the limitations of cluster analysis is that it works on the premise of means clustering, so doesn't identify discrete ranges for length of stay by which patients can be easily assigned to their appropriate cluster. For this reason, histograms were plotted and using the percentile values for each cluster, it was possible to identify

appropriate ranges for length of stay between the clusters. As can be seen from the histograms and box plots, some overlap does occur between some of the clusters.

The costs for each cluster are more difficult to assign a range to because HRG costs need to be a standard cost, weighted in the same way as reference costs are for university hospitals and hospitals located in London. Costs were assigned to each HRG using the mean and 95% confidence intervals.

The proposed 20 HRG classifications consist of the six organs and the no organ support, each of which had sub-groups (clusters) relating to length of stay and total cost. Table 7.3 presents the 20 HRGs where the length of stay ranges and total costs are described. The key to the codes shown in table 7.3 is as follows:

HRG Code	HRG Description
HRG0	No organs supported
HRG1	One organ supported
HRG2	Two organs supported
HRG3	Three organs supported
HRG4	Four organs supported
HRG5	Five organs supported
HRG6	Six organs supported

Table 7.3: Proposed Health Care Resource Groups

HRG	HRG Cluster	N	% of HRG occupied by the clusters	% of total sample (7,094 patients)	LOS Ranges	Total costs (£) (95% Confidence Intervals)
1	HRG 0 Cluster 1	362	91.2	5.1	≥ 1 day ≤ 4 days	1,059 (1,013-1,106)
2	HRG 0 Cluster 2	35	8.8	0.5	≥ 5 days ≤ 12 days	3,195 (2,903-3,486)
3	HRG 1 Cluster 1	1214	82.2	17.1	≥ 1 day ≤ 3 days	1,736 (1,699-1,773)
4	HRG 1 Cluster 2	236	16.0	3.3	≥ 4 days ≤ 8 days	4,377 (4,254-4,500)
5	HRG 1 Cluster 3	26	1.8	0.4	≥ 9 days ≤ 20 days	10,919 (9,694-12,144)
6	HRG 2 Cluster 1	2088	77.1	29.4	≥ 1 day ≤ 4 days	2,523 (2,480-2,566)
7	HRG 2 Cluster 2	505	18.6	7.1	≥ 5 days ≤ 10 days	6,928 (6,778-7,077)
8	HRG 2 Cluster 3	115	4.2	1.6	≥ 11 days ≤ 25 days	15,421 (14,730-16,112)
9	HRG 3 Cluster 1	1239	63.5	17.5	≥ 1 day ≤ 5 days	3,827. (3,744-3,909)
10	HRG 3 Cluster 2	429	22.0	6.0	≥ 6 days ≤ 10 days	9,789 (9,603-9,976)
11	HRG 3 Cluster 3	198	10.1	2.8	≥ 11 days ≤ 16 days	17,458 (17,112-17,804)
12	HRG 3 Cluster 4	85	4.4	1.2	≥ 17 days ≤ 26 days	25,858 (25,239-26,477)
13	HRG 4 Cluster 1	245	48.1	3.5	≥ 1 day ≤ 8 days	5,797 (5,488-6,106)
14	HRG 4 Cluster 2	167	32.8	2.4	≥ 9 days ≤ 16 days	15,021 (14,532-15,509)
15	HRG 4 Cluster 3	97	19.1	1.4	≥ 17 days ≤ 37 days	27,361 (26,475-28,248)
16	HRG 5 Cluster 1	21	42.9	0.3	≥ 1 day ≤ 11 days	12,830 (10,840-14,819)
17	HRG 5 Cluster 2	19	38.8	0.3	≥ 12 day ≤ 22 days	25,957 (24,026-27,888)
18	HRG 5 Cluster 3	9	18.4	0.1	≥ 23 days ≤ 33 days	44,700 (41,387-48,013)
19	HRG6 Cluster 1	2	50.0	0.0	≥ 1 day ≤ 20 days	16,448 (-33,826-66,723)
20	HRG6 Cluster 2	2	50.0	0.0	≥ 21 day ≤ 28 days	36,006 (11,625-60,387)

The majority of patients fell into three groups; those requiring 2 organs supported with a length of stay greater than 1 day yet less than 4 days (HRG 2 Cluster 1) (n=2,088), followed by 1,239 patients 3 organs supported with a length of stay greater than 1 day but less than 5 days and 1,214 patients with 1 organ supported staying between 1 and 3 days. Only a very small number of patients had 6 organs supported during their stay.

Appendix 7.1 presents the descriptive statistics of each HRG and Appendix 7.2 gives the box-plots and histograms plotted for each HRG both in terms of patients' total costs and their length of stay.

This analysis however had a number of problems. Firstly, not allowing for interactions between the different organs meant that the only way that patients' daily costs could be determined was to add together the

different cost coefficients to reflect multiple organ failure. For example, if a patient had advanced respiratory support and neurological support, it would be necessary to add £575.72 (the cost of advanced respiratory support) to £50.70 (the cost of neurological support). The main problem with treating the organs as independent of one another is that in practice, it may cost less to support two organ systems at the same time than two organs supported at different times and it runs a very high risk of co-linearity within the model.

Secondly, the standard errors and the 95% confidence intervals were very large which caused some concern.

Thirdly, excluding the constant term from the model was problematic.

Finally, the clusters themselves presented an additional problem, that of introducing a perverse incentive to critical care units to keep patients longer in the critical care unit so as to re-coup the higher reimbursement tariff associated with a longer length of stay.

For these reasons, it seemed appropriate to investigate the feasibility of modelling the interactions between the different organ systems. Section 7.8 now describes the models that were subsequently developed to improve on the random-effects model where the organs had been treated as independent of one another (Section 7.6.1).

7.8 Additional models explored for the case-mix adjusted daily costs

7.8.1 Types and combinations of organ support

It was decided to model the types and combinations of organ support days available from the 46 critical care units, with the exception of dermatological support, that due to the very small number of observations in the data set was excluded from subsequent models. The same type of model was used i.e. a random-effects model but rather

than excluding the constant term as in the previous model, the constant term was included.

The 5th model that was developed used the monthly expenditure on nurses, drugs and fluids and disposable equipment as the dependent variable and the monthly number of patient days stratified by the type and combinations of organ support received by patients as the independent variables. Table 7.4 shows the frequency of each type of organ system support within the data set. The column entitled 'N (total sample)' refers to the data used in the model, with the column to the right showing how these data compare to the total sample (i.e. the 7,243 patients).

Table 7.4: Frequency of patient days by type and combination of organ support

Number of organ systems	Basic respiratory support	Advanced respiratory support	Circulatory support	Neurological support	Renal support	N (total sample)	N (% of total sample)
0						2 554	1 612 (63.1)
1	X					3 611	2 358 (65.3)
1		X				2 854	1 910 (66.9)
1			X			3 191	2 241 (70.2)
1				X		142	102 (71.8)
1					X	33	25 (75.8)
2	X		X			6 252	4 621 (73.9)
2	X			X		299	233 (77.9)
2	X				X	121	65 (53.7)
2		X	X			11 864	8 177 (68.9)
2		X		X		396	265 (66.9)
2		X			X	270	84 (31.3)
2			X	X		119	110 (92.4)
2			X		X	134	78 (58.2)
2				X	X	0	0 (0.0)
3	X		X	X		491	269 (54.8)
3	X		X		X	342	241 (70.5)
3	X			X	X	4	4 (100.0)
3			X	X	X	0	0 (0.0)
3		X	X		X	1 959	1 165 (59.5)
3		X	X	X		2 261	1 294 (57.2)
3		X		X	X	26	16 (61.5)
4	X		X	X	X	6	3 (50.0)
4		X	X	X	X	241	153 (63.8)
TOTAL						**37 170**	**25 025 (67.3)**

The 6th model was similar to the 5th and used the same dependent variable, but in model 6, some of the independent variables with smaller numbers of observations were grouped together in order to reduce the number of variables and the high standard errors produced by the independent variables with very few observations. In an attempt to produce more meaningful estimates, it was decided to combine some of the smaller observations. In doing so, the following decisions were taken:

1. To combine the days where neurological support was given, to the days where basic respiratory support was given. The rationale for this was based on similar expected resource use for both types of organ support. Note that the same rationale was applied to subsequent decisions;
2. To combine the days where renal support was given to the days where advanced respiratory support was given;
3. To combine the days where circulatory and renal support was given to days where advanced respiratory, circulatory and renal support was given;
4. To combine the days where basic respiratory, circulatory and renal support was given to days where advanced respiratory, circulatory and renal support was given;
5. To combine the days where basic respiratory, circulatory and neurological support was given to days where advanced respiratory, circulatory and neurological support was given;
6. To combine the days where basic respiratory, neurological and renal support was given to days where advanced respiratory, neurological and renal support was given; and
7. To combine the days where basic respiratory, circulatory, neurological and renal support was given to days where advanced respiratory, circulatory, neurological and renal support was given.

7.8.2 Results of model 5

The results produced by model 5 are shown in table 7.5. In order to scale the results produced by the model to a daily level, the following formula was used:

$$\text{Daily case-mix adjusted costs} = \frac{\text{Constant term}}{\text{Average number of Patient days}} + \text{Coefficients}$$

The average number of patient days in the sample was 229.

Table 7.5: Results of the random-effects model (Model 5)

Number of organ systems	Basic respiratory support	Advanced Respiratory support	Circulatory Support	Neurological Support	Renal Support	Coefficients (£)	95% Confidence Intervals (£)	Standard errors	Z	P>|z|
0						-285	-830-261	278	-1.02	0.306
1	X					323	-276-922	306	1.06	0.290
1		X				988	449-1526	275	3.60	0.000
1			X			155	-253-562	208	0.74	0.457
1				X		-1 077	-6 723-4 569	2 881	-0.37	0.709
1					X	- 3 011	-13 061-7 038	5 127	-0.59	0.557
2	X		X			388	66-709	164	2.36	0.018
2	X			X		934	-2 425-4 293	1 714	0.55	0.586
2	X				X	578	-6 863-8 018	3 796	0.15	0.879
2		X	X			702	453-950	127	5.53	0.000
2		X		X		2 179	46-4 313	1 088	2.00	0.045
2		X			X	6 514	-654-13 681	3 657	1.78	0.075
2			X	X		3 487	-1 385- 8 360	2 486	1.40	0.161
2			X		X	-1 530	-7735- 4 676	3 166	-0.48	0.629
2				X	X					
3	X		X	X		-59	-3 380- 3 262	1 694	-0.03	0.972
3	X		X		X	-440	-4 000- 3 121	1 817	-0.24	0.809
3	X			X	X	22 995	-8 769-54 760	16 207	1.42	0.156
3			X	X	X					
3		X	X		X	649	-404-1 703	538	1.21	0.227
3		X	X	X		263	-480-1 005	379	0.69	0.488
3		X		X	X	1 332	-11 573-14 237	6 584	0.20	0.840
4	X		X	X	X	10 096	-51 490- 71 681	31 421	0.32	0.748
4		X	X	X	X	1 668	-1 213-4 549	1 470	1.13	0.257
Constant						52 599	26 771- 78 426	13 178	3.99	0.000

Table 7.6 presents the apportioned daily estimates using the above formula.

This model was able to explain 70% of the variation in monthly expenditure using the number of days of each type and combination of organ support ($R^2 = 0.70$ (R^2 within 0.71; R^2 between 0.61, $p<0.0001$).

Table 7.6: Results of the apportioned estimates for daily costs from the random-effects model (Model 5)

Number of organ systems	Basic respiratory support	Advanced Respiratory support	Circulatory Support	Neurological Support	Renal Support	Apportioned constant term (£)	Coefficients (£)	Daily cost estimates (£)
0						52 599/229	-285	-56
1	X					52 599/229	323	552
1		X				52 599/229	988	1 217
1			X			52 599/229	155	384
1				X		52 599/229	-1 077	-848
1					X	52 599/229	- 3 011	-2 782
2	X		X			52 599/229	388	617
2	X			X		52 599/229	934	1 163
2	X				X	52 599/229	578	807
2		X	X			52 599/229	702	931
2		X		X		52 599/229	2 179	2 408
2		X			X	52 599/229	6 514	6 743
2			X	X		52 599/229	3 487	3 716
2			X		X	52 599/229	-1 530	-1 301
2				X	X			
3	X		X	X		52 599/229	-59	170
3	X		X		X	52 599/229	-440	-211
3	X			X	X	52 599/229	22 995	23 224
3			X	X	X			
3		X	X		X	52 599/229	649	878
3		X	X	X		52 599/229	263	492
3		X		X	X	52 599/229	1 332	1 561
4	X		X	X	X	52 599/229	10 096	10 325
4		X	X	X	X	52 599/229	1 668	1897

7.8.3 Results of Model 6

Model 6 was able to explain 69% of the variation in monthly expenditure (overall $R^2 = 0.69$ (R^2 within, 0.69; R^2 between, 0.61), $p<0.0001$). Table 7.7 presents the results produced by the model.

Table 7.7: Results of the random-effects model (Model 6)

Number of organ systems	Basic respiratory support	Advanced Respiratory support	Circulatory Support	Neurological Support	Renal Support	Coefficients (£)	95% Confidence Intervals (£)	Standard errors	Z	P>|z|
0						-271	-782-239	261	-1.04	0.298
1	X					421	-152-995	293	1.44	0.150
1		X				988	467-1508	266	3.72	0.000
1			X			127	-240-494	187	0.68	0.498
1				X		421	-152-995	293	1.44	0.150
1					X	988	467-1508	266	3.72	0.000
2	X		X			408	112-703	151	2.70	0.007
2	X			X		-210	-2370-1950	1102	-0.19	0.849
2	X				X	1487	-5261-8235	3443	0.43	0.666
2		X	X			702	467-937	120	5.86	0.000
2		X		X		2023	43-4003	1010	2.00	0.045
2		X			X	6069	-222-12360	3210	1.89	0.059
2			X	X		3268	-1120-7657	2239	1.46	0.144
2			X		X	363	-531-1256	456	0.80	0.426
2				X	X					
3	X		X	X		205	-381-791	299	0.69	0.493
3	X		X		X	363	-531-1256	456	0.80	0.426
3	X			X	X	4948	-6294-16190	5736	0.86	0.388
3			X	X	X					
3		X	X		X	363	-531-1256	456	0.80	0.426
3		X	X	X		205	-381-791	299	0.69	0.493
3		X		X	X	4948	-6294-16190	5736	0.86	0.388
4	X		X	X	X	1741	-773-4254	1282	1.36	0.175
4		X	X	X	X	1741	-773-4254	1282	1.36	0.175
Constant						50872	**26134-75609**	**12621**	4.03	0.000

Changes to the interpretation of the results were as follows:

1. Estimates produced for basic respiratory support also applied to days where neurological support was given;
2. Estimates produced for advanced respiratory support also applied to days where renal support was given;
3. Estimates produced for advanced respiratory, circulatory and renal support also applied to days where just circulatory and renal support was given;
4. Estimates produced for advanced respiratory, circulatory and renal support also applied to days where basic respiratory, circulatory and renal support was given;
5. Estimates produced for advanced respiratory, circulatory and neurological support also applied to days where basic respiratory, circulatory and neurological support was given;
6. Estimates produced for advanced respiratory, neurological and renal support also applied to days where basic respiratory, neurological and renal support was given; and
7. Estimates produced for advanced respiratory, circulatory, neurological and renal support also applied to days where basic respiratory, circulatory, neurological and renal support was given.

Despite these changes, the R^2 value remained largely unaffected. The apportioned daily estimates shown in table 7.8.

Table 7.8: Results of the apportioned estimates for daily costs from the random-effects model (Model 6)

Number of organ systems	Basic respiratory support	Advanced Respiratory support	Circulatory Support	Neurological Support	Renal Support	Apportioned constant term (£)	Coefficients (£)	Daily cost estimates (£)
0						50 872/ 229	-271	-49
1	X					50 872/ 229	421	643
1		X				50 872/ 229	988	1 210
1			X			50 872/ 229	127	340
1				X		50 872/ 229	421	643
1					X	50 872/ 229	988	1 210
2	X		X			50 872/ 229	407	629
2	X			X		50 872/ 229	-210	12
2	X				X	50 872/ 229	1 487	1 709
2		X	X			50 872/ 229	702	924
2		X		X		50 872/ 229	2 023	2 245
2		X			X	50 872/ 229	6 069	6 291
2			X	X		50 872/ 229	3 268	3 490
2			X		X	50 872/ 229	363	585
2				X	X			
3	X		X	X		50 872/ 229	205	427
3	X		X		X	50 872/ 229	363	585
3	X			X	X	50 872/ 229	4 948	5 170
3			X	X	X			
3		X	X		X	50 872/ 229	363	585
3		X	X	X		50 872/ 229	205	427
3		X		X	X	50 872/ 229	4 948	5 170
4	X		X	X	X	50 872/ 229	1 741	1 963
4		X	X	X	X	50 872/ 229	1 741	1 963

7.8.4 Discussion of Models 5 and 6

Model 5 produced the highest R^2 value of the two models, the coefficients produced by the model varied considerably according to the type of organ supported. There were large standard errors for some of the organs that could be attributed to the very small numbers of observations. The coefficients produced by the model were negative for some organs, namely:

- No organ support;

- Neurological support;
- Renal support, circulatory + renal support;
- Basic respiratory support, circulatory + neurological support and;
- Basic respiratory, circulatory + renal support.

Of the 22 different types and combinations of organ support (and the constant term), there were very few organs that reached statistical significance:

- Advanced respiratory support;
- Advanced respiratory + circulatory support;
- Basic respiratory + circulatory support;
- Advanced respiratory + neurological support and;
- The constant term.

In Model 6, a negative coefficient was still observed for patients with no organs supported and some wide-ranging estimates of cost produced for the other organ systems that defied logical sense (insofar that the 3 organ system combinations were incurring lower costs than some of the 2 organ system combinations).

Despite the high degree of predictive power, due to the non-sensible coefficients evident through face validity checks it was not felt that either of these models could be used as a basis for estimating case-mix adjusted costs. For this reason, it was decided to explore the total number of organs supported as opposed to the type of organs supported (Section 7.8.4). It is important to note that with a much larger sample it is anticipated that model 5 would generate meaningful estimates of cost, however models that have a high number of variables run the risk of an increased possibility of multicollinearity[46] and a lack of degrees of freedom, therefore a degree of aggregation is often needed which is

[46] Collinearity occurs when there is a linear relationship between the covariates, which can influence stability of model coefficients and predictions (Beaver *et al.*, 1998)

why it was decided to investigate modelling the total number of organs supported instead (Smet, 2002).

7.8.5 Total Number of Organs Supported

Based on the high predictive power of the total number of organ systems found in the previous analysis (Section 7.7), it seemed appropriate to explore this concept further in subsequent models.

In Models 7, 8 and 9 the total number of organs was determined for each patient day and summed for each month in question. The independent variables represented the monthly sum of patient days that fell into the categories of 0 organs supported, 1 organ supported and so on, up to 4.

Model 7 used the monthly number of patient days stratified by the total number of organs supported on that day[47] as the independent variables (which ranged in this model from 0 organs supported to 4 organs supported) and the monthly expenditure on nurses, drugs and fluids and disposable equipment as the dependent variable in the model.

Model 8 was very similar to Model 7, but in this model the number of patient days where 3 organs were supported were added to the number of days where 4 organs had been supported to form a new independent variable called '3 or more' organs supported.

Model 9 adopted the same independent variables as Model 8, but also added the number of patient days were no organs had been supported to the number of days where one organ had been supported to form another new independent variable called '0 or 1 organ supported'.

47 To calculate the total numbers of organs supported per day, basic and advanced respiratory support were re-classified into one organ system, which was respiratory support.

7.8.6 Results of Model 7

Model 7 yielded an R^2 of 0.58 (R^2 within 0.58; R^2 between 0.87, $p<0.0001$). All of the independent variables were found to be statistically significant (including the constant term) (Table 7.9).

Table 7.9: Results of the random-effects model (Model 7)

Number of organ systems	Coefficients (£)	95% Confidence Intervals (£)	Standard errors	Z	P>|z|
0	-506	-984 - -27	244	-2.07	0.038
1	544	287-801	131	4.15	0.000
2	610	433-786	90	6.78	0.000
3	464	47-881	2213	2.18	0.029
4	2 707	581-4832	1084	2.50	0.013
Constant	52 688	26 198-79 178	13 516	3.90	0.000

The R^2 value for this model (0.58) was nevertheless lower than the previous 2 models (Models 5 and 6), however the standard errors surrounding each estimate were less. When looking at the apportioned estimates (Table 7.10) patients having 3 organs supported incurred lower daily costs than those with 4 organs supported. Yet again, the problem of a negative coefficient occurred for patients with no organs supported. It was decided therefore to combine the 3 and 4 organs supported category in Model 8.

Table 7.10: Results of the apportioned estimates for daily costs from the random-effects model (Model 7)

Number of organ systems	Apportioned constant term	Coefficients (£)	Daily cost estimates (£)
0	52 688 / 229	-506	-277
1	52 688 / 229	544	773
2	52 688 / 229	610	839
3	52 688 / 229	464	693
4	52 688 / 229	2 707	2 936

7.8.7 Results of Model 8

Model 8 yielded an overall R^2 of 0.57 (R^2 within 0.57; R^2 between 0.84, $p<0.0001$). This model (like model 7) found all of the independent variables to be statistically significant (Tables 7.11 – 7.12).

Table 7.11: Results of the random-effects model (Model 8)

Number of organ systems	Coefficients (£)	95% Confidence Intervals (£)	Standard errors	Z	P>|z|
0	-569	-1049- - 90	245	-2.33	0.020
1	553	293-813	133	4.17	0.000
2	582	406-758	90	6.48	0.000
3 or more	691	343-1038	177	3.89	0.000
Constant	53 206	26 399-80 014	13677	3.89	0.000

Table 7.12: Results of the apportioned estimates for daily costs from the random-effects model (Model 8)

Number of organ systems	Apportioned constant term	Coefficients (£)	Daily cost estimates (£)
0	53 206 / 229	-569	-340
1	53 206 / 229	553	782
2	53 206 / 229	582	811
3 or more	53 206 / 229	691	920

The logical sequencing of cost rising in line with the increasing number of organs supported was achieved with this model, however the problem of a negative cost coefficient still remained for patients with no organs supported. It was thus decided to retain the 3 and 4 organs supported category and combine the 0 and 1 organ support categories in Model 9.

7.8.8 Results of Model 9

By combining the 0 and 1 organ support variables, the overall R^2 dropped to 0.52 (R^2 within 0.52; R^2 between 0.89, $p<0.0001$), however the three organ support categories were all statistically significant and here, the negative coefficient became positive (Tables 7.13 - 7.14).

Table 7.13: Results of the random-effects model (Model 9)

Number of organ systems	Coefficients (£)	95% Confidence Intervals (£)	Standard errors	Z	P>|z|
0 or 1	217	31-402	95	2.29	0.022
2	654	48-834	92	7.13	0.000
3 or more	669	304-1 034	186	3.59	0.000
Constant	53 566	25 398-81 733	14 371	3.73	0.000

Table 7.14: Results of the apportioned estimates for daily costs from the random-effects model (Model 9)

Number of organ systems	Apportioned constant term (£)	Coefficients (£)	Daily cost estimates (£)
0 or 1	53 566 / 229	217	451
2	53 566 / 229	654	888
3 or more	53 566 / 229	669	903

All 3 organ support categories retained their logical sequencing with the 0 or 1 organ support category being less costly than the 2 and 3 (or more) categories. On this basis, it was decided that Model 9 provided the most logical and reliable estimates of daily cost by organ support, despite this model representing the crudest way of classifying patients compared to the models so far developed.

7.9 Evaluation Of The Usefulness of The Findings For Use In HRGs

7.9.1 Accuracy of Model 9 when compared to expenditure

Table 7.15 shows the actual expenditure on nursing staff, drugs and fluids and disposable equipment by critical care unit and compared to this, estimated expenditure using the coefficients produced by Model 9. Overall, the model predicted 97.6% of expenditure for the 46 critical care units as a whole. The square root of the difference in monthly observed vs. modelled expenditure was determined for each critical care unit and the average of the sum (for the whole sample) calculated. (281.83).

Table 7.15: Predicted expenditure using Model 9 vs. actual expenditure by Critical Care Unit

Hospital	Expenditure (£)	Modelled Expenditure (M£)	Difference (Model M£ - Expenditure £)	Square Root Differences
Aberdeen Royal Infirmary	152960	351671	198691	445.75
Bristol Royal Infirmary	762652	610902	-151750	389.55
Broomfield Hospital	613105	705084	91979	303.28
Colchester General Hospital	485915	436619	-49296	222.03
Cumberland Infirmary	356823	515030	158207	397.75
East Surrey Hospital	244852	261863	17011	130.43
Eastbourne District General Hospital	326057	362892	24835	157.59
Frimley Park Hospital	616909	824528	207619	455.65
George Eliot Hospital	349540	472497	122957	350.65
Good Hope Hospital	628814	432077	-196737	443.55
Hemel Hempstead Hospital	324564	350726	26162	161.75
Hope Hospital	301724	372825	71101	266.65
John Radcliffe Hospital	701478	424527	-276951	526.26
Leighton Hospital	299638	278907	-20731	143.99
Lincoln County Hospital	307021	373894	66873	258.60
Luton & Dunstable Hospital	400421	389214	-11207	105.87
Monklands District General Hospital	274430	343918	69488	263.61
New Cross Hospital	694936	797553	102617	320.34
Northwick Park Hospital	627430	562300	-65130	255.21
Queen Elizabeth Hospital, Birmingham	320545	342178	21633	147.08
Queen Elizabeth Hospital, Gateshead	307716	164856	-142860	377.97
Queen Elizabeth Hospital, King's Lynn	521769	342292	-179477	423.65
Queen Elizabeth II Hospital	226444	182920	-43524	208.63
Queen Mary's Hospital	248879	305851	56972	238.69
Royal Brompton Hospital	1141423	866276	-275147	524.55
Royal Devon & Exeter	353170	310162	-43008	207.39
Royal Marsden Hospital	194679	264475	69796	264.19
Royal National Orthopaedic Hospital	120161	130937	10776	103.81
Scunthorpe General Hospital	209702	245717	36015	189.78
Southampton General Hospital	299316	446191	146875	383.24
St. Peter's Hospital	539047	479867	-59180	243.27
Taunton & Somerset Hospital	838363	218790	-619573	787.13
The Horton Hospital	143251	211001	67750	260.29
Torbay Hospital	382284	419197	36913	192.13
Trafford General Hospital	265887	230295	-35592	188.66
Victoria Infirmary HDU	107285	254138	146853	383.21
Walton Centre for Neurology & Neurosurgery	629253	604235	-25018	158.17
Warrington Hospital	334860	206805	-128055	357.85
Worcester Royal Infirmary	548236	503024	-45212	212.63
Worthing Hospital	580446	560169	-20277	142.40
Walsgrave Hospital C2 HDU	160418	222064	61646	248.29
Walsgrave Hospital C2 ICU	305007	213568	-91439	302.39
Walsgrave Hospital C5 ITU	229073	230466	1393	37.32
Derriford Hospital	686843	931035	244192	494.16
Leeds General	300308	255114	-45194	212.59
St. James' Hospital	620969	626775	5786	76.07
Total	**19086643**	**18625425**	**-461219**	**12964.02**
Average				**281.83**

In order to determine total per diem case-mix adjusted costs, it is necessary to add to these estimates, the costs of the other resources not included in the cost model. These included the costs of: Consultant Medical Staff; Other Medical Staff; Administration; Radiology; Laboratory Services; Blood and blood products; Nutritional products; Specialised bed therapy; Dieticians; Physiotherapists; Speech and

language therapy; Occupational therapy; Medical Technical Officers; Clinical Pharmacists; Information Technologists; Clinical and Biomedical Scientists; Clinical Psychologists; Directorate Accountants and Personnel Officers (Table 7.16). Taking out the costs of nursing staff, drugs and fluids and disposable equipment from the total cost of care, leaves an overhead (non-modelled cost) of £522.50 per day (Hibbert *et al.*, 2003).

Table 7.16: Mean costs of major resource components per calendar day

Resource Number	Resource	Number of centres (%)	Number of months	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean ±SD cost per calendar day (£)
1	Nursing staff	46 (66%)	107	165	462	587 ± 214
2	Other Medical Staff	27 (39%)	67	14	49	111 ± 66
3	Consultant Medical Staff	25 (36%)	61	16	56	97 ± 55
4	Administrative support	26 (37%)	62	3	8	11 ± 5
5	Drugs and Fluids	46 (66%)	107	11	59	105 ± 68
6	Disposable Equipment	46 (66%)	107	9	57	89 ± 51
7	Blood and blood products	23 (33%)	59	7	18	38 ± 25
8	Nutritional products	29 (41%)	75	0	2	10 ± 16
9	Laboratory services	25 (36%)	64	8	22	42 ± 26
10	Radiology	28 (40%)	70	2	11	24 ± 23
11	Physiotherapists	41 (59%)	103	2	12	21 ± 14
12	Medical Technical Officers (MTOs) & Assistant MTOs	31 (44%)	78	0	0	10 ± 13
13	Clinical and biomedical scientists	28 (40%)	70	0	0	9 ± 23
14	Information Technologists	29 (41%)	74	0	0	6 ± 9
15	Clinical Pharmacists	42 (60%)	104	0	1	6 ± 7
16	Dieticians	47 (67%)	115	0	2	5 ± 5
17	Directorate Accountants	47 (67%)	116	0	1	3 ± 5
18	Personnel Officers	31 (44%)	77	0	0	2 ± 4
19	Speech & Language therapists	38 (54%)	100	0	0	1 ± 1
20	Psychologists	26 (37%)	68	0	0	0 ± 2
21	Occupational therapy	28 (40%)	69	0	0	0 ± 1
22	Specialised bed therapy	47 (67%)	114	0	0	6 ± 10
	TOTAL COST					**1185.14**
23	Capital Equipment (10% of total cost)					118.51
	Total cost					**1303.65**

Table 7.17 shows the total per diem costs that include the organ support-weighting factor for nursing staff, drugs and fluids and disposable equipment and the overhead (non-modelled cost). The way in which these non-modelled costs have been apportioned assumes equal use of resources independent of the number of organs supported.

Table 7.17: Per diem cost estimates that Include the case-mix adjusted costs of nursing staff, drugs and fluids and disposable equipment and the non-modelled costs.

Number of organ systems	Daily cost estimates (£)	Non-Modelled Costs (£)	Total Daily Costs (£)
0 or 1	451	522.50	973.50
2	888	522.50	1410.50
3 or more	903	522.50	1425.50

The organs were weighted as follows:

- 0 or 1 organ supported = (Model Coefficient of £451 / Mean cost per day of nursing staff, drugs and fluids and disposable equipment of £781) = 0.577
- 2 organs supported = (Model Coefficient of £888 / Mean cost per day of nursing staff, drugs and fluids and disposable equipment of £781) = 1.137
- 3 or more organs supported = (Model Coefficient of £903 / Mean cost per day of nursing staff, drugs and fluids and disposable equipment of £781) = 1.156.

After having performed the cluster analysis described in Section 7.7, and discussed the results of the subsequent models with the NHS Information Authority (NHSIA) and the Department of Health Critical Care Working Group on Funding, the question of whether formal

groupings were needed was mooted. This was because knowing the daily costs of patients weighted for case-mix offered a perfectly adequate solution to the problems of estimating the costs of patients using more traditional methods. The possibility of hospitals abusing this method of reimbursement compared to the groupings described in Section 7.7 was also less likely. By the time that these analyses had been performed, the focus of the work (being directed towards HRG development) became more centred on devising an appropriate method for reimbursing costs. The NHSIA believed that patients could be assigned to HRGs retrospectively, given their daily profile of organ support data, which overcame the need to define specific groups up front.

7.9.2 User Survey

Model 9 met all of the NHS Information Authority criteria described in Section 7.4.3.

The methodology – that being the collection of daily organ support data to support this way of estimating total patient costs – was piloted for a 3-month period (1st August 2004-1st October 2004) in 6 adult critical care units. Sites were selected through a formal evaluation process following a national advertisement seeking Expressions of Interest.

Critical care units were asked to evaluate the use of the method in terms of:

- Its relevance to patient costs;
- Time taken to record the necessary data;
- Whether the proposed HRGs were able to capture sufficient information to describe the treatments given and the differences in treatments given to different patients;
- The consistency of the data collection process;

- Its usefulness as a clinical and management tool beyond its primary use as an indicator resource cost.

The respondents found the amount of time taken to record the information acceptable. They were also satisfied that the different types of organ support measured what they claimed to measure and that the definitions listed for each type of organ support provided about the right amount of information. The issue of data definitions falls within the scope of the Critical Care Minimum Data Set (CCMDS) authored by the Critical Care Information Advisory Group (CCIAG) formed by the Department of Health and the NHS Modernization Agency. The CCIAG Submission to the Information Standard's Board for the CCMDS stated that '*comments pertaining to the definitions have been considered by CCIAG and the definitions revisited. The robust CCMDS Training Programme that is planned will help to ensure that any lingering uncertainty is minimized*'.

The respondents further felt that the different types of organ support distinguish between those patients that actually have the organ support and those that don't. A high number of respondents stated that they believed that (all things constant) they would complete the data collection materials in the same way even if they collected the data at a different time of the day.

7.10 Discussion

DRGs have not been found to correspond well to the costs of critical care patients because of their emphasis on diagnosis rather than treatment (Munoz *et al.*, 1989; Bekes *et al.*, 1988; Hughes *et al.*, 1989; Goldman *et al.*, 1989). It was for this reason that a different approach – such as an emphasis on treatment – the organ support component of care – was employed here.

The first aim of this chapter was to identify an appropriate method from which estimates of daily case-mix adjusted costs could be determined. The cost per weighted day measure is preferable to the

straight per diem cost indicator because it is a more refined indicator and is best used when wanting to capture cost difference that arise because of cases with different types of organ support (Jacobs & Baladi, 1996). The aim was achieved by analysing the organ support and expenditure data collected from a sub-set of 46 volunteer critical care units.

Multilevel modelling has wide potential for adapting to a variety of data structures and research questions (Carey, 2000) and was the first time that data had been analysed in this way within the adult critical care setting. The model of choice was informed by the Breusch-Pagan and Hausman specification tests that favoured a random-effects model based on the number of organs supported on a daily basis; clustered to include 0 or 1 organ, 2 organs and 3 or more organs. Whilst the R^2 produced for this final model was less than other models developed, it offered a simple and reproducible system that could be implemented with ease and coefficients that followed logical sense. The model using single and multiple combinations of organ support suffered from having too many independent variables in the model that even when some re-grouping was undertaken (to reduce the extent of the problem), failed to yield cost estimates that made logical sense. It is possible, that with a much larger sample, that these problems could have been emolliated in the most part, however it is unlikely that within the existing data set that this approach would have met the NHSIA criteria in terms of the number of groups being 'manageable' since many conceivable combinations of organ support were possible.

The purpose of the Adult Critical Care HRGs is to enable the service to collect resource usage for critical care in a standardised manner. The HRGs will be used to calculate standard reference costs and tariffs. It is the intention of the Financial Flows, Payment By Results team to establish a set of national tariffs for the commissioning of critical care services from 2006/7. It is intended that the HRG will be used as a means of fulfilling the requirement that funding for the majority of work carried out by the NHS is funded at a national tariff as specified

in Payment By Results. The approval standards for the proposed HRGs were based on their purpose (which is their ability to case-mix adjust the funding requirements for critical care) and as such, the HRGs needed to be:

- Clinically meaningful; and
- Homogeneous (as far as homogeneity can be achieved in this patient population).

To be acceptable to people collecting the information from which HRGs can be derived, the source data needed to be:

- Integrated into a routine data set (CCMDS) and
- Relatively easy to collect (by audit staff that are perhaps not clinically trained).

Ease of collection can be defined in terms of whether the items (and definitions) and the HRGs had to:

- Make sense i.e. did everyone understand basic respiratory support from the definition as being basic respiratory support as received by the patient) and;
- Were collectable within existing infrastructures for data collection within critical care units. By this, I am referring to the quantity of items within the source data set.

Not all types of organ support were included in the model. Dermatological support was excluded due to very small patient numbers and liver support was also excluded. Liver was excluded deliberately as because of the very high cost of liver support and its specialist nature (see below), the Payment By Results team had decided that liver support would be reimbursed outside of the HRG based tariff system. There is only one treatment available for liver support within the critical care setting. It has not been scientifically evaluated and for that reason it is not recognised as a conventional treatment for liver failure. The treatment in question is called molecular adsorbent

recirculating system (MARS®). MARS® employs an albumin-enriched dialysate to facilitate the removal of albumin-bound toxins (ABT). It is thought (through a number of case studies) to remove both hydrosoluble substances such as urea, creatinine, and ammonium and these so-called ABTs – phenol, bile acids, bilirubine, branched chain amino acids and short chain fatty acids. It is used to enable recovery to reach pre-decompensation status by liver regeneration, act as a short or long term bridge to liver transplantation and to improving the pre-operation condition of the patient before liver transplantation.

The work of this chapter shaped the development of HRGs for the purpose of the Department of Health's Financial Flows Policy and was formally approved by the following bodies:

- NHS Information Standard's Board (ISB)[48]
- NHS Information Authority Clinical Working Group
- Department of Health Funding Working Group
- The Critical Care Information Advisory Group
- The Intensive Care Society
- Department of Health's Payment By Results Team.

The work went through an extensive review process by the above bodies (Hibbert *et al.*, 2004). The NHS Information Standards Advisory Board commented in their appraisal summary that '*there was a general consensus that the submission was a very good piece of work*' (See Appendix 7.3).

Based on these findings, the second aim of this chapter was met; that being to propose a set of HRGs that met both the criteria of the NHS Information Authority (2002) and that of Hornbrook (1982).

Two key benefits to Model 9 are that:

48 The standard will be known as Healthcare Resource Groups (HRGs) for Adult Critical Care, Levels 2 and 3. Version 3.6. Conditional approval was granted on 4th March 2005 – dependent on approval of the CCMDS which would be data set capturing the organ support data. See Appendix 7.2.

- It does not ignore the recognised trend in resource consumption with increasing duration of stay since the approach works on daily organ support data and;
- It avoids all of the problems associated with diagnostic grouping due to its focus on grouping patients according to resource consumption. Not every patient with the same diagnosis will follow the same clinical course and hence will have variable resource consumption.

In conclusion, this Chapter has produced a cost model from which daily case-mix adjusted estimates of cost can be determined and through a rigorous approval process, can be deemed a reliable and acceptable means of supporting the Department's of Health Financial Flows reimbursement policy for adult critical care.

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CHAPTER 8: APPLICATION OF ORGAN SUPPORT COST WEIGHTS TO A TRIAL- BASED ECONOMIC EVALUATION

8.1 Introduction

This Chapter considers the application of the organ support weights described in Chapter 7 to an ongoing economic evaluation alongside a clinical trial. The CESAR trial is one of the first multi-centre trial-based economic evaluations performed in adult critical care units in the U.K, which has been designed to investigate the clinical and cost-effectiveness of two treatments for severe but potentially reversible, respiratory failure. These treatments are Extracorporeal Membrane Oxygenation (ECMO) and conventional therapy. At this present time, the trial is still recruiting patients.

ECMO is a specialist treatment to allow lung rest that is currently being evaluated in one centre in the U.K. (Glenfield Hospital in Leicester) and conventional therapy for respiratory failure (the comparator arm of the trial) is provided in a number of different critical care units across the country. Whilst the economic evaluation will adopt a full societal perspective, the work of this Chapter focuses only on the collection of critical care unit costs for the two treatment arms.

The overall aim of this exercise was to estimate the incremental costs of ECMO, over and above the costs of conventional therapy for patients with severe, but potentially reversible, respiratory failure recruited to the CESAR trial. Organ support data has been collected on all recruited patients which will enable us to case-mix adjust the average daily costs of participating critical care units using the organ support weights described in Chapter 7 (Section 7.9.1).

Centre-specific estimates of intensive care cost were sought based on Raikou *et al.*, (2000) who consider hospitals to operate as cost-minimizing firms. A survey of participating centres was conducted to

obtain centre-specific estimates of critical care units' average daily costs that related to the same time period when individual patients had been recruited to the trial. The completeness of the returned expenditure data was investigated by resource item and the steps taken to account for the missing data are also described. Despite difficulties in accessing the needed expenditure data relating to the costs of providing ECMO at Glenfield Hospital and the limited information provided, an attempt was made to derive average daily costs. The Chapter closes with a discussion of the main findings.

8.2 Aims

The overall aim of this study was to estimate the incremental cost of ECMO over and above the costs of conventional therapy for patients with severe, but potentially reversible, respiratory failure.

The objectives of the study were:

- To collect expenditure data from all critical care units that recruited patients to the CESAR trial together with data on their unit characteristics (these included both conventional treatment centres and the Glenfield ECMO Unit);
- To compare the daily conventional treatment costs with those described in Chapter 6; and
- To apply the cost weights developed using model 9 (described in Chapter 7, Section 7.9.1), to the daily costs of conventional treatment and ECMO to estimate patient-level case-mix adjusted costs for patients in both arms of the trial.

8.3 Description of the CESAR clinical trial

CESAR is one of the first multi-centre trial-based economic evaluations performed in adult critical care units in the U.K. The trial is investigating two treatments for critically ill patients with severe, respiratory failure namely, conventional ventilatory support and

Extracorporeal Membrane Oxygenation (ECMO) (www.cesar-trial.org).

The National Co-ordinating Centre for Health Technology Assessment (NCCHTA) and the Department of Health National Specialist Commissioning Advisory Group (NSCAG) are jointly funding both the clinical trial and the concurrent economic evaluation.

Recruitment of patients started in July 2000 and the trial is presently still recruiting. Trent Multi-Centre Research Ethics Committee (MREC/00/4/046) granted ethical approval for the trial in 2000.

The primary hypotheses of the trial are two-fold: that ECMO will increase the rate of survival without severe disability by six months post-randomisation and be cost effective from the viewpoints of the NHS and society, compared to conventional ventilatory support. A full societal perspective has been adopted and a cost-utility analysis is anticipated. Analysis of the data collected will be by intention to treat, with sub-group analyses based on the minimisation criteria at trial entry.

8.3.1 Treatments under evaluation

Extracorporeal Membrane Oxygenation (ECMO)

ECMO uses cardio-pulmonary bypass technology to allow lung rest in patients with severe (but potentially reversible) respiratory failure. The treatment provides sufficient oxygen transfer and carbon dioxide removal so that ventilator settings (inspired oxygen concentration and peak inflating pressures) may be decreased to less injurious levels. The technique of veno-venous perfusion is used, where blood is drained from the right atrium via a catheter placed via the right internal jugular vein, and pumped using a roller pump to the oxygenator; a device designed for gas exchange. Blood is returned via the femoral vein raising the oxygen content of venous blood before it enters the heart.

ECMO is a high cost treatment because specialist nurses and doctor are required to oversee the fluid and ventilator management of patients and treat any complications. A common complication with ECMO is bleeding (and so patients require blood products such as red blood cells, platelets and clotting factors) (Lancey & Anderson, 2003).

Conventional Therapy

Conventional therapy is any other treatment for severe respiratory failure that relies on the lungs to provide gas exchange.

8.3.2 Study Inclusion Criteria

There are two types of inclusion criteria for the trial; one for the adult critical care units and the other for patients.

Centre Inclusion Criteria

ECMO is provided at the Cardio-thoracic Intensive Care Unit (ICU) at Glenfield Hospital, Leicester. Note that this is the only specialist centre providing ECMO in the U.K.

Conventional treatment is provided within Adult Critical Care Units (hereon after referred to as 'conventional treatment centres' (CTCs)) that:

- Provide an appropriately high standard of care for ECMO-eligible patients;
- Treat $\geq$ 350 patients per year; and
- Provide pressure controlled ventilation and veno-venous haemofiltration.

In addition to the CTCs, patients meeting the patient inclusion criteria can be entered into the trial from other hospitals (so-called referral hospitals), if those hospitals concerned are prepared to transfer the patient(s) to a designated CTC, should the allocation [of the patient] be to conventional management.

Patient Inclusion Criteria

Adult patients (aged between 18-65 years) with severe, but potentially reversible respiratory failure are eligible. Severe respiratory failure is defined by a Murray score (Murray *et al.*, 1998) of $\geq$3.0.

The Murray score is a grading system for adult respiratory distress syndrome that uses 4 parameters to give a severity index for the syndrome. The parameters are PaO_2/FIO_2 which is the ratio between the oxygen tension in the arterial blood and the fraction of inspired oxygen), positive end expiratory pressure (PEEP), lung compliance and chest x-ray appearance) or uncompensated hypercapnoea with a pH <7.20. A Murray score of 3.0 is the minimum entry criterion.

8.3.3 Patient Exclusion Criteria

The patient exclusion criteria covers patients who have received high pressure and high FIO_2 ventilation > 7 days, patients who have experienced severe trauma or undergone surgery within the last 24 hours with a contra-indication to limited heparinisation; patients with intra-cranial bleeding and any other contra-indication to limited heparinisation and finally, patients who are moribund and have any contra-indication to continuation of active treatment.

8.3.4 Delivery of Treatment

ECMO

Patients randomised to receive ECMO are transferred to the Cardio-thoracic ICU at Glenfield Hospital for consideration of ECMO support. There is no crossover to ECMO for patients allocated to conventional management.

Conventional Management

Patients randomised to conventional therapy receive standard critical care provided in one of a number of participating CTCs. This may

occasionally involve transfer from a referring hospital (see Section 8.3.3). Conventional ventilatory support can include any treatment modality thought appropriate by the patient's doctor (excluding ECMO). A low volume ventilation strategy (tidal volume ≤ 6ml/Kg, peak inspiratory pressure ≤ 30 cm/H_2O) is recommended, following a ventilation study of lower tidal volumes compared with traditional tidal volumes by The Acute Respiratory Distress Syndrome Network (2000).

8.3.5 Sample Size

The sample size calculated for the clinical trial assumes a 10% risk of severe disability among survivors in both trial arms, an alpha = 0.05 (2 sided test) and beta = 0.2. This calculation suggests a sample size of 120 patients in each group (i.e. a total sample size of 240) is required to detect a reduction in the rate of primary outcome (mortality) from 73% to the 55% which is a conservative estimate based on descriptive studies of adult ECMO (Peek *et al.*, 1997). No sample size calculation was performed for the economic evaluation.

8.4 Methods of the CESAR Economic Evaluation

The primary objective of the economic evaluation was to assess incremental cost-effectiveness of ECMO in terms of the incremental costs of additional survival with and without disability at six months post-randomisation, compared to conventional treatment for severe, respiratory failure. The evaluation set out to assess the cost of treatment to the health and social services and to patients and their families in each treatment group (See Appendix 8.3). The remainder of this Chapter will focus on the estimation of critical care unit costs of treatment for both arms and the application of the organ support weights described in Chapter 8.

8.4.1 Methods for estimating the Critical Care Unit Conventional Treatment Costs (CTCs)

Whilst the economic evaluation adopted a full societal perspective, the time span for the estimation of the costs of conventional treatment in the critical care unit was confined to the number of days spent by patients in the trial in the critical care unit until discharge to a hospital ward (or death within the critical care unit). The same rule applied to the estimation of ECMO costs.

Collection of the organ support data

The cost trigger for patients recruited to the clinical trial was days of organ support measured daily from the point of randomisation until discharge from the critical care unit (or death) (see Appendix 8.1). These data were collected for both arms using the trial proforma which once completed by the staff working in the respective critical care units was faxed back to the Data Co-ordinating Centre (DCC) at the London School of Hygiene & Tropical Medicine in London and the data then entered into the clinical trial database. Note that data on the types of organ support were defined in the same way as those used in the Cost Model described in Chapter 7. The collection of these data was coordinated by the DCC and it was not known the extent to which missing or inaccurate data presented. It was assumed that for all patients a proforma documenting their organ support data was returned and that these data were complete.

Collection of the Cost Data

The aim of the costing study was to estimate a daily costs from each recruiting critical care unit with a view to adjusting this cost according to the organ support profile of patients. To this end, critical care unit expenditure data from each of the recruiting units (relating to the same financial year during which patients were studied within the trial) were sought. The Finance Director at each NHS Hospital Trust held accountable for the administration of the critical care unit's funds was contacted in June 2004. Accompanying a covering letter and a copy of

the economic evaluation protocol was a cost questionnaire that facilitated the entry of the expenditure estimates for the financial year in question (Appendix 8.2-8.4). The collection of data covered four financial years (1st April 2001-31st March 2002, 1st April 2002-31st March 2003, 1st April 2003-31st March 2004, 1st April 2004-31st March 2005). Questionnaires were produced for each financial year and the content of those matched those described in Chapter 5 (i.e. the definitions used for each resource item were the same). In order to calculate estimates of daily cost, the unit characteristics questionnaire had to be completed as the latter questionnaire provided data on the total number of patient days within the same financial year (with which the expenditure data could be apportioned down to an average daily cost).

A copy of the covering letter was also sent to the named critical care unit collaborator, responsible for the collection of the clinical trial data (for their information). As already alluded to above, the same definitions for each resource use item were employed for the costing study described in Chapter 5.

The mailing of questionnaires was repeated twice due to poor response levels, up until the end of July 2005.

Coverage of The Costing Study

The coverage of costs included in this study was exactly the same as those resource use items collected in the multi-centre study described in Chapters 5 and 6.

Collection of the Unit Characteristics Data

A unit characteristics questionnaire was sent to the named critical care unit collaborator that sought to elicit descriptive information about the critical care unit in terms of its size (number of staffed beds) and patient throughput (number of patient days) during the financial year when a patient was recruited to the trial. This questionnaire was produced for 3 reasons: 1) to describe the characteristics of the critical

care units in resultant publications stemming from the work, 2) to be able to make comparisons between the sample of units studied in the HRG study – Chapters 6 and 7, and finally, 3) to allow the expenditure data to be apportioned accurately by obtaining data on the number of patient days.

Fifty-eight unit characteristic questionnaires were sent out to 40 hospitals (because some units recruited patients in different financial years), which produced an average of 1.45 questionnaires per hospital.

Steps taken to deal with missing data

No steps were taken to compensate for data missing from the unit characteristic questionnaires because it was not possible or appropriate to substitute missing data on these characteristics using data from the other critical care units. Missing average daily cost data was however substituted using the mean estimates obtained from the responding CTCs by financial year.

8.4.2 Methods for estimating the costs of ECMO

Due to difficulties in obtaining expenditure data from Glenfield Hospital because of a lack of co-operation from the Hospital Accountants, the only available information that was forwarded by them consisted of prospective budget statements for 2 financial years. Budget statements differ from expenditure statements by detailing anticipated costs for a financial year (1st April – 31st March) instead of reporting actual annual expenditures, so are not as informative. However, given that this was the only information available, it had to suffice.

Budget statements for the Cardio-thoracic ICU at Glenfield Hospital were therefore obtained for the financial years (2002-2003 and 2004-2005). Statements for the financial years (2001-2002) and (2003-2004) were missing. The budget statements related to the costs of looking after adult patients alone (as opposed to paediatric and neonatal patients who are also treated with ECMO at Glenfield Hospital).

In order to apportion the budgeted costs down to a patient-day measurement, the Glenfield Hospital Accountants advised an anticipated throughput of 1,000 patient days for each financial year in question. This throughput estimate was based on the ICU treating 30 adult patients with ECMO, all of which would stay an average of 33 days. The sum of all budgeted costs was thus divided by 1,000.

The budget statements covered all of the costs associated with treatment with ECMO.

8.5 Response rates for the cost and unit characteristics survey: CTCs

8.5.1 Response Rates

Forty hospitals recruited patients up until the 31st March 2005. Given that more than one hospital recruited, in some cases, more than one patient during each financial year and patients could have received treatment in both an ICU and an HDU, one hundred and sixteen cost questionnaires were sent out in total to account for this (58 for the ICU and combined ICU / High Dependency Units (HDUs) and 58 for the separate HDUs – where provided). The types of critical care units i.e. which of the participating critical care units had both an ICU and an HDU or operated as a combined ICU / HDU, were not known, so each critical care unit was sent two cost questionnaires for each financial year when a patient was recruited to the trial.

The response rates by financial year and hospital are shown and report the status of the study as of 20th June 2005 (table 8.1). The crosses indicate the non-return of the cost questionnaires. As is evident, there were a very low number of responses (ticks).

Table 8.1: Response rates for the return of cost questionnaires by Hospital

Hospital name	Cost Questionnaires ICU				Cost Questionnaires HDU			
	2001-2002	2002-2003	2003-2004	2004-2005	2001-2002	2002-2003	2003-2004	2004-2005
Bedford Hospital			X	X			X	X
Ipswich Hospital				✓				
Luton & Dunstable Hospital	✓		✓	✓	✓		✓	✓
West Suffolk Hospital			✓				X	
North Middlesex Hospital				X				X
Royal London Hospital		X		X		X		X
Aintree Hospital				✓				
Arrowe Park Hospital		X				X		
Blackpool Victoria Hospital			✓				✓	
Leighton Hospital		✓	✓			✓	✓	
Macclesfield District General Hospital		✓		X		✓		X
Manchester Royal Infirmary	X				X			
Royal Albert Edward Infirmary		✓				✓		
Royal Bolton Hospital		✓				X		
Royal Preston Hospital		X		X		X		X
Southport & Formby Hospital				✓				✓
Castle Hill Hospital	X		X	X	X		X	X
Huddersfield Royal Infirmary				✓				X
Hull Royal Infirmary				X				X
Queen Elizabeth Hospital, Gateshead	X		X		X		X	
Ninewells Hospital	X				X			
Southern General Hospital				X				X
Kettering General Hospital		✓	✓			X	X	
Milton Keynes General Hospital				X				X
St. Mary's Hospital, Isle of Wight		✓						
Cheltenham General Hospital	X		X		X		X	
Gloucestershire Royal Hospital	X	X	X	X	X	X	X	X
Chesterfield & North Derbyshire Hospital		X		X		X		X
Derbyshire Royal Infirmary			X				X	
Glenfield Hospital			X				X	
Leicester General Hospital			X				X	
Leicester Royal Infirmary	X				X			
Northern General Hospital	✓	✓			✓	✓		
Nottingham City Hospital				X				X
Rotherham District General Hospital				X				X
Royal Hallamshire Hospital			✓				✓	
Glan Clwyd District General Hospital		X				X		
University Hospital of Wales	X			X	X			X
Warwick Hospital	X				X			
Worcester Royal Hospital		✓						

Table 8.2 lists the hospitals and indicates whether or not they returned their unit characteristics questionnaires. Of the 116 distributed questionnaires, 34 (29%) were returned. The 34 questionnaires related to 26 hospitals.

Table 8.2: Response rates for the return of unit characteristic questionnaires By Hospital

Hospital name	Unit Characteristics Questionnaire			
	2001-2002	2002-2003	2003-2004	2004-2005
Bedford Hospital			✓	✓
Ipswich Hospital				✓
Luton & Dunstable Hospital	✓		✓	✓
West Suffolk Hospital			✓	
North Middlesex Hospital				✓
Royal London Hospital		X		X
Aintree Hospital				✓
Arrowe Park Hospital		X		
Blackpool Victoria Hospital			✓	
Leighton Hospital		X	X	
Macclesfield District General Hospital		X		✓
Manchester Royal Infirmary	X			
Royal Albert Edward Infirmary		✓		
Royal Bolton Hospital		✓		
Royal Preston Hospital		✓		X
Southport & Formby Hospital				X
Castle Hill Hospital	✓		✓	✓
Huddersfield Royal Infirmary				X
Hull Royal Infirmary				X
Queen Elizabeth Hospital, Gateshead	✓		✓	
Ninewells Hospital	✓			
Southern General Hospital				X
Kettering General Hospital		✓	✓	
Milton Keynes General Hospital				X
St. Mary's Hospital, Isle of Wight		X		
Cheltenham General Hospital	✓		✓	
Gloucestershire Royal Hospital	✓	✓	✓	✓
Chesterfield & North Derbyshire Hospital		✓		X
Derbyshire Royal Infirmary			X	
Glenfield Hospital			X	
Leicester General Hospital			✓	
Leicester Royal Infirmary	X			
Northern General Hospital (ICU & HDU)	✓	✓		
Nottingham City Hospital				✓
Rotherham District General Hospital				✓
Royal Hallamshire Hospital (ICU and HDU)			✓	
Glan Clwyd District General Hospital		✓		
University Hospital of Wales	X			X
Warwick Hospital	X			
Worcester Royal Hospital		✓		

8.5.2 Return of both unit characteristics and cost data

Only 11 hospitals returned data on both their unit characteristics and expenditures (Table 8.3). Of these 11 hospitals, 13 critical care units existed, as the Northern General and Royal Hallamshire Hospitals provided both cost and unit characteristics data for their ICUs and geographically adjacent HDUs. Some critical care units provided data for more than one financial year, resulting in 18 observations in total.

Table 8.3: Response rates for the return of both unit characteristic and cost questionnaires by Hospital

Hospital name	Unit Characteristics And Cost Questionnaires			
	2001-2002	2002-2003	2003-2004	2004-2005
Bedford Hospital			X	X
Ipswich Hospital				✓
Luton & Dunstable Hospital	✓		✓	✓
West Suffolk Hospital			✓	
North Middlesex Hospital				X
Royal London Hospital		X		X
Aintree Hospital				✓
Arrowe Park Hospital		X		
Blackpool Victoria Hospital			✓	
Leighton Hospital		X	X	
Macclesfield District General Hospital		X		X
Manchester Royal Infirmary	X			
Royal Albert Edward Infirmary		✓		
Royal Bolton Hospital		✓		
Royal Preston Hospital		X		X
Southport & Formby Hospital				X
Castle Hill Hospital	X		X	X
Huddersfield Royal Infirmary				X
Hull Royal Infirmary				X
Queen Elizabeth Hospital, Gateshead	X		X	
Ninewells Hospital	X			
Southern General Hospital				X
Kettering General Hospital		✓	✓	
Milton Keynes General Hospital				X
St. Mary's Hospital, Isle of Wight		X		
Cheltenham General Hospital	X		X	
Gloucestershire Royal Hospital	X	X	X	X
Chesterfield & North Derbyshire Hospital		X		X
Derbyshire Royal Infirmary			X	
Glenfield Hospital			X	
Leicester General Hospital			X	
Leicester Royal Infirmary	X			
Northern General Hospital	✓	✓		
Nottingham City Hospital				X
Rotherham District General Hospital				X
Royal Hallamshire Hospital			✓	
Glan Clwyd District General Hospital		X		
University Hospital of Wales	X			X
Warwick Hospital	X			
Worcester Royal Hospital		✓		

8.5.3 Data Completeness

The completeness of the returned data was first investigated by resource item (Table 8.4) and then by critical care unit (Table 8.5). The rate of completeness (termed 'data availability' in Table 8.4) was taken as the number of responses divided by the total number of 18 possible responses and expressed as a percentage.

The expenditure questionnaires were not fully completed as can be seen from Table 8.4. Data on nursing and administrative staff together with drugs and fluids yielded the highest number of responses (77%). Data on clinical and biomedical scientists and clinical psychologists yielded the lowest number of responses at 14%. Some hospitals were more adept at providing the expenditure data than others. For example, Ipswich hospital was able to provide expenditure data for all of the resource items captured within the questionnaire. Other hospitals such as the Royal Bolton Hospital and West Suffolk Hospital returned their questionnaires with a lot of missing data.

Table 8.4: Response rates for the return of resource use items contained within the cost questionnaires

Resource Use Item	Number Of Responses	Data Availability (%)
Nursing staff	17	77%
Administrative staff	17	77%
Drugs and fluids	17	77%
Nutritional products	12	55%
Disposable equipment	16	73%
Consultant medical staff	16	73%
Other medical staff	15	68%
Radiology	14	64%
Laboratory services	16	73%
Blood and blood products	14	64%
Specialised bed therapy	13	59%
Dietician	7	32%
Physiotherapists	13	59%
Speech and language therapists	6	27%
Occupational therapists	6	27%
Medical Technical Officers	7	32%
Clinical Pharmacists	5	23%
Information Technologists	6	27%
Clinical and Biomedical Scientists	3	14%
Clinical Psychologists	3	14%
Directorate Accountants	9	41%
Personnel Officers	5	23%

Table 8.5: Number of Critical Care Units contributing cost data for analysis

Hospital Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Ipswich Hospital ICU																						
Financial year 2004/2005	✓	✓	✓	✓	✓	✓	✓	✓	✓	✖	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Luton & Dunstable Hospital ICU																						
Financial year 2001/2002	✓	✓	✓	✖	✓	✓	✓	✓	✓	✓	✓	✓	✖	✓	✓	✖	✓	✖	✖	✖	✓	✖
2003/2004	✓	✓	✓	✖	✓	✓	✓	✓	✓	✓	✓	✓	✖	✓	✓	✖	✓	✖	✖	✖	✓	✖
2004/2005	✓	✓	✓	✖	✓	✓	✓	✓	✓	✓	✓	✓	✖	✓	✓	✖	✓	✖	✖	✖	✓	✖
West Suffolk Hospital ICU																						
Financial year 2002/2003	✓	✓	✓	✖	✓	✖	✖	✖	✖	✖	✓	✖	✖	✖	✖	✖	✖	✖	✖	✖	✖	✖
Aintree Hospital ICU																						
Financial year 2003/2004	✓	✓	✓	✖	✓	✓	✓	✓	✓	✓	✓	✓	✓	✖	✖	✖	✓	✓	✖	✖	✓	✖
Blackpool Victoria Hospital ICU / HDU																						
Financial year 2003/2004	✓	✓	✓	✖	✓	✓	✓	✖	✓	✓	✖	✖	✓	✖	✖	✖	✖	✖	✖	✖	✖	✖
Royal Albert Edward Infirmary ICU																						
Financial year 2002/2003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✖	✓	✖	✖	✖	✖	✖	✖	✖	✖	✖

Hospital Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Royal Bolton Hospital ICU																						
Financial year 2002/2003	✗	✗	✗	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Kettering General Hospital ICU																						
Financial year 2002/2003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗	✗
2003/2004	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓	✗	✗
Northern General Hospital ICU																						
Financial year 2001/2002	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	✓
2002/2003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	✓
Northern General Hospital HDU																						
Financial year 2001/2002	✓	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	✓
2002/2003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗	✓	✓
Royal Hallamshire Hospital ICU																						
Financial year 2003/2004	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗
Royal Hallamshire Hospital HDU																						
Financial year 2003/2004	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✓	✗	✓	✗	✗	✗	✗	✓	✗	✗	✗	✗

Hospital Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Worcester Royal Hospital ICU 2002/2003	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	x	x	x	x	x	x	x	x	x

Key

1 Nursing staff
2 Administrative staff
3 Drugs and fluids
4 Nutritional products
5 Disposable equipment
6 Consultant medical staff
7 Other medical staff
8 Radiology
9 Laboratory services
10 Blood and blood products
11 Specialised bed therapy
12 Dieticians
13 Physiotherapists
14 Speech and language therapy
15 Occupational therapy
16 Medical Technical Officers
17 Clinical pharmacists
18 Information Technologists
19 Clinical and biomedical scientists
20 Clinical Psychologists
21 Directorate accountants
22 Personnel Officers

8.6 Characteristics of the CTCs that returned their Unit Characteristic Questionnaires

Although there was a very poor response rate, comparisons were made with the responding CTCs, the HRG study and the ICNARC CMPD. The results of these comparisons need to be interpreted with caution because of a) the low response rate and b) neither the HRG nor the ICNARC CMPD studies were representative. Comparisons were made just to see how valid the application of organ support weights derived from the HRG sample would be to the CESAR study.

8.6.1 Geographical location of centres

Table 8.6 stratifies the responding critical care units by geographical region. The North West and Trent had a higher proportion of CTCs than the other regions, followed by the Eastern Region and the South West and Northern & Yorkshire. The geographical representation of the sample was not comparable to the critical care units that participated in the HRG study as there were fewer CTCs represented in the South East, West Midlands and London.

Table 8.6: Geographical location of CESAR centres

Geographical Location	Number of Centres (CESAR) (% of total)	Number of Centres (HRG) (%) of total
Northern & Yorkshire	2 (8)	8 (11)
Trent	6 (23)	5 (7)
Eastern	4 (15)	7 (10)
London	1 (4)	6 (9)
South East	1 (4)	12 (17)
South West	2 (8)	10 (14)
West Midlands	1 (4)	9 (13)
North West	7 (27)	8 (11)
Wales	1 (4)	0 (0)
Scotland	1 (4)	3 (4)
Northern Ireland	0 (0)	2 (3)

8.6.2 Hospital Type

Table 8.7 reports the presence of a medical school within the hospital and whether the CTC could be deemed a tertiary referral centre. There appeared to be a lower proportion of CTCs with a medical school and those regarded as tertiary referral centres than in the HRG study.

Table 8.7: Hospital Type

Hospital Type	Number of Centres (CESAR) (%)	Number of Centres (HRGs) (%)
Medical School within the hospital	6 (15.0)	17 (24.0)
Tertiary Referral Centre	7 (17.5)	25 (36.0)
Unknown	14 (35.0)	7 (10.0)

8.6.3 Unit Type

Table 8.8 shows the frequency of CTCs by unit type. The sample was split in a similar manner to that of the HRG study between adult general intensive care units and combined adult general intensive care unit / high dependency units. There was however a much larger proportion of the CTC sample listed under the 'unknown' category. The main distinguishing feature of this comparison was the specialist critical care units that were absent from the CTC sample when compared to the HRG study.

Table 8.8: Types of Critical Care Unit

Unit Type	Number of centres (CESAR) (%)	Number of centres (HRG) (%)
Adult General Intensive Care Unit	13 (32.5)	17 (24.0)
Adult General High Dependency Unit	2*	2 (3.0)
Adult General Intensive Care Unit/ High Dependency Unit	13 (32.5)	32 (46.0)
Adult Surgical Intensive Care Unit	0 (0.0)	0 (0.0)
Adult Surgical High Dependency Unit	0 (0.0)	2 (3.0)
Adult Cardiothoracic Intensive Care Unit	0 (0.0)	2 (3.0)
Adult Coronary Care Unit	0 (0.0)	0 (0.0)
Adult Burns / Plastic Surgery Unit	0 (0.0)	2 (3.0)
Adult / Paediatric Burns Unit	0 (0.0)	0 (0.0)
Adult Neurological Intensive Care Unit / General Intensive Care Unit	0 (0.0)	2 (3.0)
Adult Neurological Intensive Care Unit / High Dependency Unit	0 (0.0)	4 (6.0)
Adult Combined Intensive Care Unit / High Dependency Unit / Coronary Care Unit	0 (0.0)	2 (3.0)
Adult Neurosurgical & Neurological Intensive Care Unit / High Dependency Unit	0 (0.0)	1 (1.0)
Adult General Intensive Care Unit / Neuro Critical Care Unit	0 (0.0)	1 (1.0)
Adult General Intensive Care Unit / High Dependency Unit / Neuro Intensive Care Unit	0 (0.0)	1 (1.0)
Unknown	14 (35.0)	2 (3.0)

* The HDUs were not included in the % calculations as these were additional units

8.6.3 Comparisons of unit type with the ICNARC CMP database (2005) and HRG centres

Table 8.9 provides a summarised version of table 8.8 where the unit type is grouped together so that comparisons may be made with the ICNARC CMP database. The Conventional Treatment Centre sample included a lower proportion of combined ICU / HDUs (than that represented in the ICNARC database and the HRG study) and had no combined ICU / HDU / Coronary Care Units or ICU / HDU / Neurological Intensive Care Units. Within the 'Other' category are those CTCs for whom the unit type is unknown.

Table 8.9: Comparisons of unit type with the ICNARC CMP database (2005) and HRG Centres

Type of Critical Care Unit	ICNARC (%)	CESAR centres (%)	HRG centres (%)
ICU	71 (42.0)	13 (32.5)	17 (24.3)
ICU / CCU	3 (1.8)	0 (0.0)	0 (0.0)
ICU / HDU	87 (51.5)	13 (32.5)	38 (54.3)
ICU / HDU / CCU	7 (4.1)	0 (0.0)	2 (2.9)
ICU / HDU / NICU	1 (0.6)	0 (0.0)	1 (1.4)
Other e.g. HDUs, cardiothoracic ICUs, specialist burns etc.	N/A	14 (35.0)	12 (17.1)

8.6.2 Unit Size

Table 8.10 compares the respective studies by the numbers of staffed beds. There were no CTCs that exceeded 18 beds, nor any with between 1 and 3 beds. Most of the CTCs had between 4-6 beds and 7-9 beds; a pattern reflected in the other studies.

Table 8.10: Numbers of staffed critical care beds

Unit Size (Numbers of staffed beds)	Number of critical care units CESAR study	Number of critical care units (%) HRG Study	Comparison with ICNARC's CMPD[49] (% of total)
1-3 beds	0 (0.0)	2 (2.9)	13 (7.6)
4-6 beds	13 (32.5)	19 (27.1)	93 (54.7)
7-9 beds	7 (17.5)	21 (30.0)	38 (22.4)
10-12 beds	3 (7.5)	13 (18.6)	19 (11.2)
13-15 beds	2 (5.0)	6 (8.6)	5 (2.9)
16-18 beds	1 (2.5)	1 (1.4)	1 (0.6)
19-20 beds	0 (0.0)	1 (1.4)	0 (0.0)
> 20 beds	0 (0.0)	0 (0.0)	1 (0.6)
Unknown	14 (35.0)	7 (10.0)	0 (0.0)

8.7 Daily costs of conventional therapy

Descriptive statistics were performed for each of the resource items for each financial year that ranged from 2001-2002 to 2004-2005. Table 8.11 shows the results of this undertaking for the responding CTCs. As can be seen from the 'Number of Centres' column, there are only a very small number of observations for each resource item. In order that average daily costs could be estimated for each CTC for the financial year where patients were treated, it was thought appropriate to substitute the missing data with mean estimates obtained from the responding CTCs by financial year. Table 8.12 shows the results of this exercise. The main difference between the two tables relates to the variability in cost, with the latter table having much less variability in the estimates than the true values. Using these data, it was possible to determine for each CTC a set of average daily costs by financial year

[49] Data from 170 critical care units was used between December 1995 and January 2005

that could be adjusted using the organ support weightings described in Chapter 7. Table 8.13 presents the adjusted daily estimates by centre.

Table 8.11: Daily cost data by resource item: Absolute values

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
1	Nursing Staff 2001-2002	3	571	594	683 (156)	618	740	862
	Nursing Staff 2002-2003	7	439	496	540 (63)	569	583	612
	Nursing Staff 2003-2004	7	460	518	609 (138)	587	669	843
	Nursing Staff 2004-2005	6	530	575	607 (55)	608	630	690
2	Other Medical Staff 2001-2002	3	144	149	152 (7)	153	156	158
	Other Medical Staff 2002-2003	7	83	94	125 (37)	117	155	175
	Other Medical Staff 2003-2004	6	57	82	120 (46)	127	139	189
	Other Medical Staff 2004-2005	5	23	76	135 (92)	147	165	263
3	Consultant Medical Staff 2001-2002	3	86	86	100 (24)	86	107	128
	Consultant Medical Staff 2002-2003	7	46	53	77 (42)	59	81	168
	Consultant Medical Staff 2003-2004	6	35	47	78 (40)	71	110	137
	Consultant Medical Staff 2004-2005	5	32	88	93 (37)	105	115	127
4	Administrative support 2001-2002	3	9	14	18 (8)	19	22	25
	Administrative Support 2002-2003	7	11	11	16 (5)	12	21	22
	Administrative Support 2003-2004	7	7	9	17(11)	13	20	37
	Administrative Support 2004-2005	6	0	17	17 (9)	18	22	24
5	Drugs and Fluids 2001-2002	3	110	126	207(142)	141	256	370
	Drugs and Fluids 2002-2003	7	57	76	93 (27)	86	107	140
	Drugs and Fluids 2003-2004	7	76	113	167 (85)	130	210	318
	Drugs and Fluids 2004-2005	5	63	78	99 (44)	83	94	175
6	Disposable Equipment 2001-2002	3	134	136	140 (8)	139	144	149
	Disposable Equipment 2002-2003	7	32	76	87 (33)	82	107	130
	Disposable Equipment 2003-2004	7	42	88	119 (56)	127	135	218
	Disposable Equipment 2004-2005	6	27	75	81 (29)	90	100	105
7	Blood and blood products 2001-2002	2	32	32	53 (29)	53	73	73
	Blood and blood products 2002-2003	6	11	23	33 (16)	35	36	59
	Blood and blood products 2003-2004	7	34	46	51 (13)	47	55	72
	Blood and blood products 2004-2005	4	25	28	32 (5)	32	36	38

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
8	Nutritional products 2001-2002	2	8	8	47 (55)	47	86	86
	Nutritional products 2002-2003	8	2	6	9 (5)	9	12	20
	Nutritional products 2003-2004	4	6	8	25 (32)	11	43	74
	Nutritional products 2004-2005	4	4	6	8 (3)	9	10	12
9	Laboratory services 2001-2002	2	29	29	34 (8)	34	40	40
	Laboratory services 2002-2003	6	15	36	44 (23)	41	47	84
	Laboratory services 2003-2004	5	3	28	44 (34)	40	57	93
	Laboratory services 2004-2005	4	16	22	31 (15)	28	41	53
10	Radiology 2001-2002	2	1	1	4 (5)	4	7	7
	Radiology 2002-2003	7	9	9	14 (8)	10	17	27
	Radiology 2003-2004	4	8	9	17 (11)	13	25	33
	Radiology 2004-2005	4	3	6	9 (4)	10	11	11
11	Physiotherapists 2001-2002	2	36	36	37 (2)	37	38	38
	Physiotherapists 2002-2003	7	10	13	24 (12)	25	32	40
	Physiotherapists 2003-2004	5	9	11	19 (12)	12	31	32
	Physiotherapists 2004-2005	3	22	24	28 (7)	27	31	35
12	Medical Technical Officers (MTOs) & Assistant MTOs 2001-2002	2	0	0	12 (16)	12	23	23
	Medical Technical Officers (MTOs) & Assistant MTOs 2002-2003	4	0	0	6 (9)	4	13	18
	Medical Technical Officers (MTOs) & Assistant MTOs 2003-2004	4	0	0	1 (1)	0	1	2
	Medical Technical Officers (MTOs) & Assistant MTOs 2004-2005	4	0	0	2 (4)	0	4	8
13	Clinical and biomedical scientists 2001-2002	1	0	0	0 (0)	0	0	0
	Clinical and biomedical scientists 2002-2003	3	0	0	0 (0)	0	0	0
	Clinical and biomedical scientists 2003-2004	3	0	0	0 (0)	0	0	0
	Clinical and biomedical scientists 2004-2005	4	0	0	0 (0)	0	0	0
14	Information Technologists 2001-2002	0	-	-	-	-	-	-
	Information Technologists 2002-2003	4	0	0	6 (8)	3	12	16
	Information Technologists 2003-2004	3	0	4	10 (10)	8	14	21
	Information Technologists 2004-2005	2	1	1	3 (3)	3	5	7
15	Clinical Pharmacists 2001-2002	2	4	4	5 (0)	5	5	5
	Clinical Pharmacists 2002-2003	2	0	0	19 (27)	19	38	38

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
	Clinical Pharmacists 2003-2004	3	4	4	19 (26)	5	27	49
	Clinical Pharmacists 2004-2005	6	5	8	9 (2)	5	11	12
16	Dieticians 2001-2002	2	3	3	5 (2)	5	6	6
	Dieticians 2002-2003	3	0	3	5 (5)	7	8	10
	Dieticians 2003-2004	4	3	4	6 (3)	6	8	9
	Dieticians 2004-2005	5	0	0	4 (5)	3	7	11
17	Directorate Accountants 2001-2002	2	0	0	1 (1)	1	2	2
	Directorate Accountants 2002-2003	4	0	0	3 (4)	1	5	9
	Directorate Accountants 2003-2004	2	0	0	6 (8)	6	12	12
	Directorate Accountants 2004-2005	6	0	0	1 (1)	1	2	2
18	Personnel Officers 2001-2002	1	-	-	3	-	-	-
	Personnel Officers 2002-2003	3	0	1	2 (2)	2	3	3
	Personnel Officers 2003-2004	1	-	-	1	-	-	-
	Personnel Officers 2004-2005	4	0	1	2 (2)	2	3	4
19	Speech & Language therapists 2001-2002	2	0	0	0 (0)	0	0	0
	Speech & Language therapists 2002-2003	3	1	1	1 (0)	1	1	1
	Speech & Language therapists 2003-2004	4	0	0	0 (1)	0	1	1
	Speech & Language therapists 2004-2005	5	0	0	0 (0)	0	0	1
20	Psychologists 2001-2002	2	0	0	0 (0)	0	0	0
	Psychologists 2002-2003	4	0	0	0 (0)	0	0	0
	Psychologists 2003-2004	3	0	0	0 (0)	0	0	0
	Psychologists 2004-2005	4	0	0	0 (0)	0	0	0
21	Occupational therapy 2001-2002	2	0	0	2 (2)	2	3	3
	Occupational therapy 2002-2003	4	0	4	6 (4)	8	9	10
	Occupational therapy 2003-2004	4	0	1	5 (4)	6	9	9
	Occupational therapy 2004-2005	4	0	0	1 (2)	1	3	3
22	Specialised bed therapy 2001-2002	3	3	3	5 (3)	4	6	9
	Specialised bed therapy 2002-2003	7	4	4	8 (4)	8.	11	15
	Specialised bed therapy 2003-2004	6	3	5	9 (5)	9.	13	15
	Specialised bed therapy 2004-2005	6	0	0	2 (3)	1	2	9

Table 8.12: Daily cost data by resource item: Substituted values

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
1	Nursing Staff 2001-2002	11	571	597	621 (81)	597	597	862
	Nursing Staff 2002-2003	14	439	569	568 (52)	597	597	612
	Nursing Staff 2003-2004	14	460	587	603 (94)	597	597	843
	Nursing Staff 2004-2005	19	530	597	600 (29)	597	597	690
2	Other Medical Staff 2001-2002	11	130	130	136 (11)	130	137	158
	Other Medical Staff 2002-2003	14	83	117	127 (25)	130	130	175
	Other Medical Staff 2003-2004	14	57	130	126 (29)	130	130	189
	Other Medical Staff 2004-2005	19	23	130	131 (43)	130	130	263
3	Consultant Medical Staff 2001-2002	11	85	85	89 (13)	85	85	128
	Consultant Medical Staff 2002-2003	14	46	59	81 (29)	85	85	168
	Consultant Medical Staff 2003-2004	14	35	85	82 (25)	85	85	137
	Consultant Medical Staff 2004-2005	19	32	85	87 (18)	85	85	127
4	Administrative support 2001-2002	11	9	17	17 (4)	17	17	25
	Administrative Support 2002-2003	14	11	12	16 (4)	17	17	22
	Administrative Support 2003-2004	14	7	13	17 (7)	17	17	37
	Administrative Support 2004-2005	19	0	17	17 (5)	17	17	24
5	Drugs and Fluids 2001-2002	11	110	133	153 (72)	133	133	370
	Drugs and Fluids 2002-2003	14	57	86	113 (28)	133	133	140
	Drugs and Fluids 2003-2004	14	76	130	150 (61)	133	133	318
	Drugs and Fluids 2004-2005	19	63	133	124 (26)	133	133	175
6	Disposable Equipment 2001-2002	11	102	102	113 (18)	102	118	149
	Disposable Equipment 2002-2003	14	32	82	95 (24)	102	102	130
	Disposable Equipment 2003-2004	14	42	102	111 (39)	102	127	218
	Disposable Equipment 2004-2005	19	27	101	95 (18)	102	102	105
7	Blood and blood products 2001-2002	11	32	41	43 (10)	41	41	73
	Blood and blood products 2002-2003	14	11	36	38 (11)	41	41	59
	Blood and blood products 2003-2004	14	34	41	46 (10)	41	47	72
	Blood and blood products 2004-2005	19	25	41	39 (5)	41	41	41

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
8	Nutritional products 2001-2002	11	8	17	22 (21)	17	17	86
	Nutritional products 2002-2003	14	2	8	13 (6)	15	17	20
	Nutritional products 2003-2004	14	6	17	19 (16)	17	17	74
	Nutritional products 2004-2005	19	4	17	15 (4)	17	17	17
9	Laboratory services 2001-2002	11	29	40	39 (3)	40	40	40
	Laboratory services 2002-2003	14	15	40	42 (14)	40	40	84
	Laboratory services 2003-2004	14	3	40	41 (19)	40	40	93
	Laboratory services 2004-2005	19	16	40	38 (7)	40	40	53
10	Radiology 2001-2002	11	0	12	11 (4)	12	12	12
	Radiology 2002-2003	14	9	10	13 (5)	12	12	27
	Radiology 2003-2004	14	8	12	14 (6)	12	12	33
	Radiology 2004-2005	19	3	12	11 (2)	12	12	12
11	Physiotherapists 2001-2002	11	25	25	27 (5)	25	25	38
	Physiotherapists 2002-2003	14	10	25	24 (8)	25	25	40
	Physiotherapists 2003-2004	14	9	25	23 (7)	25	25	32
	Physiotherapists 2004-2005	19	22	25	25 (3)	25	25	35
12	Medical Technical Officers (MTOs) & Assistant MTOs 2001-2002	11	0	4	6 (6)	4	4	23
	Medical Technical Officers (MTOs) & Assistant MTOs 2002-2003	14	0	4	5 (4)	4	4	18
	Medical Technical Officers (MTOs) & Assistant MTOs 2003-2004	14	0	2	3 (2)	4	4	4
	Medical Technical Officers (MTOs) & Assistant MTOs 2004-2005	19	0	4	4 (2)	4	4	8
13	Clinical and biomedical scientists 2001-2002	11	0	0	0 (0)	0	0	0
	Clinical and biomedical scientists 2002-2003	14	0	0	0 (0)	0	0	0
	Clinical and biomedical scientists 2003-2004	14	0	0	0.(0)	0	0	0
	Clinical and biomedical scientists 2004-2005	19	0	0	0 (0)	0	0	0

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
14	Information Technologists 2001-2002	11	0	0	0 (0)	0	0	0
	Information Technologists 2002-2003	14	0	6	6 (4)	6	6	16
	Information Technologists 2003-2004	14	0	6	7 (4)	6	6	21
	Information Technologists 2004-2005	19	1	6	5 (2)	6	6	7
15	Clinical Pharmacists 2001-2002	11	4	12	11 (3)	12	12	12
	Clinical Pharmacists 2002-2003	14	0	12	13 (8)	12	12	38
	Clinical Pharmacists 2003-2004	14	4	12	14(11)	12	12	49
	Clinical Pharmacists 2004-2005	19	5	11	11 (2)	12	12	12
16	Dieticians 2001-2002	11	3	5	5 (1)	5	5	6
	Dieticians 2002-2003	14	0	5	5 (2)	5	5	10
	Dieticians 2003-2004	14	3	5	5 (1)	5	5	9
	Dieticians 2004-2005	19	0	5	5 (2)	5	5	11
17	Directorate Accountants 2001-2002	11	0	2	2 (1)	2	2	2
	Directorate Accountants 2002-2003	14	0	2	2 (2)	2	2	9
	Directorate Accountants 2003-2004	14	0	2	3 (3)	2	2	12
	Directorate Accountants 2004-2005	19	0	2	2 (1)	2	2	2
18	Personnel Officers 2001-2002	11	2	2	2 (0)	2	2	3
	Personnel Officers 2002-2003	14	0	2	2 (0)	2	2	3
	Personnel Officers 2003-2004	14	1	2	2 (0)	2	2	2
	Personnel Officers 2004-2005	19	0	2	2 (0)	2	2	4
19	Speech & Language therapists 2001-2002	11	0	0	0 (0)	0	0	1
	Speech & Language therapists 2002-2003	14	0	0	0 (0)	0	0	0
	Speech & Language therapists 2003-2004	14	0	0	0 (0)	0	0	1
	Speech & Language therapists 2004-2005	19	0	0	0 (0)	0	0	1
20	Psychologists 2001-2002	11	0	0	0 (0)	0	0	0
	Psychologists 2002-2003	14	0	0	0.(0)	0	0	0
	Psychologists 2003-2004	14	0	0	0 (0)	0	0	0
	Psychologists 2004-2005	19	0	0	0 (0)	0	0	0
21	Occupational therapy 2001-2002	11	0	4	3 (1)	4	4	4
	Occupational therapy 2002-2003	14	0	4	5 (2)	4	4	10
	Occupational therapy 2003-2004	14	0	4	4 (2)	4	4	9
	Occupational therapy 2004-2005	19	0	4	3 (1)	4	4	4

Resource Number	Resource	Number of centres	Minimum cost per calendar day (£)	25% Interquartile range cost per calendar day (£)	Mean (SD) cost per calendar day (£)	Median cost per calendar day (£)	75% Interquartile range cost per calendar day (£)	Maximum cost per calendar day
22	Specialised bed therapy 2001-2002	11	3	6	6 (2)	6	6	9
	Specialised bed therapy 2002-2003	14	4	6	7 (3)	6	8	15
	Specialised bed therapy 2003-2004	14	3	6	8 (3)	6	7	15
	Specialised bed therapy 2004-2005	19	0	6	5 (3)	6	6	9

Table 8.13: Per diem costs by critical care unit and financial year

Hospital	Financial Year	Average Daily Cost including 10% Equipment Cost (£)	0 or 1 organ supported (£)	2 organs supported (£)	3 or more organs supported (£)
Aintree Hospital	2004-2005	1,240	715	1,410	1,433
Arrowe Park Hospital	2002-2003	1,293	746	1,470	1,494
Bedford Hospital	2003-2004	1,404	810	1,597	1,623
Bedford Hospital	2004-2005	1,343	775	1,527	1,553
Blackpool Victoria Hospital	2003-2004	1,098	634	1,248	1,269
Castle Hill Hospital	2001-2002	1,436	829	1,633	1,660
Castle Hill Hospital	2003-2004	1,404	810	1,597	1,623
Castle Hill Hospital	2004-2005	1,343	775	1,527	1,553
Cheltenham General Hospital	2001-2002	1,436	829	1,633	1,660
Cheltenham General Hospital	2003-2004	1,404	810	1,597	1,623
Chesterfield & North Derbyshire Hospital	2002-2003	1,293	746	1,470	1,494
Chesterfield & North Derbyshire Hospital	2004-2005	1,343	775	1,527	1,553
Derbyshire Royal Infirmary	2003-2004	1,404	810	1,597	1,623
Glan Clwyd District General Hospital	2002-2003	1,293	746	1,470	1,494
Glenfield Hospital	2003-2004	1,404	810	1,597	1,623
Gloucestershire Royal Hospital	2001-2002	1,436	829	1,633	1,660
Gloucestershire Royal Hospital	2002-2003	1,293	746	1,470	1,494
Gloucestershire Royal Hospital	2003-2004	1,404	810	1,597	1,623
Gloucestershire Royal Hospital	2004-2005	1,343	775	1,527	1,553
Huddersfield Royal Infirmary	2004-2005	1,105	638	1257	1,278
Hull Royal Infirmary	2004-2005	1,343	775	1,527	1,553
Ipswich Hospital	2004-2005	1,230	710	1,398	1,422
Kettering General Hospital	2002-2003	948	547	1,078	1,096
Kettering General Hospital	2003-2004	1,003	579	1,141	1,160
Leicester General Hospital	2003-2004	1,404	810	1,597	1,623
Leicester Royal Infirmary	2001-2002	1,436	829	1,633	1,660
Leighton Hospital	2002-2003	1,144	660	1,301	1,323
Leighton Hospital	2003-2004	1,234	712	1,403	1,426
Luton & Dunstable Hospital	2001-2002	1,326	765	1,508	1,533
Luton & Dunstable Hospital	2003-2004	1,332	769	1,515	1,540
Luton & Dunstable Hospital	2004-2005	1,531	883	1,741	1,770
Macclesfield District General Hospital	2002-2003	1,299	750	1,477	1,502

Hospital	Financial Year	0 or 1 organ supported (£)	2 organs supported (£)	3 or more organs supported (£)
Macclesfield District General Hospital	2004-2005	1,437	829	1,634	1,661
Manchester Royal Infirmary	2001-2002	1,436	829	1,633	1,660
Milton Keynes General Hospital	2004-2005	1,343	775	1,527	1,553
Ninewells Hospital	2001-2002	1,436	829	1,633	1,660
North Middlesex Hospital	2004-2005	1,343	775	1,527	1,553
Northern General Hospital	2001-2002	1,483	856	1,686	1,715
Northern General Hospital	2002-2003	1,401	808	1,593	1,619
Nottingham City Hospital	2004-2005	1,343	775	1,527	1,553
Queen Elizabeth Hospital, Gateshead	2001-2002	2,142	1,236	2,436	2,476
Queen Elizabeth Hospital, Gateshead	2003-2004	1,854	1,070	2108	2,143
Rotherham District General Hospital	2004-2005	1,343	775	1,527	1,553
Royal Albert Edward Infirmary	2002-2003	1,273	735	1448	1,472
Royal Bolton Hospital	2002-2003	1,356	783	1542	1,568
Royal Hallamshire Hospital	2003-2004	1,804	1,041	2051	2,086
Royal London Hospital	2002-2003	1.293	787	1,552	1,578
Royal London Hospital	2004-2005	1,343	775	1,527	1,553
Royal Preston Hospital	2002-2003	1.293	787	1,552	1,578
Royal Preston Hospital	2004-2005	1,343	775	1,527	1,553
Southern General Hospital	2004-2005	1,343	775	1,527	1,553
Southport & Formby Hospital	2004-2005	1,237	714	1407	1,430
St. Mary's Hospital, Isle of Wight	2002-2003	1,379	796	1,568	1,594
University Hospital of Wales	2001-2002	1,436	829	1,633	1,660
University Hospital of Wales	2004-2005	1,343	775	1,527	1,553
Warwick Hospital	2001-2002	1,436	829	1,633	1,660
West Suffolk Hospital	2003-2004	1,782	1,028	2,026	2,060
Worcester Royal Hospital	2002-2003	1, 110	640	1262	1,283

8.8 Daily costs of ECMO

The budget data provided for 2 financial years is reported in Table 8.14. There were some resource items that were excluded from the estimates on the basis that these items were not collected for the conventional treatment costs (See Table 8.15).

£2,184,652 was budgeted for ECMO in 2002-2003 and £2,637,774 budgeted in 2004-2005. Apportioned down to a per diem measurement, resulted in a cost of £2,184.65 for 2002-2003 and £2,637.77.

The total cost of these excluded resources was £961,235 for the financial year 2002-2003 and £1,088,400 for 2004-2005. The overheads represented 97.8% and 97.2% of this for 2002-2003 and 2004-2005 respectively (Table 8.15). When questioned, the Glenfield Accountants were unable to explain what resource items constituted the 'overhead' component of the budget and so these data were not considered to be reliable.

Table 8.14: Budget data for the 2 financial years for ECMO

Resource item	Budget Items	2002-2003 (£)	2004-2005 (£)
	Consultants	46,285	142,944
Consultant Medical Staff	Consultant payments	15,000	0
Other Medical Staff	ECMO Fellows (including on-call payments)	182,365	254,249
	Senior Manager input	18,976	17,241
Administration	Admin & Clerical Grade 4	16,249	18,534
	CITU Nursing	559,418	623,027
Nursing Staff			
	ECMO Coordinator	25,949	29,617
	ECMO Specialists	104,034	222,677
Physiotherapy	Physiotherapy	9,960	12,542
	Radiology	6,090	7,684
	Radiology – consumables / tests	6,120	0
	Imaging tests – variable costs	0	7,776
Radiology	Imaging tests – fixed costs	0	11,664
Laboratory services	Laboratory Consumables -	0	6,158

	Other		
	Pathology costs – variable costs	96,642	31,598
	Pathology costs – fixed costs	107,380	47,397
	Cardiac Investigations - Variable Costs*	0	840
	Cardiac Investigations - Fixed Costs*	0	1,260
Pharmacy / Nutritional products	Pharmacy / Nutrition	7,710	9,723
	Drugs	420,105	443,478
Drugs / nutritional products	Drugs / TPN	23,373	
Specialised bed therapy	Bed Hire	33,615	30,542
Disposable equipment	M&S Consumables – Post-ECMO	275,000	275,000
	M&S Consumables – Catheters	0	10,230
	M&S Consumables - ECMO	150,000	150,000
Blood and blood products	Recharges - Blood Products	0	135,000
Other	Transport Costs	63,000	81,000
	Perfusionists	14,670	25,616
	PMT Lung function tests	0	6,158
	Theatre Staffing (Bronchs)	0	21,041
	Instruments / Equipment Purchases	2,711	2,463
	Equipment Maintenance (incl. Bronchoscopes)	0	12,315
TOTAL		2,184.652	2,637, 774

* Could also be classified under the 'radiology' heading.

Table 8.15: Additional costs excluded from the calculations for ECMO

Resource item (Budget Statement)	2002-2003	2004-2005
Advertising	0	1,232
Travel & Subsistence	2,033	3,695
Furniture, office & computer equipment	0	5,288
Subscriptions\Consultancy\Training	8,133	7,389
Telecomms recharges	0	657
Other Recharges	5,422	4,926
Staff uniforms	1,084	985
Printing & stationary / books & journals	4,609	6,404
Overheads	939,954	1,057,824
TOTAL	**961,235**	**1,088,400**

8.8.1 Apportionment of budget data

The budgeted costs of each resource item were apportioned by the predicted number of patient days (n = 1,000) for the two financial years.

Total costs per day for the financial years 2001-2002, 2003-2004 and 2005-2006 where budget data were missing, were estimated by taking the mid-point cost between the 2 financial years (2002-2003 and 2004-2005) (Table 8.16). A 10% equipment allowance was not added onto the ECMO costs since the costs of equipment were already included in the budgeted costs.

Table 8.16: Daily costs by financial year for ECMO

2001-2002* (£)	2002-2003 (£)	2003-2004* (£)	2004-2005 (£)	2005-2006* (£)
1,958	2,185	2,411	2,638	2,864.33

***Daily costs for the financial years 2001-2002, 2003-2004 and 2005-2006 were estimated by taking the mid-point cost between the 2 financial years where data were available.**

8.8.2 Application of organ support weightings

The same organ support weightings were applied to the average daily costs of ECMO. The case-mix adjusted daily costs are presented in Table 8.17.

Table 8.17: Adjusted daily costs of ECMO

Hospital	Financial Year	Average Daily Cost (£)	0 or 1 organ supported (£)	2 organs supported (£)	3 or more organs supported (£)
Glenfield Cardiothoracic ICU	2001-2002	1,958	1,130	2,226	2,264
	2002-2003	2,185	1,261	2,484	2,525
	2003-2004	2,411	1,391	2,742	2,787
	2004-2005	2,638	1,522	2,999	3,049
	2005-2006	2,864	1,653	3,257	3,311

8.9 Discussion

The CESAR trial was actually the first multi-centre concurrent economic evaluation and clinical trial conducted in adult critical care in the UK at the time at which it was designed. For this reason, there was not any previous studies that could be used to inform the design of the economic evaluation to provide a comparable 'benchmark'. For this reason, the methods described were new.

The decision to collect organ support data as part of the trial proforma was based on the findings from the exploratory research described in Chapter 4. It was always the intention to use the using the data collected in Chapter 6 to develop the organ support weights because of the quantity of data that this study generated, making it more likely that the development of a regression-based model would be possible. In order to develop an independent set of organ support weights relating to the CESAR CTCs, it would have been necessary to collect the organ support data on all patients (irrespective of whether they were in the trial) and to have been able to get all of the necessary expenditure data. This would have significantly increased the burden of data collection

on the participating critical care units and given the poor response rates to the expenditure survey, it is highly unlikely that this would have worked.

An appealing and attractive option so as to minimise the work conducted for the economic evaluation would have been to apply to average daily unit cost estimates reported in Chapter 7 to the recruiting CTCs. However, the rationale for collecting centre-specific estimates of cost was based on the findings from a simulation exercise that found a significant difference in overall costs when using unit costs averaged across centres and when using centre-specific costs to value resource use measured in a clinical trial (Raikou *et al.*, 2000). This finding goes against the standard analytical approach that is to ignore the inter-dependence between costs and resource use by applying unit cost estimates from one or a few centres to pooled resources use and to relate costs to pooled outcome data (Sculpher *et al.*, 2000). A site selection bias can nevertheless occur when measures of cost can be obtained only from a single or small number of centres (Jacobs & Baladi, 1996).

As such, the aim of Chapter 8 was to collect expenditure data from all critical care units that recruited patients to the CESAR trial together with data on their unit characteristics; the objective being to estimate average daily costs of care for each centre relating to the time period during which patients were recruited (these included both conventional treatment centres and the Glenfield ECMO unit).

Evidently, there was a very poor response rate with respect to both the unit characteristics and cost questionnaires – particularly with the latter questionnaire. Attempts made to compensate for the missing cost data (by substituting the missing data with the mean estimates by financial year) provided each CTC with a set of unit costs. There was a considerable amount of missing data, which was a concern. It is debatable whether attempting to collect these unit costs by centre added any value to the economic evaluation over and above merely applying

the average daily cost estimates reported in Chapter 5. However, what the study did highlight was just how difficult it is to obtain cost data from critical care units and supports the observations of Street & Dawson (2002) based on their experience that '*the NHS lags behind instutitions in many other countries in terms of the routine cost data collected by health care providers*' (p.4). The critical care units that participated in the HRG study were offered an important incentive i.e. unit-specific reports that summarised and compared their data with the other participating units. The absence of a clear incentive in the CESAR trial was undoubtedly a contributing factor with respect to the poor response rates. The altruistic motivation of contributing to research and new knowledge was not a sufficient incentive. This is an important research finding for future studies. Pharmaceutical companies overcome the likelihood of missing or poor quality data by paying critical care units a set amount for each patient they recruit to the trial. This amount can extend to up to £5,000 per patient and not surprisingly appears to work very effectively in boosting recruitment and ensuring high quality data collection. In government-funded trials such as CESAR, it is not possible to secure the necessary funds to reward hospitals in this way.

Feedback from some of the critical care units suggested a reluctance to complete the questionnaires on the basis that it was for the benefit of 1 patient. Due to the low incidence of severe, but potentially reversible, respiratory failure it was not unusual for some critical care units to recruit just one patient in each financial year. With this in mind, it was possibly unrealistic to expect staff to complete the unit characteristic and cost questionnaire for the purposes of estimating the costs of care for one patient. When the economic evaluation was designed, it was not anticipated that study recruitment would extend over so many financial years as data on the numbers of treated patients provided by the Cardio-thoracic ICU at Glenfield Hospital suggested a much higher capacity for treating patients using ECMO than was observed in the trial. In the first two years of recruitment, it became evident that a large

number of patients were not recruited to the trial because of bed shortages at the Cardio-thoracic ICU. This contributed to the need to extend recruitment for a much longer time period than was expected and further contributed to small numbers of patients recruited over an increasing number of financial years.

Had time permitted, the only sure way of obtaining accurate and timely expenditure data from the CTCs would have been to visit each centre. The potential problem with this would have been ensuring that the directorate accountants and the critical care unit staff were available on the day of the visit and sufficiently prepared with the necessary budget statements in order to complete the cost questionnaires. Based on previous experience of visiting critical care units in this way, it is not uncommon on the day of the visit to find staff not available to attend meetings due to clinical commitments etc.

Whilst the cost questionnaire covered the majority of key critical care resources, it excluded the capture of data on capital equipment. This would have included expenditure on new items of equipment, rental and hire charges on equipment (except specialised beds), annual depreciation costs and equipment maintenance. This was an obvious weakness of the questionnaire but based on the variable completion rates, it is unlikely that even had a section on capital equipment been included, that data would have been provided. The decision to omit capital equipment was based on *a priori* expectation that these data would not be available from the critical care unit (based on pilot studies of the Critical Care National Cost Block Programme) (Edbrooke *et al.*, 1999). It is not known the extent to which this expectation held with the CTCs.

The absence of cost data for the majority of the CTCs was not the only problem with the study. In order to estimate the costs of ECMO, the only data that was made available was the budget statements for 2 financial years. Despite several attempts to obtain the expenditure data for each financial year in question, no data was forthcoming. One

possible reason for this could have related to a discrepancy between the agreed budget and the actual expenditure. When the accountant responsible for setting the ECMO budget was questioned as to what resources had been included in the 'overhead' budget, he was unable to provide any details of this. On these grounds, the overhead costs had to be excluded from the cost estimates because of uncertainty as to how the budget for this had been used in the care of patients. The budgeted sums were apportioned by the expected number of patient days for each financial year (1,000 patient days) rather than the observed number of patient days.

As far as it was possible to consider the generalisability of the characteristics of the responding CTCs with the HRG centres and the ICNARC CMP described in Chapter 6, as far as geographical representation was concerned, there was little evidence to suggest the two samples were comparable. It is important to note however that both samples were formed on a voluntary basis and not stratified *a priori* by any given characteristics. There was a lower proportion of CTCs with a medical school and those critical care units regarded as tertiary referral centres. The HRG study also had a much larger number of specialist critical care units in the sample than the CESAR study. It is difficult to postulate the effect that these characteristics would have on the costs of care because of the absence of these data generated by the CESAR study.

The mean costs per day for nursing staff were slightly higher in the HRG study (£587.00 vs. £570.92 (2001-2002); £439.48 (2002-2003); £459.92 (2003-2004) and £529.98 (2004-2005). The costs of other medical staff were highly variable across financial years for the CESAR study and appeared to decline over time although this was most likely just a sampling problem (£143.81 (2001-2002); £83.33 (2002-2003); £57.13 (2003-2004) and £22.65 (2004-2005) vs. £111.40 for the HRG study. A similar phenomenon was observed for the Consultant Medical Staff (£85.76 (2001-2002); £45.87 (2002-2003); £35.10 (2003-2004) and £31.62 (2004-2005) vs. £97.40 for the HRG

study. In fact with all of the different resources, an inconsistent pattern was observed across financial years. The data reported for 2001-2002 appeared to most closely reflect that reported for the HRG study but after that time the estimates appeared to drop (most noticeably for disposable equipment and physiotherapy). Comparisons are hampered by the low number of responses for the CESAR trials however if one had to make a definitive statement, it would have to be that the CESAR CTCs incurred lower costs than the HRG sample. It is impossible to make any judgements as to whether the case-mix of the two studies is comparable; suffice to say that patients with severe respiratory failure are acutely ill, in multiple organ failure, with a poor chance of survival.

The final aim of this Chapter was to apply the cost weights developed in the model described in Chapter 7 to the daily costs of conventional treatment and ECMO in order that case-mix adjusted estimates of daily cost for both arms of the trial could be determined. This proved to be a straightforward undertaking and enabled a stratification of daily costs by the numbers of organs supported.

In conclusion, this chapter has set out to estimate a set of unit-specific costs relating to care received in the adult critical care setting to inform an economic evaluation of ECMO versus conventional therapy. The short-comings of the study have been well described, in particular, the poor response rate to the cost survey that resulted in missing data that had to be substituted using mean values obtained from those centres best able to provide these data. The organ support weightings described in Chapter 7 were applied to these substituted centre-specific estimates in order that the average daily costs could be case-mix adjusted.

Whilst the results of the trial are not as yet known, ECMO was found to be more costly than conventional therapy and in order to be shown to be cost-effective, will need to demonstrate some form of clinical benefit that justifies the additional cost of treatment.

Chapter 9 will now examine the contributions of the research reported in this thesis, followed by a discussion of future research in this area.

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CHAPTER 9: CONCLUSIONS

9.1 Introduction

The core of the thesis is the identification of the key patient characteristics and '*cost generating events*' in the care of critically ill adults, and the development and application of the use of a '*top-down*' method of costing (the cost block method), that when combined with data on these events can be used to generate daily case-mix adjusted costs of care. Given that knowledge of the costs of critical care patients is extremely limited, the thesis goes some way to describing the costs of different critical care units and exploring possible reasons for their variation (case-mix and efficiency).

The systematic literature review established that very little multi-centre research has been conducted to inform the debate as to which method of estimating costs works best across different settings from a reimbursement perspective. The 'bottom-up' method of costing offers the most accurate means of cost estimation at the patient level but comes with the disadvantage of being both time-consuming and costly to perform outside of the research setting. 'Top-down' costing is too crude an approach to adopt in isolation of an appropriate case-mix adjustment given the heterogeneity of patients both in their length of stay and treatment needs. A considerable amount of time was spent attempting to identify the best means of describing patients in terms of their clinical and cost characteristics because of this heterogeneity and the need to curtail the number of explanatory variables in the model.

The thesis covers both a methodological and empirical component and the main contributions are the role that the work has played in shaping the Department of Health's reimbursement strategy in adult critical care and more generally, providing a means of estimating patient costs in a relatively simple way across centres that previously had not been achievable.

This chapter begins by offering a critical appraisal of the work performed, then examining the contributions that the research reported in this thesis has made and a discussion of future research in this area completes this thesis.

9.2 Critical appraisal of the research

There are several learning outcomes from the work performed in this thesis. Had resources allowed, it would have been preferable to have extended the period of time over which data had been collected from critical care units participating in the multi-centre study and to improve the representativeness of the sample by investing greater efforts to recruit critical care units located in Wales. This would have expanded the data set for analysis and as a result, possibly improved the reliability of the cost estimates because a large number of organ support combinations suffered from having only a very small number of observations which only became apparent after the period of data collection had finished. Furthermore, it may have been helpful to have conducted some bottom-up costing of the different types of organ support in some of the participating critical care units to better understand the reasons why some organs are more costly to support than others – be it related to staffing or equipment utilisation (or both) or other factors such as the need for additional tests or investigations. Such knowledge may have facilitated the interpretation of the coefficients produced by the statistical models to a greater extent.

Data on capital equipment expenditure is not straightforward to capture and records relating to the purchase and maintenance of this equipment can be difficult to obtain, however it is important not to overlook the fact that critical care units use a considerable amount of monitoring and other equipment in the care of their patients. The cost of this equipment is largely unknown and the expenditure data obtained from the critical care units on other resources were inflated by a percentage factor to allow for an estimate on capital equipment expenditure. The challenge for the critical care units financed under a reimbursement system will be to plan

strategically for major capital investments and ensure that there are adequate financial plans in place to meet the necessary purchase and maintenance costs. It may be more realistic for critical care units to lease equipment than to purchase it outright in order to spread the re-payments over time (as an example).

Section V of Chapter 6 explored the relationship between the expenditure of a critical care unit in relation to its size and is probably one of the most interesting and important areas for further research, which with a larger sample of critical care units would have been greatly enhanced. The recent financial problems experienced by the NHS mean that how critical care units organize their resources in terms of deciding how many beds they should have in order to achieve optimal efficiency will be of greater importance than ever before.

Chapter 8 served to illustrate how the cost weights derived from the modelling work undertaken could be applied to a trial-based economic evaluation. This chapter highlighted the problems of obtaining data under trial conditions, particularly when the time span for patient recruitment is lengthy in duration and there are few incentives in place to reward timely data return. Greater engagement with the staff at Glenfield Hospital at an earlier stage may have proved fruitful in obtaining more complete financial data on the ECMO costs. Earlier discussions with the accountants about the need for accurately estimating the treatment costs because of the importance of demonstrating the economic case for ECMO may have generated the necessary expenditure as opposed to budget data provided. It would have been very helpful to have had these data to have been able to investigate possible economies of scale within the ECMO provision and if found to be clinically effective, to have explored the most cost-effective way of delivering the care to a greater number of patients.

9.3 Contribution of the research

9.3.1 Development of costing methods for economic evaluation

The originality of academic offerings was demonstrated in a number of ways. Firstly, I contributed to the development of the cost block costing method as both a member of the Critical Care National Working Group on Costs (Edbrooke *et al.,* 1999; Edbrooke *et al.,* 2001) and as the main researcher on this project for 6 years (1995-2001). Extending the use of method to producing daily case-mix adjusted costs was where my contribution can be most clearly defined. In its original form, the cost block method can only estimate average daily costs, which restricts the use of the method to benchmarking expenditure patterns between different critical care units, rather than reflecting the variation in daily costs between individual patients. Now, it is possible to do both. There have been no studies performed in adult critical care units in the U.K. that have been able to estimate the costs of individual patients across centres. A recent clinical trial that investigated the clinical and cost-effectiveness of pulmonary artery catheters in the U.K relied on the use of average daily costs taken from the NHS Reference Costs in order to estimate the costs of critical care patients, without any form of case-mix adjustment.

The beauty of the organ support approach in conjunction with the cost block method lies in its simplicity and reproducibility. It has the potential to be used in both multi-centre and multinational economic evaluations, which for critical care patients is particularly advantageous. Since its development, the cost block method has been used in Hungary, Germany and France to estimate the costs of critical care units (Csomos *et al.*, 2005 & Negrini *et al.*, 2006). There is a growing trend of multinational clinical trials because of the opportunities to recruit large numbers of patients quickly, particularly in heterogeneous patient populations such as critical care and it is certainly true that collecting detailed cost data from hospitals is

extremely difficult. The successfulness of exporting the cost block method to different countries further improves the likelihood of its potential use for economic studies in critical care units.

Whilst the very low response rate for the return of the cost and unit characteristic questionnaires from the CESAR trial centres detracted attention away from the benefits of having organ support weights towards the more pressing problem of missing data, the merits of the weights still hold. They can easily be applied to national (aggregated) tariffs / costs in an attempt to allow for the effect of case-mix variation on daily costs of care. This is a particularly appealing use for the organ support weights, given the aforementioned difficulties.

9.3.2 Identification of the key characteristics and cost generating events in critical care patients

Without the exploratory research conducted in the single centre setting, it would not have been possible to identify the key cost generating events, since the relationship between patients' organ support and their costs of care had not been studied previously. Certainly, there have been no studies to date that have reported such a relationship. John Morris's survey identified the variables that clinicians perceived to be important but organ support was not one of them. This is likely to be because it had not featured in any of the commonly used scoring systems until 1998 when the ACP data set first became mandatory in the UK. The ACP data set did not request the collection of daily organ support data but instead required critical care unit to record the total number of organs supported during a patients' stay.

Credit for the multivariate analyses of both the former variables and the daily organ support data, described in Chapter 4 lies with Professor Jacobs, however it was my decision to explore the usefulness of daily organ support data and the design and conduct of this study was my own work. I was also solely responsible for configuring the activities of

care that were needed for estimating the costs of patients included in these analyses.

9.3.3 Specifying the cost model for the HRGs

The specification of a model for iso-cost grouping based on the number of organs supported per day was the result of exhaustive efforts to identify the most appropriate model that was capable of generating sensible estimates of cost. Whilst the sample of patients studied represents the largest prospectively collected cohort of data collected to date, the number of explanatory variables had to be kept to the minimum in order to produce these estimates of cost. The exploratory work on patients' organ support was able to guide what could be considered 'sensible' e.g. a logical ordering to the hierarchy of costs, with renal support costing more than neurological support etc.

The ideal model would have been one that was capable of estimating daily costs that varied according to the type and combination of organ support (Model 5). However, in order to achieve this, a much larger sample of data collected over a longer time period would have been needed. There were too many independent variables in the model, many with a very small number of observations that produced some quite spurious estimates. It is likely that a sample of 100 critical care units collecting data over a six-month period may have been sufficient to generate the volume of necessary data.

The approach to costing care in this way was however well received by the Critical Care Community and the NHS Information Standards Board.

9.4 Peer-reviewed outputs

The work undertaken as part of this thesis resulted in a number of peer-reviewed publications and conference presentations. Arising from Chapter 2 came was a paper on cost definitions co-authored with Jegers *et al.*, (2002) and an invited lecture (Hibbert, 2004[1]).

Outputs from Chapter 3 consisted of one peer-reviewed paper, a book chapter and two oral presentations describing the findings from my systematic review (Hibbert, 2001, 2002[1-2]; Hibbert & Edbrooke 2002) and an invitation to contribute to a closed workshop hosted by the American Thoracic Society (Angus *et al.*, 2002). Methods used in the systematic review were also applied to a study of sepsis patients that resulted in one peer-reviewed publication (Hibbert & Coates, 2004) and two invited oral presentations (Hibbert, 2003[1] & Hibbert, 2004[2]).

Professor Philip Jacobs performed the multivariate analyses described in Chapter 4, however all remaining analyses were performed by myself. This collaboration resulted in a peer-reviewed publication stemming from the first multivariate analysis described in Chapter 4, (Section 4.5.2) looking at APACHE II scores, length of critical care unit stay, survival at critical care unit discharge, admission status, the percentage of patients receiving advanced respiratory support and whether patients had received surgery prior to their admission (Jacobs *et al.*, 2001). The relationship between daily organ support and costs (Chapter 4, Section 4.5.3) was published in the form of an NHS Information Authority Research Report (Hibbert *et al.*, 1998) and presented at two conferences; the European Society of Intensive Care Medicine's Annual Conference (Hibbert *et al.*, 1999) and the Trent Institute for Health Services Research Annual Conference (Hibbert, 1999).

The design of the multi-centre study described in Chapter 6 was published in a peer-reviewed journal (Hibbert *et al.*, 2003) and presented at 5 conferences (Hibbert, 2003[2-6]). The results from the cost survey were also published in a peer-reviewed journal (Hibbert *et al.*, 2005) and the cost models presented at the European Health Economics Conference (Hibbert *et al.*, 2004[2]). The final results of the HRG analyses were presented to the Department of Health (Hibbert *et al.*, 2004[3]) and at a national conference (Hibbert *et al.*, 2004[4]).

All of the work performed as part of the HRG study was peer-reviewed by the Department of Health's Critical Care Funding Working Group, the NHS Information Authority, the Intensive Care Society, and the NHS Information Standards Board.

9.5 Limitations of the research

I have attempted, at the end of each Chapter, to highlight the shortcomings of the work described. However, the most evident limitations are summarised as follows:

The exploratory research described in Chapter 4 that identified the key cost-generating events was based on a very small sample of patients and used a non-validated costing method. It is not known how representative this sample of patients was, compared to the rest of the U.K at that time.

The non-capture of data on capital equipment in the multi-centre study was a weakness. These data were neither captured in the costing of conventional treatment for the CESAR trial. In both cases, a 10% levy was applied to account for this.

The exclusion of foreign papers from the systematic literature review produced a language bias, although it is not anticipated that through contact with key opinion leaders[50], any important methodological studies were missed as a result. Had resources permitted, a second reviewer would have been used to check both the screening of abstracts and full papers and the data extraction and quality evaluation tasks.

The variable completion of the expenditure questionnaires used in the multi-centre study meant that the models developed in Chapter 6 only included the costs of nursing staff, drugs and fluids and disposable equipment. The remaining costs had to be apportioned on the basis of length of stay. More sophisticated econometric methods may have

[50] I am co-chair of the European Society of Intensive Care Medicine Research Group on Health Economics and am in regular contact with all of the active researchers involved in costing studies in Europe.

proved useful in the development and evaluation of the cost models described in Chapter 7.

The poor response to the unit characteristic and cost survey described in Chapter 8 resulted in the extensive use of substituted data in order to estimate an average daily cost of care for many of the conventional treatment centres. Furthermore, the limited data provided on ECMO was a disappointment, given the importance of the clinical trial for Glenfield Hospital.

Finally, given that much of the work described in this thesis has not been attempted before, there wasn't a gold standard as such, against which the results produced could be compared. Nevertheless, it provides a rich data set against which future studies can be compared and improved upon.

9.6 Further research

9.6.1 Studies of the relationship between expenditure, case-mix and outcomes

Critical care units often attribute their high costs and poor outcomes to an atypical case-mix. An interesting area worthy of further research relating to the work of this thesis is studies looking at the relationship between expenditure levels, standardised mortality rates and case-mix now that we have a way of describing and quantifying case-mix by organ support. Along similar lines are studies looking at the relationship between the duration of patients' organ support (and the combinations of such), and their outcomes e.g. quality-adjusted survival, to answer questions such as 'which of the types of organ support result in the best outcomes and the worst outcomes and what role does the time component play?' This sort of research is needed to inform evidence-based decision-making on the withdrawal of treatment. I would argue that the daily collection of organ support parameters is infinitely more informative in quantifying a patient's

improvement or decline than physiological severity of illness measures recorded within the first 24 hours of admission, such as patients' APACHE II scores, that do not account for the effect of interventions on outcomes.

9.6.2 Studies of efficiency

Akin to the valuable research performed in neonatal intensive care on economies of scale, further research is required in adult critical care on determining the optimal size and configuration of critical care units in the U.K. In particular, what is the most efficient way of providing a service in terms of cost and whether patients achieve a better outcome if units operate to a given size? Some preliminary work has been done, but it was heavily criticised for not accounting for case-mix and outcomes (Jacobs *et al.*, 2004). It is certainly now possible to explore this line of research in a large multi-centre study, given the robust data generated by the ICNARC Case-Mix Programme on patient outcomes and the availability of a reasonable case-mix measure.

9.6.3 Studies of the factors that limit the availability of expenditure data in hospitals

It is important that a greater understanding is gained as to why studies such as the CESAR trial, should experience such poor response rates to requests for what should be routinely available information. This is important as it has the potential to influence the design of future studies, if there is a perception that cost data and basic information on the characteristics of centres is unobtainable. Based on the success of the HRG study with a high number of critical care units able to provide data, the issue seems to be linked to incentives but that may not be the case in all hospitals. It would be useful to know, for example, the times of the year when best to avoid burdening the finance departments with requests for data (and vice-versa).

9.7 Conclusion

In conclusion, the aims of this PhD in Health Services Research were to synthesise current knowledge about the different methods used to estimate costs and to develop and apply a method for estimating daily case-mix adjusted costs of critical care patients to proposing a set of HRGs and for use in a trial-based economic evaluation. Through a programme of original work, involving a systematic review, a single centre study and a large multi-centre study worthy of publication in peer-reviewed journals, I believe that the aims of this thesis have been achieved.

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[4]Hibbert CL (2003). The Critical Care HRG Study. North Manchester Clinical Network Meeting, Manchester.

[5]Hibbert CL (2003). The Critical Care HRG Study. Mid-Trent Clinical Network Meeting, Derby.

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[3]Hibbert CL, Coates EJ, Brazier JE, Morris J (2004). Critical Care HRG Study, Department of Health, February 5th.

[4]Hibbert CL, Coates EJ, Brazier JE, Morris J (2004). Critical Care HRG Study, NHS Modernisation Agency Day for Critical Care. March.

Hibbert CL & Coates EJ (2004). Methodological issues in studies reporting the costs of sepsis patients. *Care of the Critically Ill*, **20**, 6, 167-176.

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ACKNOWLEDGEMENTS

Academic Supervision

Professor John Brazier supervised this PhD in health services research. I wish to thank John for his encouragement and support throughout my studies. I would also like to thank Professors Mike Campbell and Jon Nichol for their help with defining the scope of the thesis and for providing statistical advice.

Research Assistance

I wish to thanks Elizabeth Coates who worked as my research assistant during the multi-centre study for her hard work and her friendship. Elizabeth, together with Elena Brooker, John Campbell and my brother, James Hibbert, performed most of the data entry resulting from this study. Elizabeth Coates and John Campbell also helped perform the quality checks of the dataset.

Literature Review

Sheffield Teaching Hospitals NHS Trust funded part of the costs of the literature review through their Pilot Project Research Scheme.[51] The Medical Economics and Research Centre, Sheffield (MERCS) funded the costs of obtaining copies of needed articles from the British Library. I wish to acknowledge Catherine Beverley, Information Specialist at the University of Sheffield who had advised me on the systematic searching of the databases.

I would like to thank the Cochrane Economics Methods Group (CEMG) and the Health Economists' Study Group[52] (HESG) who I

[51] The intention of the Pilot Project Research Scheme is to promote primary and secondary projects addressing important questions with clinical relevance by new researchers.

[52] The HESG is one of the most active of the UK-based groups with members meeting twice a year for conferences. The HESG has an active e-mail network with membership limited to economists and researchers actively working in the field.

contacted for advice about the methodological aspects of the review[53]. The following individuals were extremely helpful in advising on appropriate information sources:

Dr. Mike Clarke	UK Cochrane Centre, Oxford
Dr. Rachel Elliott	School of Pharmacy and Pharmaceutical Sciences, University of Manchester
Ms Kath Hartnell	Cochrane Economics Methods Group, University of East Anglia, Norwich
Dr. Guy Hutton	Swiss Tropical Institute, Basel, Switzerland
Professor R Lilford	University of Birmingham
Ms. Kate Misso	NHS Centre for Reviews & Dissemination, University of York
Professor Miranda Mugford	Cochrane Economics Methods Group, University of East Anglia, Norwich
Dr. Vilma G. Varande-Kulis	Prevention Effectiveness Branch, U.S. Centre for Disease Control and Prevention, Atlanta
Mr. Ian Greener	University of the West of England, Bristol
Professor Philip Jacobs	Institute of Health Economics, Edmonton, Alberta, Canada
Dr. Tom Jefferson	Viareggio, Italy
Dr. Wendy Ungar	Department of Health Policy, Management and Evaluation, Faculty of Medicine, University of Toronto, USA.

Exploratory Analyses

I wish to thank the nursing and medical staff from the adult Critical Care Unit at the Royal Hallamshire Hospital for collecting all of the patient data needed for the exploratory analyses.

Furthermore, I wish to acknowledge the intellectual contributions of Adrian Wilson, Vivien Stevens, Andy Mann and David Edbrooke at the Royal Hallamshire Hospital for their part in developing the Patient Data Management System (PDMS) and the Sheffield Healthcare

[53] The Group formally registered as a Cochrane entity in 1998 and includes economists and other health professionals and researchers involved in the Cochrane Collaboration.

Costing System, used to generate the necessary data to perform the exploratory analyses described in Chapter 5. Dr. John Morris's initial survey provided the impetus for all of the single-centre exploratory analyses and John himself was instrumental in securing funding from the NHSIA to meet the costs of the exploratory research.

- Bumni Fajemisin designed the drug database from which the daily estimates relating to patients' drug usage could be extracted. Professor Philip Jacobs and Dr. Konrad Fassbender from the Institute of Health Economics in Edmonton, Canada, advised on the analysis of the logged daily cost data and ran the multivariate analyses described in Chapter 5.

Multi-Centre Study

The multi-centre study was commissioned by the NHS Information Authority, Winchester and jointly funded by the Medical Research Council (MRC), London through a Department of Health / MRC Fellowship in Health Services Research.

Input from representatives of the NHS Information Authority and the Department of Health proved invaluable throughout the duration of the study. The following individuals are hereby acknowledged:

Mr. Jason Bradley	Ms. Collette Clark	Dr. Jane Eddleston
Ms. Ginny Edwards	Mr. Ian Hargreaves	Ms. Anne Kennedy
Mr. W Martin	Dr. Peter Nightingale	Mr. Richard Ord
Ms. Sinead Partridge	Dr. Mike Pepperman	Ms. Evanna Rees
Ms. Eileen Robertson	Mr. Alistair Rose	Ms. Jayne Slater
Mr. Steve Sutch	Mr. Mark Tomlin	Mr. Carl Vincent
Mr. Chris Watson	Dr. Andy Webb	Mr. John Welch
Dr. Bob Winter	Mr. Keith Young	Ms. Marion Kerr

In addition, staff members working within the 70 critical care units are acknowledged for their participation in the study:

S Agrawal
M Aird
C Algar
J Allen
L Allan
N Allen
S Almond
M Anderson
S Anderson
J Andreozski
P Annison-French
S Anthony
P Archer
R Ashley
S Ashman
S Ashmore
A Ashurst
J Astill
K Atchison
P Auberry
D Bacon
R Baile
M Bailey
D Bainbridge
J Baker
M Baker
S Baker
T Balk
S Barraclough
K Baldryy
D Barber
H Barlow
L Boulding
J Bass
A Batchelor
C Bates
S Bates
L Batt
R Beale
J Beard
S Beasley
J Begley
J Bellin
I Bennum
A Berry
G Bertolini
L Beswick
A Biamey
A Binks
T Birch
S Blake
A Blamey
Y Blencowe
H Blockley
O Boomers
B Borden
R Boreham
M Borthwick
J Bottle
C Boyce
T Bows
S Boyes
R Bradley
S Braithwaite
B Bray
J Breckenbridge
M Brett
A Bridges
E Bridges
H Brittain
E Brooker
C Brookfield
C Brownhill
A Bruce
R Bryson
TBuckenham
S Bully
J Buontempo
K Burchett
A Burgess
D Burkenhead
A Burley
K Burrow
C Burton
J Busby
A Butler
I Butler
J Butler
E Buttle
I Calder
A Cameron
J Cameron
E Campbell
J P Campbell
J Caldicott
A Carr
T Carruthors
K Carpenter
M Casebow
B Casey
P Caudwell
C Carr
B Chadwick
P Challoner
D Chapman
C Charlton
D Childs
M Chomyn
I Chow
L Clapham
M Clay
C Clements
G Coghlan
L Clark
N Clarke
S Clarke
D Clayton
J Cliff
P Clifton
J Coates
S Cockbill Black
P Congdon
A Cook
M Cooper
S Coppell
J Corcoran
M Corcoran
J Cordingley
E Corrick
P Cosgriff
S Cotterill
M Coughlin
S Cowlam
G Cox
T Cox
R Cranage
M Crichton
H Crisp
H Crowe
E Crunden
M Cunningham
P Cunningham
C Curtis
L Dack

S Dando
S Daniels
C Danson
S Dar
L Darroch
R Davidson
K Davies
M Davies
K Davies
M Davis
W Davis
A Day
P Dee
J Dean
R Dean
S Dean
S Deochan
P Deplar
A Devine
M Devine
T Dexter
H Dickie
G Dickman
E Dickson
S Digby
V Dimmock
E Dobson
C Dodd
I Dody
W Doherty
J Doyle
J Drake
M Dranfield
P Drummond
L Duff
C Dunnell
J Durman
P Durrant
B Dziombak
C Eade
U Eastwood
P Eden
C Edmondson
D Edwards
G Edwards
M Edwards
D Elbourne
A Elhusseim
S Elliott
T Elliott
M S Eljamel
R English
R Emsli
F Evans
M Evans
S Evans
J Everatt
K Everitt
A Eynon
G Faulkener
E Feasey
J Featherstone
A Fender
A Ferguson
L Ferguson
M Ferguson
N Ferguson
J Fewings
P Field
S Fildes
C Fishwick
M Fitzgeral
A Flanagan
J Forlow
P Forste
S Forster
R Fox
C Franks
V Frost
I Fry
N Galbraith
I Gamle
M Gandy
M Gaune-Cain
C Garrard
M Gathercole
K Gibb
P Gibson
S Gibson
L Gilbert
P M Gilbert
S Giles
C Godfrey
D Goldhill
A Goodhead
S Goodwin
H Gordan
G Gordo
L Gough
T Gould
R Grant
G R Gray
S Graystone
C Greaves
M Green
O Griffin
J Griffiths
P Griffiths
D Groom
K Gunning
B Guidet
H Hagan
A Hague
C Haig
M Hale
E Hall
J Hall
K Hall
D Hallett
M Hammer
J Hanna
C Hannon
D Harding
C Hardwidge
S Harris
I Hartopp
I Hamilton
S Hamilton
T Harley
G Harmon
I Harrison
J Harrison
R Hart
I Hartop
E Harwood
J De Havilland
J Hawkins
P Hawkins
J Hawthorne
A Haylin
D Hargreaves
S Healy
D Heller
D Heyburn
J E Hibbert
M Hickton
M Higginbottam
D Hill
M Hill
R Hill
T Hilton
J Hollingworth
R Holton
J Honley

T Hopley
E Horkin
D Horne
C Hoult
C Howorth
R Hoy
M Hubbard
C Hudson
S Hudson
C Hughes
J Hull
D Hunt
J Hunt
N Hunter
J Humphries
A Hutchinson
T Hutchinson
K Hydes
H Iafrati
J Ingham
J Iqbal
D Iredale
C Irving
P Isaac
E Iqbal
E Jackson
H Jackson
S Jenkins
T Jenkins
A Jensen
P Johnson
R Johnson
S Johnson
I Jolly
B Jones
C Jones
K Jones
P Jones
T Jones
J Joyce
N Karadikar
J Farmall
M Kastakity
J Kay
J Kaye
P Kearns
P Kemp
A Kennedy
J Kennelly
G Kensington
M Kelse
M Kilby
H Killer
A Kilner
J Kinch
R M Kipling
M Kitson
R Klimczax
D Knight
M Knowles
T Koleoso
K Konieczko
Z H Krukowski
P Kyte
Y Lacey
A Lamb
D Lane
R Lane
A Larkin
A Latty
M Laughlin
D Lawes
R Laws
N Lawrence
D Lawson
K Lee
L Lee
C Leith
A Leese
C Lewis
G Lewis
S Louth
M Lightbody
E Lindley
I Lister
J Little
S Little
T Long
R Longbottom
D Lowe
D Lynch
S Lythgoe
N Mabb
R Mackenzie
J Maginness
C Main
G Marshall
R Marshall
A J Martin
E Martin
N Martin
R Martin
S Marshall
S Marzaioli
A Mason
K Mason
K Massie
G Masterson
D Matthews
L Matthews
S MacDonnell
W MacKay
G MacLeod
C Mac Nab
I Macartney
N Macartney
I Mackenzie
R Mackenzie
H Madder
A McMahon
K Mansfield
J Margary
D Mason-Watson
D Matthews
R Matts
R Matuza
F McAuley
S McAuslan-Crine
A McCann
D McCarthy
J McClymont
C McCormack
A McDowall
J McGarrity
P MacNaughton
M Maynard
S McKenna
J McKiernan
L McKinnon
J Mcrae
C McCabe
A McCann
L McCaughan
J McClymont
A Mc Cormick
C McGowan
H McDale
N McDumnell
S Mcquarrie
J McWhan
G Marshall
R Marshall
D Mason-Watson
T Merrifield

A Middlemiss	C Middleton	R Miles	C Miller
R Miller	D Milligan	F Millington	P Mills
P Milne	R Milne	M Mitchell	
C Mitchell-Inwang			
H Moffat	F Moore	J Moore	G Moore
G Morgan	J Morgan	T Morgan	P Mosdell
E Mortlock	S Morton	S M Mostafa	J Munn
D Murchison	T Murray	K Murphy	N Murtagh
S Musgrave	D Mwanje	S Mynes	V Nealer
V Nelme	M Nevin	T Neman-Smith	P Nightingale
R Norris	S Norris	D Northwood	M Noyes
R Nuth	L Nuttal	L O'Brion	E O'Connell
G O'Gara	C O'Hara	K Okpa	P Orrill
F O'Shea	J Owson	V Page	E Palayiwa
K Parmar	N Parekh	D Parker	C Parons
R Partington	S Patel	M Patten	S Patton
D Penhole	K Pepper	S Pepperell	A Phillip
D Pilkington	M Pinsky	J Polyk	C Ponton
J Powell	V Powell	E Price	L Price
J Pulyk	L Punter	R Pylypczuk	S Racz
P Ramsay	D Rawlings	P Razis	A Reid
B Reid	M Relter	M Ribbands	H Rigby
R Richardson	J Richie	S Ridley	N Ring
C Roberts	L Robertson	D Robinson	J Robinson
L Robinson	N Roebuck	A Rolli	D Rooney
J Ross	P Ross-Elba	K Rowan	J Rowe
C Rudd	M Ruff	A Rush	P Rushton
M H Russell	J Ryman	M Sair	J Sarjant
L Sawrey	R Schneider	C Scott	D Scott
R Seadon	A Searle	B Sellwood	P Shand
L Shaikh	R Sharawi	P Sharpley	C Shaw
D Shead	J Sheard	R Sheldrak	B Sherwin
E Shingleton-Smith	B Shipley	A Short	P Simes
G Simmons	R Sinclair	L Sissons	J Skinner
S Smilt	J Smith	R Smith	V Smith
R Snead	R Solly	T Sonavone	C Sonke
G Spiers	M Spittal	E Spouse	T Stambach
P Stead	L Stewart	D Stickland	D Stoke
C Straughan	A Street	S Stricklan	M Strydom

C Summers
M Swart
I Tatlow
J Thomas
T Thomson
A Timmins
A Tronconi
A Turrell
M Urmston
C Waldmann
B Warren
D Watson
J Westbrook
D White
S Whittingham
A Williams
J Wilson
S Winkle
T Wolff
E Woods
D Wright
D Young

S Supp
C Sykes
S Taylor
P Thomas
F Thorpe
S Tisdall
A Truesdale
A-M Twart
P Vickey
M Walker
H Warwick
D M Watson
J West-Moreland
M White
J Whitwarm
H Williams
L Wilson
A Winkley
J Woodcock
G Worden
J Wright
K Young

V Suppian
J Szafranski
W The
S Thomas
J Thurston
J Tozer
S Tucker
M Tweeddale
C Wade
S Ward
L Water
N Watson
H Wharton
R White
C Wickens
A Willis
M Wilson
J Winter
L Woodham
A Worth
Z Wright
M Young

D Sutton
A Tagg
A N Thomas
R Thompson
A Tice
W Traverse
I Turner
C Tyson
C Wait
W Ware
S Wathington
A Weatherly
R Whetton
C Whitehead
M Willcox
N Wilkinson
S Wiltshire
J Wojdyla
A Wooding
I Wren
R Wyatt

The following hospitals are gratefully acknowledged and thanked for contributing data for use in this study:

Aberdeen Royal Infirmary	Surgical High Dependency Unit
Addenbrooke's Hospital	Critical Care Unit
Antrim Area Hospital	Critical Care Unit
Bristol Royal Infirmary	Critical Care Unit & High Dependency Unit
Broomfield Hospital	Critical Care Unit
Calderdale Royal Hospital	Critical Care Unit
Chelsea Westminster Hospital	Burns Centre
Colchester General Hospital	Critical Care Unit & High Dependency Unit
Conquest Hospital	Critical Care Unit & High Dependency Unit
Cumberland Infirmary, Carlisle	Critical Care Unit
Derriford Hospital	Critical Care Unit, Neurological Unit & HDU
East Surrey Hospital	Critical Care Unit
Eastbourne District General Hospital	Critical Care Unit
Freeman Hospital	Critical Care Unit
Frimley Park Hospital	Critical Care / High Dependency Unit
George Eliot Hospital	Critical Care / High Dependency Unit
Glenfield Hospital	Adult Cardiac Critical Care Unit
Good Hope Hospital	Critical Care Unit & High Dependency Unit
Grantham & District Hospital	Critical Care Unit
Hemel Hempstead General Hospital	Critical Care Unit
Hope Hospital	Critical Care Unit
Huddersfield Royal Infirmary	Critical Care Unit / High Dependency Unit
Hurstwood Park Neurological Centre	Neurosurgical Critical Care Unit
John Radcliffe Hospital	Critical Care Unit
Leeds General Infirmary	Critical Care Unit
Leighton Hospital	Critical Care Unit & High Dependency Unit
Lincoln County Hospital	Critical Care Unit
Luton & Dunstable Hospital	Critical Care Unit
Monklands District General Hospital	Critical Care Unit
New Cross Hospital	Critical Care Unit
North Devon District Hospital	Critical Care / High Dependency Unit
North Manchester General Hospital	Critical Care Unit & High Dependency Unit
Northwick Park Hospital	Critical Care / High Dependency Unit
Pilgrim Hospital	Critical Care / Coronary Care Unit
Queen Elizabeth Hospital, Birmingham	Neurosciences Unit
Queen Elizabeth Hospital, Gateshead	Critical Care Unit

Queen Elizabeth Hospital, Kings Lynn	Critical Care / Coronary Care Unit
Queen Elizabeth II Hospital	Critical Care Unit
Queen Mary's Hospital, Sidcup	Critical Care Unit
Queen Victoria Hospital	Burns / Plastic Surgery Unit
Radcliffe Infirmary	Neurosciences Critical Care Unit
Royal Brompton Hospital	Cardiothoracic Critical Care Unit
Royal Cornwall Hospital	Critical Care Unit
Royal Devon & Exeter Hospital	Critical Care Unit
Royal Hallamshire Hospital	Neurological Critical Care Unit
Royal Liverpool University Hospital	Critical Care Unit
Royal London Hospital	Critical Care Unit
Royal Marsden Hospital	Critical Care Unit
Royal National Orthopaedic Hospital	Adult / Paediatric Surgical Critical Care/ HDU
Sandwell General Hospital	Critical Care Unit / High Dependency Unit
Scunthorpe General Hospital	Critical Care Unit / High Dependency Unit
Southampton General Hospital	Neurosciences Critical Care Unit
St. James' Hospital	Critical Care Unit
St. Peter's Hospital	Critical Care Unit
Taunton & Somerset Hospital	Critical Care Unit
The Horton Hospital	Critical Care / HDU / Coronary Care Unit
Torbay Hospital	Critical Care Unit
Trafford General Hospital	Critical Care / Coronary Care Unit
Tyrone County Hospital	Critical Care Unit / High Dependency Unit
Victoria Infirmary, Glasgow	High Dependency Unit
Walsgrave Hospital	Intensive Care Unit & HDU & ITU
Walton Centre for Neurology & Neurosurgery	Neurological Critical Care Unit
Warrington Hospital	Critical Care Unit / HDU
Worthing Hospital	Critical Care Unit / HDU
Wycombe General Hospital	Critical Care Unit
Yeovil District Hospital	Critical Care Unit

CESAR Trial Group

I wish to thank members of the CESAR Trial Group for their help and advice during my PhD and acknowledge their hard work with the clinical trial.

- Miranda Mugford and Mariamma Thalanney at the University of East Anglia
- Diana Elbourne, Ann Truesdale and Steve Robertson at the London School of Hygiene and Tropical Medicine
- Giles Peek, Hilliary Killer, Gail Faukener and Ravindranath.Tiruvoipati at the Cardiothoracic ICU at Glenfield Hospital.
- Elizabeth Coates at the University of Surrey.

Critical Care National Working Group on Costing

I wish to thank and acknowledge the efforts of the founding members of the Critical Care National Working Group on Costing who helped developed the cost block methodology (that was adapted for use in the multi-centre study).

Dr. Anna Batchelor; Dr. Ken Burchett; Dr. David Chapman; Ms. Margaret Corcoran; Mr. Carl Dodd; Sr. Helen Dickie; Dr. David Edbrooke; Dr. Tim Long; Mr. Brian McNaught; Dr. George McLeod; Mr. John Morgan; Dr. Fred Mostafa; Dr. Mike Nevin; Dr. Peter Nightingale; Dr. Saxon Ridley; Dr. Mark Smithies; Professor Alan Williams

Reviewers and Facilitators

I would also like to thank everyone involved in the review and approval processes of the multi-centre study. This includes members of the Trent Multi-Centre Ethics Committee (MREC), the respective

Local Research Ethics Committees (LRECs), the local R&D departments, the Clinical Working Group established by the NHS Information Authority and the NHS Information Standards Board who externally reviewed the work.

I finally wish to thank Professor Marc Jegers at the University of Brussels for his comments on earlier drafts of the thesis and acknowledge Kathy Rowan and her colleagues from the Intensive Care National Audit & Research Centre (ICNARC) and critical care network managers for encouraging their critical care units to participate in the multi-centre study.

Significant Others

I wish to thank Rich and Adie for their patience and support.