Innovation in surgical training and its impact on healthcare

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Abstract

Surgical training is currently in a state of flux, with dramatic changes in the way it is structured and delivered. The greatest challenges to surgical training have come from the advent of minimally invasive surgery in the 1990’s and more recently the reduction in a doctors working hours. This has led to a significant decrease in training opportunities that are available to the surgical trainee. Simulation has been heralded as an effective adjunct to surgical training whilst ensuring high standards of patient safety. This thesis aims to investigate the factors influencing current surgical training methods and whether simulation can be used to improve the effectiveness of surgical training in a cost efficient manner.

The first part of this thesis investigates the impact that the reduction in working hours has had on surgical training, and whether the use of simulation can alleviate this. The reduction in working hours for doctors has led to a significant reduction in training opportunities. However, laboratory based simulation training can improve technical skills, provided it is used as part of a proficiency based technical skills curriculum.

The second part of this thesis investigates the impact that innovations in surgery have had on surgical training, and whether simulator technology can advance at a similar rate. The introduction of single incision laparoscopic surgery provides further challenges for the surgical trainee, and it is clear that a novice laparoscopic surgeon needs further technical skills curriculum based training before entering the operating room. In addition, advancement in simulator technology now allows senior surgeons to learn advanced techniques in the skills laboratory.

The final part of this thesis aims to assess the current costs of surgical training in the operating room, and whether simulation can improve operating room efficiency such that cost
savings can be made. One of the main criticisms of simulation training is that it is expensive. However, the evidence in this thesis demonstrates that traditional training is also very expensive; and with prior training on simulation, operating times can be significantly reduced, providing sufficient cost savings that make simulation cost efficient.

Simulation works. This is clear from the literature and from evidence provided by this thesis. Although simulation alone is not sufficient to train surgeons to operating room proficiency, it can provide a useful adjunct to surgical training. It allows trainees to train in the safety of skills laboratory, and shorten the learning curve in the operating room which in turn improves patient safety. If appropriate simulators are selected and used correctly, it can provide benefits to the healthcare system by reducing costs through an improvement in operating room efficiency.
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1. Introduction

Surgical training is currently in a state of flux, with dramatic changes in the way it is structured and delivered. The greatest challenges to surgical training have come from the advent of minimally invasive surgery (MIS) in the 1990’s and more recently the reduction in a doctors’ working hours (Aggarwal and Darzi, 2006).

Traditionally, the medical profession has relied on experience based learning, with knowledge, skills and decision making ability developed over a long period of time through treating large numbers of patients (Reznick and MacRae, 2006). For surgical training in particular, in the late 1800’s, Sir William Halsted brought a residency style training structure from Germany to the United States of America (USA) that had an emphasis on graded responsibility (Carter, 1952). This model provided the foundations of modern day surgical residency training in both the USA and the United Kingdom (UK), with generations of highly skilled surgeons having trained using this method (Krummel, 1998). Surgical trainees would spend huge amounts of time in the hospital setting both “on call” and with their team. The time in hospital would provide the opportunity for the trainee to learn and develop their clinical skills primarily on-the job with patient encounters, all under the supervision of a surgical master (Royston et al., 1994). It is estimated that a surgical trainee would spend close to 30,000 hours working from the start of their training at Senior House Officer (SHO) until becoming a consultant. This would require an average of 85 hours a week for more than 10 years, before having the experience necessary to become an independent practitioner.

However, it is not clear how much of that time was used for training. This figure is now closer to 6,000 hours due to changes in the way surgeons are trained (Elbadrawy et al., 2008). The Calman reforms were introduced for surgical training in 1995. These were a set of regulations that put a limit on training time, by clearly defining an end point for training with
the certificate for completion of training (Calman, 1995). The most important aspect of the reforms was the definition of a clearly structured training program that pushed training away from the full apprenticeship model. The reforms attempted to limit unsupervised operating, and replace it with supervised learning and structured training. It was suggested that the traditional apprenticeship model was only successful due to the extreme length of both the working day, and the years of the entire training program. Post-Calman training aims to limit the hours, with a focus on gaining clearly defined competencies in the knowledge, skills and attitudes required (Elbadrawy et al., 2008).

1.1 Reduction in training opportunities

Since the Calman reforms, there has been a significant reduction in training opportunities for surgeons and other medical specialties alike (Reznick and MacRae, 2006). The factors influencing training opportunities can be divided into (Aggarwal and Darzi, 2006):

a) Working hour restriction,

b) Patient outcome related issues,

c) Management factors,

d) Technological advances.

1.1.1 Working hour restriction

The most recent influential factor is the working hour reduction for doctors. The New Deal for doctors and the European working time directive (EWTD) have both had a significant impact on the hours that a doctor is allowed in hospital, with no increase in the length of training (Figure 1). This has dramatically reduced the number of training opportunities available for the trainee doctor (Department of Health, 2004). Many doctors agree that patient outcome and satisfaction is the most important measure for a successful
healthcare system, and any changes to the system must be with patient safety in mind (Gaba and Howard, 2002). One of reasons that the working hour restrictions have been introduced has been due the research into medical error and the sleep deprivation of a doctor associated with long working hours (Landrigan et al., 2004).
Figure 1 – Definitions of the New Deal and EWTD

<table>
<thead>
<tr>
<th>Legislation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>The New Deal for Doctors</td>
<td>This was a piece of legislature developed in 1991. The key subject was to limit the amount of hours that a doctor was allowed to work. By 1996, it was agreed that there was a limit of 72 hours per week on call, 64 hours per week partial shifts and 56 hours per week full shifts.</td>
</tr>
<tr>
<td>The European Working Time Directive</td>
<td>The EWTD is European law seeking to protect the health and safety of workers. It was enacted into UK law in 1998 as the Working Time Regulations. The Working Time Directive limits the number of hours that doctors are allowed to work over an average week. In 2009, doctors were only permitted to work 48 hours per week.</td>
</tr>
</tbody>
</table>
1.1.2 Patient outcome

Patient safety should be the primary concern for all clinicians, but patient outcome has also had a direct influence on training opportunities. In surgery, learning curve analysis of procedures confirm that medical error is more likely when a surgeon performs surgery, or a new operation for the first time. Thus the more experienced a surgeon, the less likely that he will make a mistake (Berwick and Leape, 1999, Tekkis et al., 2005, Reissman et al., 1996). This has led to an increase in patient demand for consultant supervision, or the consultant to perform the operation. Media coverage of medical errors has further led the public to demand a consultant delivered service rather than a consultant led service (Dowie and Langman, 1999). Although this is unquestionably better for the patient, there could be a negative impact on junior doctor training, through a decrease in the number of operations that a trainee can perform.

1.1.3 Management factors

Hospital management is a significant factor affecting training opportunities for doctors of all specialties. Quality assurance targets, both for hospitals and departments have led to increased pressure from hospital management on surgical teams to reach these targets, sometimes to the detriment of training (Aggarwal and Darzi, 2006). It is now possible for patients to access the public records of hospital performance, and specific performance rates of individual consultants. This has occurred following the public enquiry into the events that occurred in the cardiothoracic surgery department in Bristol in 1998 (Mayor, 2001). The enquiry was established to investigate the reasons behind an increase in mortality rates of babies undergoing cardiothoracic surgery between 1991 and 1995 at Bristol Infirmary (Dyer, 1999). The results of this enquiry recommended that all patients should have access to “the relative performance of the trust” and “the consultant units within the trust” (Anon). As a
result, many surgeons are more likely to be the lead surgeon in their operations to prevent any potential detriment on their publicised outcomes. A significantly poor mortality rate may also have an impact on the re-certification process. Therefore, a consultant surgeon will be acutely aware of the need for a good patient outcome, obviously for the patient, but will also be aware of its importance for their own career progression (Pearce et al., 1999). This provides potential for reducing the training opportunities for surgeons in training.

1.1.1. Technological advances

Technological advances, such as minimally invasive surgery (MIS), are influential factors that have reduced training opportunities for surgeons in the modern era. MIS has had a significant impact on the way in which we deliver surgical care, with laparoscopic management now the gold standard treatment for a large number of general surgical conditions (Harrell and Heniford, 2005). However, the operations are very different from the traditional operations, and the introduction of laparoscopic surgery has had a significant impact on training for junior surgeons. The technical skills required for laparoscopic procedures are distinctly different from those required for open surgery, which results in a prolonged learning curve for a surgeon performing laparoscopic surgery who is already a competent open surgeon (Figert et al., 2001). It has been shown that complication rates are higher at the start of the learning curve, as a surgeon develops the technical skills required. Therefore, a senior surgeon is more likely to operate than the junior surgeons (Pellegrini et al., 2004). Operations such as the appendectomy, which has traditional been the “training operation” for junior surgeons, is now often carried out using a laparoscopic approach. As a result it is frequently performed by the consultant or senior surgical trainee (Monson, 1993, Schick et al., 2008). This has led to a reduction in numbers of procedures a junior trainee can learn from (Hindmarsh, 2003). In addition, it is inappropriate and unacceptable for novices to
“learn on patients” meaning that the traditional “see one, do one” apprenticeship approach to surgical skills training is no longer considered acceptable (Kneebone and Aggarwal, 2009, Grantcharov and Reznick, 2008).

1.2 Filling the training void

It is suggested that adequate clinical experience can no longer be gained through operating alone, therefore effective adjuncts must be found. As a result of this, it is generally accepted that technical skills should initially be taught using simulation in training laboratories prior to entering the operating room or procedure suite (Aggarwal et al., 2006a). The skills laboratory provides a safe and controlled environment, and using simulation as the training platform, surgical trainees can learn, develop and perfect technical skills, learning from mistakes, without detriment to the patient.

The development of technical skills is a vital aspect of becoming a competent surgeon. However, it is increasingly important for other healthcare professionals who perform any diagnostic or therapeutic procedure. Despite the complexity of many surgical procedures, the teaching and assessment of technical skills has traditionally been one of the least systematic components of medical education (Reznick, 1993). To improve learning opportunities, there has been significant financial and institutional support for skills training, which has seen a rapid expansion of training laboratories. This has been approved by the trainees, with a rise in skills laboratory attendance, to try and bridge the gap in technical skills training (Figert et al., 2001). Policy makers in the USA and UK also support the shift from the operating room to the skills lab. The landmark “To Err is Human” report by the Institute of Medicine in the USA suggested that the key strategy in reducing medical error would be by providing better training and objective assessment (Kohn, 2000). This view is supported in the UK with the Chief Medical Officer for England Wales, Sir Liam Donaldson, stating that “simulation
offers an important route to safer care for patients and needs to be more fully integrated into health services and doctors training programs” (Donaldson, 2002). Despite this, simulation training has been slowly adopted by the surgical community as it often cited as lacking fidelity or being too expensive (Sutherland et al., 2006). This appears to be changing, with junior surgeons in particular taking responsibility for their own training by using simulation if it is accessible (Rosenthal et al., 2008).

1.3 The current role of simulation in surgical training

The key challenge for surgical training is providing an appropriate platform for learning and practicing technical skills that does not harm the patient. Practising on patients is both unacceptable and inappropriate, thus simulation (the “act of mimicking a real object, event or process by assuming its appearance or outward qualities”) presents an possible alternative (Gorman et al., 1999). Kneebone et al suggested that there are four key advantages of simulator based learning (Kneebone, 2003):

a) The training agenda can be determined by the needs of the learner, not the patient. Learners can focus on whole procedures or specific components, practising these as often as necessary.

b) Because the environment is safe, learners have permission to fail and to learn from such failure in a way that would be unthinkable in the current clinical setting. This gives the opportunity to explore the limits of each technique rather than having to remain within the zone of clinical safety.

c) Simulators can provide objective evidence of performance, using their inbuilt tracking functions to map a learner’s trajectory in detail. An increasing range of metrics is being developed and validated, offering potential for formative and summative assessment.
d) The capacity of simulators to provide immediate feedback in digital form offers potential for collaborative as well as individual learning.

Simulators have been widely validated as training and assessment tools, and there is significant evidence demonstrating that they can improve a surgeon’s technical skill. Simulators have also been shown to improve a surgeon’s performance in the operating room or procedure suite (Torkington et al., 2001b, Andreatta et al., 2006). Simulators vary hugely from inexpensive, low fidelity plastic models for suturing skills to high fidelity, expensive virtual reality (VR) simulators (Maran and Glavin, 2003). They are now used for teaching technical skills at some point to most grades of surgeons in multiple specialities including general surgery, urology, vascular surgery, ears nose and throat surgery (ENT), orthopaedics and gynaecology (Gurusamy et al., 2008). Simulators can be broadly categorised into physical simulators and VR simulators.

1.3.1 Physical simulation

Physical simulators vary widely in cost and realism, but are routinely used in skills centres to teach a wide array of practical procedures from venepuncture and wound closure to thoracostomy (Kneebone and ApSimon, 2001, Wang et al., 2008). Technological advances in physical materials has vastly improved the realism of physical simulation which can provide a realistic way of practising the technical skills needed for minor surgical procedures such as the removal of sebaceous cysts or lipomas (Issenberg et al., 2001). Despite the advances, physical simulators have some limitations; it is impossible to have totally realistic models, and without sufficient supervision, feedback of performance is limited (Kneebone, 2003).
1.3.2 Virtual reality simulation

VR simulation uses a computer based program to develop a realistic representation of a system or body region. It has a physical interface that when moved by a trainee will be tracked in the virtual field, appearing on the screen as surgical instrument movements. Thus a trainee is able to perform basic tasks, navigate around organs or perform full length operative procedures within a virtual world. In 1993, Satava et al first suggested the use of VR to teach surgeons anatomy and to practice surgical procedures prior to entering the operating room (Satava, 1993). The initial VR simulators were very effective at teaching psychomotor skills, but were not very realistic, resulting in criticisms regarding their effectiveness for skills training (Aggarwal et al., 2004). Since then, there have been advances in computer power and graphics that have resulted in the development of extremely realistic VR simulators for many surgical specialities (Fried et al., 2004). There has also been an improvement in acceptance of VR simulation, as there is considerable evidence demonstrated the acquisition of skill after using a VR simulator (Seymour et al., 2002, Grantcharov et al., 2004). Although VR simulation has become far more accepted by surgeons, it has struggled to become widely adopted, and as such, it remains difficult for many surgeons to gain access to VR simulators (Haluck et al., 2001).

1.4 Adoption

Simulation training provides a platform for a surgeon to learn and develop the skills needed to perform operations. An area of simulation that needs be explored is its potential in improving the adoption of new operations and techniques. This is the case for both junior surgical trainees operating at the start of their learning curve and senior surgeons performing new complex operations. Currently, there are no formal guidelines stipulating when and where a junior surgeon can perform their first operations. Traditionally, a trainee would assist
in a number of cases with an experienced surgeon before being allowed to operate
themselves. The first time a trainee operates, and the type of operation they perform is purely
at the discretion of the supervising surgeon. There is no formal exam, training course or skills
program that a trainee must complete before they can start operating. This is also true for
senior surgeons. In the United Kingdom, when a surgeon finishes their training they receive a
certificate of completion of training (CCT), they can then register as a specialist with the
General Medical Council (GMC) and are allowed to become independent practitioners. Once
practising as a consultant surgeon, there is minimal legislation stipulating what operations
they are allowed to perform. A consultant surgeon will usually perform operations that lie
within the sub-speciality, but may adopt more complex operations at their discretion.
However, they would be liable professionally if they performed operations in a reckless
manner. Currently, we must rely on the honesty and diligence of individual surgeons to
ensure that they have the appropriate technical skills to perform these operations.
Furthermore, the only method of monitoring the success of newly adopted procedures is by
departmental audit of morbidity and mortality. This is not the optimal way of ensuring the
delivery of high standards of care. There needs to be further research into the adoption
decision of individual surgeons and surgical departments, and the role that simulation could
play in standardisation.

1.5 Cost of training

One of the common criticisms of simulation training, especially in terms of VR
simulation, is that it can be expensive to purchase the simulators (Satava, 2001). However,
the aim of simulation training is to reduce the inherent errors that are associated with a
procedural learning curve that could potentially harm the patient. Medical errors can result in
lifelong morbidity or mortality to the patient, and can be extremely costly to a healthcare
system, both in the cost of added interventions to remedy the error, and the associated litigation costs that may occur (Weingart et al., 2000). Therefore, simulation may provide a cost efficient way of training junior surgeons (Sutherland et al., 2006). Despite the potential increase in medical errors, surgical training in the operating room is considered to be very expensive (Babineau et al., 2004, Blendon et al., 2002). There are limited studies that accurately measure the cost of training in the United Kingdom. Quantitative data on the cost of training are provided by Bridges and Diamond who in 1997 assessed the increase in costs as a direct result of training surgical residents in the operating room in the USA (Bridges and Diamond, 1999). They assessed the costs of running an operating room, and produced a cost per hour for operating room function. They compared the time it took residents to perform operations with attending surgeons. This was extrapolated to estimate that the cost of training each surgical resident in the operating room is $47,970, which equates to $54 million per annum for all residents in the USA (Bridges and Diamond, 1999). Although there are some limitations in this study’s methodology, as it does not account for the salaries of surgeons or anaesthetists, it purely measures the “lost time” due to training, and the associated cost. The study took place in 1997; therefore the cost of training today’s surgeons is likely to be considerably more than this. Therefore, on assessing the costs of simulation training, it is important to consider the reduction in operating room time that could occur as a result. Together with the potential decrease in litigation costs that could occur from medical error; the initial outlay required for simulation training does not appear to be too expensive. Further work is required to analyse the current costs of surgical training and equate them with the costs and effectiveness of simulation training.
1.6 Challenges to training

It is clear that there needs to be a change in surgical training to bridge the gap that has resulted in the loss of training opportunities. Doctors of all specialities and surgeons in particular have a finite time for training, in which they are expected to develop the core knowledge, skills and attitudes required to be competent and safe independent practitioners. As the number of hours per week a doctor is allowed to work is reduced, with no extension in the length of training, it is vital that a new framework is developed for technical skills training with simulation as its core.

Evidence regarding the cost of surgical training in the operating room is limited, but the costs are considered to be significant. There is finite amount of resources that is available for training, therefore it is crucial to evaluate the current costs of surgical education. This would allow us to establish strategies for improving the efficiency of surgical training in terms of effectiveness and cost. It is vital to establish the most economic solutions to developing a generation of competent surgeons.

New models need to be developed for training in the practical specialities that focus on improving the efficiency of training on the job. It is important to investigate the most efficient ways of training surgeons both in simulation and in the operating room. Thus trainees can maximise the training opportunities when they arise. Further work is needed to develop structured curricula for technical skills training that can be integrated into current speciality training programs, without impeding on service provision. To ensure that service provision is maintained at high standards, innovation is required in the way healthcare is delivered.
1.7 Hypothesis

Current surgical training is expensive and inefficient;

1.8 Aims

- To investigate the current state of surgical training and the impact of the reduction in working hours for doctors
- To evaluate the impact of virtual reality simulation on surgical training
- To assess the impact that innovations in surgery have had on training
- To establish the importance of proficiency based curricula for technical skills training
- To assess the current cost of surgical training
- To establish the most efficient way of training surgical technical skills
2. **The impact of the reduction in doctors working hours**

The career path of a hospital doctor has traditionally required a long period of postgraduate training. It has conventionally required extensive training through a number of attachments within one or many hospitals or medical institutions, usually under the supervision of a master or trainer (Reznick and MacRae, 2006). The doctor gathers the skills and knowledge required to be a specialist “on the job” using an experience based training method. It has often required substantial hours per week in hospital taking care of patients, and frequently working overnight shifts as the “on call” doctor for a particular speciality (Figure 2). One hundred hours a week was often the norm for the doctor in training, however, it is not evident how much of that time was used for training (Lloyd, 2005). The traditional model of training via experience based practice requires a long period of time, with long hours, to gain the knowledge, skills and decision making ability required to be an independent practitioner (Reznick and Macrae, 2006). It has been estimated that in the speciality of surgery, a junior doctor would be expected to work over 30,000 hours between SHO jobs and consultant jobs. This would occur during an average of 85 hours per week over a period of 10 years (Elbadrawy et al., 2008). In the past decade however, there has been a huge amount of scrutiny of the hours that a doctor is required to work (Landrigan et al., 2008). The media, politicians and patient groups, as well as influential members of the medical community have raised concerns about the effect that long hours has on an individual doctor to perform their duties in a safe and efficient manner. A number of studies and commentaries have identified the role that fatigue and sleep deprivation of a clinician has on medical error and patient safety, with the conclusion being that the longer the hours worked, the more likely that patient safety would be put at risk (Landrigan et al., 2004). In response to this, policies were developed by governments and regulatory bodies in both the United States
and the United Kingdom to reduce the number of hours that a doctor was allowed to work in hospital (Pickersgill, 2001, Lockley et al., 2004).

### 2.1 Legislation regarding doctors working hours

The subject of limiting doctors’ hours was first broached in the United Kingdom in 1991, under the New Deal for Junior doctors (Pickersgill, 2001). This was a piece of legislature agreed by profession representatives, National Health Service (NHS) management and the government. It outlined a package of measures that aimed to improve the conditions that junior doctors worked in. The key objective was to limit the amount of hours that a doctor was allowed to work. By 1996, it was agreed that there was a limit of 72 hours per week on call, 64 hours per week partial shifts and 56 hours per week full shifts (Jagṣi and Surendr, 2004).
Figure 2 - Definitions of working patterns (Department of Health, 2008)

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>On call</strong></td>
<td>Periods of duty must not exceed 32 hours (56 at weekends) and the average duty hours for the week should not exceed 72 hours. Rest requirement: approximately 8 hours of rest in total (12 per weekend day), of which 5 should be continuous between 10pm and 8am.</td>
</tr>
<tr>
<td><strong>24-hour partial shift</strong></td>
<td>This is similar to an on-call rota except that the period of duty must not exceed 24 hours and the average duty hours for the week should not exceed 64 hours. Rest requirement: 6 hours of rest in total, of which 4 should be continuous between 10pm and 8am.</td>
</tr>
<tr>
<td><strong>Full shift</strong></td>
<td>The maximum length of duty for a full shift is 14 hours and the maximum average should not exceed 56. Natural breaks of 30 minutes’ uninterrupted rest should be taken every four hours.</td>
</tr>
<tr>
<td><strong>Partial shift</strong></td>
<td>The maximum length of duty for a partial shift is 16 hours and the average duty hours for the week should not exceed 64 hours. Rest should total one quarter of the out-of-hours duty period.</td>
</tr>
</tbody>
</table>
At a similar time, the European Working Time Directive (EWTD) was introduced. However, initially doctors in the UK as well as employees of air, rail, sea and road industries were exempt from the directive. The British government challenged the directive, but it was confirmed as European Law by the European Court of Justice in 1996. The European Commission always intended that doctors be included in the EWTD, and the European Commission revised the directive in 2000 to include doctors in training (MacDonald, 2003). This made it illegal for doctors to work over the set hour restriction. In October 2000, the SiMAP ruling (figure 3) by the European Court of Justice (ECJ) declared that all duty whilst on trust property should be considered as working time. This was confirmed by the Jaeger ruling in 2003, which reiterated the SiMAP ruling and added that compensatory rest should be mandatory following partial shifts. A timetable for the implementation of EWTD was devised with all NHS employees to work a maximum of 58 hours a week from August 1st 2004, with a decrease to 56 hours a week from August 1st 2007, and full compliance to a 48 hour week by 2009 (Sheldon, 2004). The implementation of the directive and the ECJ rulings have forced many NHS Trusts to abandon partial shifts due to the stringent rest requirements, with all rest on site counting as working time, thus breaching EWTD requirements. This makes resident on call practically and financially non-viable for workers and trusts. On August 1st 2009, EWTD came into full effect, with the majority of NHS trusts aiming to have compliant rotas (Jones et al., 2004).
Figure 3 – Definitions of court rulings concerning EWTD

<table>
<thead>
<tr>
<th>Ruling</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The SiMAP</td>
<td>2000</td>
<td>This is a ruling from the European Court of Justice, which defines all time spent on duty on Trust premises as work.</td>
</tr>
<tr>
<td>ruling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Jaeger</td>
<td>2003</td>
<td>This ruling in the European court confirmed the SiMAP judgement. It also recommended that when 11 hours continuous rest was not possible, compensatory rest should be taken &quot;immediately&quot;, before the doctor starts their next shift.</td>
</tr>
</tbody>
</table>
Figure 4 – Timeline of legislation regarding doctors working hours

- **1991** • Government introduce the New Deal for Junior Doctors
- **1993** • European Working Time Directive agreed
- **1996** • UK Working Time Regulations implemented (excluding junior doctors)
- **2000** • New Deal contract implemented
- **2000** • Horizontal Amending Directive (HAD) extends EWTD to cover doctors in training
- **2002** • DOH and Modernisation Agency develop timeline for implementation
- **2004** • Working hours restricted to 58 hours per week
- **2007** • Working hours restricted to 56 hours per week
- **2009** • EWTD in full effect restricting hours to 48 per week
2.2 Impact of the European Working Time Directive

The medical community is divided on the EWTD arguing that patients deserve to have doctors that are fully rested and less likely to make mistakes, but a reduction in working hours could impact on training. The British Medical Association (BMA) appears to support EWTD with two thirds of their members being in favour of the reduction in working hours (Thornley et al., 2008). However, many feel that a reduction in hours increases the intensity of work, with more frequent handovers that could potentially have a negative impact on patient safety (Laine et al., 1993). It is also argued that EWTD could have a negative impact on the training of junior doctors (Kapur, 1997). This is especially apparent in the experienced based practical specialities such as surgery and anaesthetics (Phillip H, 2003). The Royal Colleges of Surgery and Anaesthesia have both condemned the EWTD and its impact on doctors training, describing it as a potential “time bomb” as an entire generation of consultants will have insufficient experience and skills compared to their predecessors (Joint project Royal College of Surgeons and the Royal College of Anaesthetists, 2008; House, 2009).
2.3 Methods and materials

2.3.1 Data sources

This chapter aims to review the independent studies that have investigated the impact a reduction in working hours for doctors has had, including patient care, training and quality of life of doctors in training. This review has been performed as a single author systematic review. A search was performed of the English language literature using online electronic components. MEDLINE was searched using the search terms.

2.3.2 Search results

Studies were selected using two levels of inclusion and exclusion criteria. The first search level reviewed the abstracts of each study and excluded studies that were only abstracts, case reports, letters, comments, editorials and reviews, animal or in vitro studies and languages other than English. This resulted in 44 original articles. (Figure 5)

The second level of selection required accessing the full papers for each study, and accessing full papers for studies that could not be previously excluded from the abstract alone. 24 studies were included that focused on one of the following criteria: The impact of the European Working Time Directive; The New deal for doctors; and the reduction in doctors working hours.

2.3.3 Study selection for data extraction

Studies were selected for data extraction that covered the impact a reduction in working hours has on various factors including: Quality of life for doctor and patient; patient outcome; medical error; doctors training; doctors experience and opinions of senior and junior doctors and patients. This resulted in 24 original articles for data extraction.
Figure 5 – Flow chart for data analysis

Abstracts identified through database search
N=687

Abstracts selected for more detailed analysis
N=44

Articles selected for data analysis
N=24

Abstracts rejected due to limits
N=643

Abstracts rejected as irrelevant
N=20
2.4 Results

2.4.1 Impact of the EWTD on the work / life balance

2.4.1.1 The impact of EWTD on working hours

Six articles were identified that analysed the impact of the EWTD on working hours (Sim et al., 2004, Soo et al., 2007, Garvin et al., 2008, Cappuccio et al., 2009, Al-Rawi and Spargo, 2009, Melarkode et al., 2009). The driving force behind implementing EWTD compliant rotas is to reduce the number of hours that a doctor is able to work, whilst increasing the amount of rest that they may take between shifts. It is obvious then, that the most notable impact of EWTD and previously the New Deal, is the change in working patterns and the reduction in hours spent in a hospital (Rodriguez et al., 2009, Al-Rawi and Spargo, 2009, Cappuccio et al., 2009, Sim et al., 2004).

Many of the studies in this category were retrospective analyses using questionnaire based studies (Melarkode et al., 2009, Soo et al., 2007). However, Cappuccio et al performed a prospective study prior to the implementation of EWTD, investigating the effects of implementing a EWTD compliant rota on trainees in a large teaching hospital. This study has a scientifically sound design, using a single blinded and randomised method, allocating 19 junior doctors to an intervention group or a control group. The intervention group was an EWTD compliant rota with split day, evening and night shifts, averaging <48 hours per week. This was allocated to 9 junior doctors covering a medical ward, whilst the control was a group of 10 junior doctors working a traditional pre 2009 EWTD rota with day and night shifts, of 54 hours per week on a different medical ward. These rotas were run concurrently for a period of 12 weeks with the doctors having to document work and sleep patterns. As expected, the study demonstrated that on average there was a 10 hour/week difference
between the two rotas, 43.2 hours per week vs. 52.4 hours per week. The maximum working hours per week on the traditional rota was 77 hours, for 3 out of 12 weeks, whilst the intervention group worked a maximum of 60 hours for only 2 weeks. This resulted in a demonstrable effect on sleep patterns with an average of 7.26 hours sleep per night for the intervention group and 6.75 hours on the traditional group (Cappuccio et al., 2009).

However, there does not appear to be any analysis of the difference between recovery sleep following a night shift on the intervention rota and the traditional rota. This analysis would have been of more significance. It would also have been of benefit to have made some formal assessment of sleepiness (Johns, 1991). This could have given important information about the doctors’ feelings of alertness, and their ability to perform their job satisfactorily. This study was designed with outcome control of a 48 hour week. It is therefore to be expected that the results would demonstrate a reduction in hours. A further criticism of this work is the selection of different wards for a concurrent analysis of the impact of an EWTD complaint rota. Although both groups covered medical wards, the intervention group covered the clinical decisions unit and the endocrinology unit, with control group (traditional rota) covering the respiratory and care of the elderly ward. Although Cappuccio et al acknowledge that there will be a difference in patient flow and work load, between the wards, this is not taken into account when measuring differences in hours and sleep patterns. It may have been more rigorous to design the study with the control and the intervention to run on the same ward at different times. This would have alleviated any discrepancies discovered that may have occurred due to different workloads on separate wards. Despite this, the study remains a strong analysis of the impact that the EWTD has on the working hours of a junior doctor.

Further evidence supporting the reduction in working hours can be provided by Sim et al who demonstrated a reduction in average hours from 48.5 hours per week to 43 hours per week with an EWTD compliant rota (Sim et al., 2004).
2.4.1.2 The impact of EWTD on quality of life

The medical profession has one of the highest rates of alcoholism, suicide, divorce and depression (Schernhammer and Colditz, 2004, Rollman et al., 1997, Murray, 1976). One of the contributing factors for this is assumed to be the long hours that doctors are required to work, and the stress and time away from home that is associated with the profession (Schernhammer and Colditz, 2004, Rollman et al., 1997, Murray, 1976). The core motives for implementing the EWTD include the potential improvement that a reduction in hours would have on an individual’s physicians quality of life (Department of Health, 2008). There have been a number of original articles that attempt to assess the improvement in a physician’s quality of life since the introduction of the EWTD.

The first qualitative data supporting the improvement in the quality of life of doctors following the implementation of EWTD was assessed by West et al (West et al., 2007). The reduction in hours, through questionnaire analysis, 55% of cardiothoracic surgeons interviewed felt that there had been an improvement in their quality of life. This is an interesting finding, as it would be expected that doctors would appreciate increased time off. However, surgery is one of the specialities that has the most vocal objections to the implementation of EWTD (Smith, 2004). Many surgeons may be concerned about training issues that arise from the reduction in hours, and this may affect their feelings of quality of life. The results of the questionnaire may also have some bias by placing questions regarding quality of life alongside questions regarding training. However, an improvement in the quality of life of doctors has also been demonstrated in further studies. Garvin et al designed a pilot rota that was EWTD compliant for surgical SHOs, with a maximum of 48 hours per week. This was run for 6 weeks in a large teaching hospital, and although 48 hours was the aim, the average hours worked per week was 58.1. Although the number of subjects was
small, with only 23 surgical trainees included, 69% of them reported a noticeable improvement in quality of life.

**2.4.2 Impact on training for doctors**

One of the main criticisms of the implementation of the EWTD is the adverse effect that it could have on doctors training. Medicine is an experience based profession, where trainees will develop the knowledge and skills required to be a specialist on the job. As previously discussed, traditionally, doctors would spend a large amount of time per week in hospital working, but not necessarily learning. The long hours were rewarded with the experience needed to be a consultant. As speciality training for all medical specialties is of fixed length, a large decrease in working hours will have a direct impact on the amount of experience a doctor can get in their training years (Thorne et al., 2006, Underwood and McIndoe, 2005). This is especially apparent in the practical specialities such as anaesthetics and surgery. As a result, the research investigating the impact of the EWTD on training has mainly looked at the impact on anaesthetics and the surgical specialities. 19 papers were identified that investigate the impact of the EWTD and New Deal on training. Of these 19 papers, 6 investigated the impact on anaesthetic trainees, 9 on the surgical specialities (including gynaecology), 2 on medical trainees and 2 did not discriminate for speciality. 15 of 19 papers were retrospective studies using questionnaire and survey design, or logbook analysis. 4 studies were prospective trials implementing new rota systems. 11 studies used objective measures to analyse the impact of training, using numbers of operating/anaesthetic lists; elective caseload; emergency caseload; numbers of supervised cases. 8 studies used subjective analysis, asking opinions and feelings regarding training. The majority of studies used subjects that were in training positions, with only one study solely canvassing consultant/trainer opinion.
2.4.2.1 Impact on anaesthetic training

The impact on anaesthetic training by the reduction in training hours that have occurred following the New Deal and the EWTD have been investigated by 6 studies, with only 1 being a prospective study. White et al retrospectively investigated the impact on training for paediatric anaesthetist trainees, by evaluating the theatre and departmental records for the 6 months immediately before and after the implementation of EWTD in 2004 (White et al., 2005). They discovered that although there was no reduction in the sub-speciality lists (neurosurgery, cardiac and cranio-facial), this was at the expense of the general anaesthetic list, demonstrating a 13% reduction in trainee anaesthetic lists (White et al., 2005).

Conflicting evidence of the impact on sub-speciality lists is provided by Melarkode et al, who in 2009 canvassed all paediatric anaesthetics trainees in the United Kingdom (Melarkode et al., 2009). Only 6.4% of all trainees managed to anaesthetise at least one child per week, and 53% of trainees did not have regular paediatric lists. This study received 552 responses, which appears comprehensive. The information that White et al supply regarding the reduction in general anaesthetic lists is supported by a number of other studies. Underwood et al undertook an extensive retrospective analysis of all cases performed in their hospital operating rooms between 1996 and 2004. During this time, the New Deal and the EWTD were implemented, and the group analysed caseloads for different grades pre New Deal, pre EWTD and post EWTD (Underwood and McIndoe, 2005). The group demonstrated annual caseload rose from 17,883 cases in 1996 to 22,866 cases in 2001. Despite this increase in hospital caseload, there was a significant impact on training for junior anaesthetic trainees with the annual caseload for SHOs reducing from 496 in 1996 to 449 in 2001 and to 400 in 2004. SPR caseload rose from 395 (1996) to 424 (2001), with a reduction to 316 in 2004. Interestingly, consultant caseload increased in this period from 313 (1996) to 328 (2001) and
400 in 2004. However, the apparent increase in consultant’s presence resulted in an increase in supervision rates from 32% to 47% of juniors lists (SHO and SPR) from 1996 to 2004.

This study highlights the criticism of current training, with a significant increase in consultant led procedures at the expense of the junior members of the team. However, this department has visibly attempted to improve training with an increase in supervised training lists to improve the efficiency of training. Sim et al provide evidence to support the decrease in training opportunities (Sim et al., 2004). They designed a prospective study to objectively and quantifiably assess the impact that a reduction in hours has on training. They designed an EWTD compliant full shift rota, changing from a traditional on call system. Information was gathered from logbooks and departmental records to assess the numbers of lists and weekly caseload of the trainees. There was a significant decrease in cases performed by the SPRs from 102 to 85, and from 119 to 96 for the SHOs. The weekly number of training lists reduced by 11% for SPRs and 14% for SHOs. This was reciprocated with a reduction in solo lists for both grades. However, it could be argued that reducing unsupervised lists, and increasing supervised lists could improve the quality of training. Departmental caseload remained similar between the two periods, implying that the reduction in caseload and training opportunities was a direct result in the change in working patterns. The work by Sim et al supports the majority of research into anaesthetic training that demonstrates a quantifiable drop in training opportunities for anaesthetic trainees due the EWTD (Underwood and McIndoe, 2005, White et al., 2005, Sim et al., 2004, Bowhay, 2008, Melarkode et al., 2009).

2.4.2.2 Impact on surgical training

The impact on surgical training can be quantified by assessing numbers of operations and operating lists that trainees can attend. Nine studies were selected for data extraction. There is
extensive evidence supporting the reduction in training opportunities by the implementation of EWTD. Hindmarsh et al in 2006 used open appendectomy as an outcome marker for junior surgical training (Hindmarsh, 2003). They demonstrated both a reduction in numbers of SHO led open appendectomies (162 cases pre-EWTD and 44 cases post-EWTD) and a reduction in the proportion of cases that were performed by SHO’s (33.5% of cases pre-EWTD and 21.3% of cases post-EWTD). This data have been assessed from 689 appendix operations. However, this could also be attributed to the advent of laparoscopic appendectomy, which is more likely to be performed by an experienced surgeon.

The reduction in training opportunities is supported by Garvin et al, who designed a prospective study that developed an EWTD compliant rota for a general surgery rotation, and assessed the impact on surgical training (Garvin et al., 2008). They demonstrated a reduction in training opportunities. All SHOs on the rota noted a reduction in time associated with their team and consultant, with the SHO only having 2.5 sessions a week with their consultant. All SHOs also reported at having to miss outpatient clinics and elective operating lists as a result of the EWTD complaint rota. Although this study lacks a pre-EWTD control, they demonstrated that post-EWTD all SHOs attended an average of 1.3 emergency cases a week and 5.5 elective cases per week.

The reduction in training opportunities can also been demonstrated in other subspecialties, such as Ears, Nose and Throat surgery (ENT), plastic surgery, neurosurgery and cardiothoracic surgery (Tait et al., 2008, West et al., 2007, Thorne et al., 2006). Wong et al demonstrated that EWTD had an adverse effect on training in plastic and reconstructive surgery by using the pinnaplasty as the training opportunity (Wong et al., 2006). The pinnaplasty is recognised in plastic surgery to be a SHO procedure, or a training procedure. Wong et al demonstrated that 55% of pinnaplasties were performed by SHOs in 1995 with
only 15% in 2004 (Wong et al., 2006). This is also the case in gynaecology, where Elbadrawy et al demonstrated that the proportion of cases performed by trainees reduced from 54.8% in 1995 to 34.2% in 2005 (Elbadrawy et al., 2008).

Opinion and morale within surgical trainees has also been affected. There has been a large amount of questionnaire based research that has canvassed the opinions of various surgical subspecialties. This is particularly apparent in cardiothoracic surgery, general surgery and neurosurgery (West et al., 2007, Tait et al., 2008, Morris-Stiff et al., 2005). Morris-Stiff et al designed a large questionnaire based study of general surgeons in Wales. 284 consultants, SPRs and SHOs were asked for their opinions on training post EWTD. The majority of questions were negative towards the EWTD, with 29% of consultants, 33% SPRs and 41% of SHOs all considering leaving the NHS once EWTD is fully implemented (Morris-Stiff et al., 2005).

However, there is also significant work that has demonstrated that EWTD can be implemented without detriment to speciality training. Lim et al gathered information into a surgical database over a period of time for one year prior to and one year following the implementation of the EWTD (Lim and Tsui, 2006). The data demonstrated that although there was a significant reduction in the number of days that an SHO was allocated to theatre from 16 to 11 per month, there was no difference in numbers of cases performed. This study highlights the impact that an institution may have if a structured training program is developed, and there is a commitment to training from both the trainee and the trainer. They have clearly demonstrated that an innovative approach can sustain exposure to surgery despite a reduction in hours.
2.4.2.3 Impact on medical training

There are only 2 papers specifically investigating the impact of the EWTD on medical training. As previously described, the work by Cappuccio et al, was a detailed prospective controlled trial, investigating the impact of a EWTD compliant rota on an acute medical ward (Cappuccio et al., 2009). The interviews with the intervention group of doctors working on the EWTD compliant rota highlighted a number of issues with medical training. The majority of doctors in the intervention group felt that their educational opportunities were limited by the EWTD rota, and also noted a lack of time to interact with their team, resulting in a lack of feedback on their performance. This was in contrast with the control group who generally made positive comments about learning opportunities on the traditional rota. These data support the previous work in the surgical and anaesthetic specialities. A criticism of this paper is that it relies on subjective opinions of junior doctors. However, unlike the practical specialities that can judge training quantifiably with numbers of training lists and operative caseload, the medical speciality is more difficult to assess in terms of quality of training. As a result, the opinions documented by the medical trainees in this study give qualitative data on the quality of medical training following the implementation of the EWTD (Cappuccio et al., 2009).

2.4.2.4 Impact on other specialities training

Two studies were identified that investigated the impact of the EWTD on training, but did not look at specific specialities, rather evaluating the opinions of doctors from all specialities (Bamford and Bamford, 2008, Tsouroufli and Payne, 2008). Both these studies were questionnaire based investigations evaluating opinions of the impact of EWTD. They provide weak evidence to support that EWTD has had a negative impact on doctors training.
2.4.3 Impact on quality of care and medical errors

2.4.3.1 Medical error

Five articles were selected for data extraction that examined the role of EWTD on patient care. The primary aim of the EWTD was to protect the health and safety of its workers (Department of Health, 2008). In the medical profession, it has been promoted to improve patient safety by ensuring the doctors are well rested, and limit the amount of decision making when exhausted. There has been extensive research into the reasons why medical errors are made, and it has been demonstrated that medical errors are more likely to be made if doctors work longer hours (Landrigan et al., 2004). However, there has not been conclusive evidence to demonstrate that the EWTD will improve patient safety. The majority of evidence in the literature that investigates the impact that the EWTD has had on patient safety has focused on retrospective questionnaire based research. There have been a number of papers that suggest that the EWTD has actually had an adverse effect on patient care (Tait et al., 2008, Morris-Stiff et al., 2005, Tsouroufl and Payne, 2008, Bowhay, 2008). Evidence supporting this is supplied by Bowhay et al, demonstrating that 38.6% of anaesthetic trainees felt that they were not functioning as well as doctors since the implementation of the EWTD (Bowhay, 2008). This is supported by Tsouroufl et al who demonstrated that medical trainers felt that the change in working patterns due to the EWTD have resulted in a loss in continuity of care which could result in being detrimental to the quality of patient care (Tsouroufl and Payne, 2008). However, the criticism of this evidence is that the studies are the result of questionnaires that supply subjective opinions of medical care. They do not provide validated and objective measurement of the impact on patient care.

There is strong evidence supporting the position that the EWTD has had a positive effect on patient care. The only study that provides objective measurement of the impact on
patient care and medical error can be supplied by Cappuccio et al. As previously discussed, this study designed a prospective, single blinded, non-randomised controlled trial by developing an intervention rota that was EWTD compliant. Doctors worked on the intervention rota concurrently with a control group working on a traditional rota. Medical errors that resulted from the two rotas were assessed retrospectively by assessing patient records for adverse events and potential adverse events (PAE) using a validated method. The assessment was completed by two experienced nurses using established adverse event assessment methodology (Fahrenkopf et al., 2008). The nurse assessors had an inter-rater reliability of 0.85, which is considered very good. The results of the analysis demonstrate 32.7% fewer medical errors on the intervention rota, with 82.6% fewer intercepted PAE and 31.4% fewer un-intercepted PAE (Cappuccio et al., 2009). There are some flaws in the design of this study, the most important of which is the non-randomised selection of doctors, and the different medical specialities of the intervention and control group. The reduction in medical errors could be explained by having more competent doctors on the intervention rota. The different specialities could also account for the discrepancy in medical errors. Despite these criticisms, the Cappuccio study provides the only quantifiable, objective evidence that supports that EWTD has had a positive impact on patient care with a reduction in medical error (Cappuccio et al., 2009).

2.4.3.2 The doctor/patient relationship

The establishment of the doctor patient relationship is one of the most valued characteristics of a good healthcare system (Stewart et al, 1979). For a patient to be satisfied with their care, they must initially have a good rapport with their clinicians which allows them to gain trust. This has traditionally developed through doctor patient interactions that occur in out-patient clinic, the emergency department, ward rounds and the operating consent
room (Simpson et al., 1991). Ideally, a patient will develop the professional relationship with doctors, as they continue to see the same doctor or group of doctors throughout their patient journey (Saultz and Albedaiwi, 2004). There is evidence to suggest that EWTD has had a detrimental effect on the doctor/patient relationship. Ramsey et al analysed the number of doctor patient interactions that occurred during 72 patients’ hospital stays during a post EWTD rota (Ramsey et al., 2007). The results demonstrated that the consultant was present at 82% of points of clinical contact (PCC) with the SPR present at 62% of PCC and the SHO present at 77% of all PCC. However, the continuity of care was impaired with the SPRs present for all of a patient’s PCC on only 42% of the time. This was even more apparent for the SHOs, as they were only present for all of a patients’ PCC for 33% of the time. Although this study only gives us a snapshot of single a department’s clinical contact on a post EWTD rota, it gives an insight into further issues surrounding junior doctors training. A reduction in the amount of clinical contact that junior doctors experience will not only impact on knowledge and skills, but could prevent them from developing relationships with patients that provide the cornerstone for good clinical care.

2.5 Discussion

“Meeting the requirements of the European Working Time Directive (EWTD) is a great opportunity to modernise the Service and provide improved treatment for patients, a better patient experience and a better working environment for staff.”

(Department of Health 2008)

The EWTD has been implemented in the United Kingdom with the aim to improve the working hours of junior doctors. It is suggested that the reduction in hours will improve the sleep patterns of doctors and prevent them from working whilst exhausted. This in turn would
lead to a decrease in medical errors and improve patient care. The impact of the EWTD on these factors is of considerable interest.

Primarily, any change in policy regarding working hours must be for the benefit of the patient. The research into the impact of the EWTD on patient outcome and medical errors is limited. The results of these studies demonstrated conflicting conclusions. The majority of opinion based research concludes that the EWTD will have a negative impact on medical care, and increase the risk of medical error. However, the only quantitative trial assessing the impact of EWTD on medical errors, demonstrated that there was a significant reduction in medical errors by doctors on a EWTD compliant rota. To accurately conclude that EWTD will improve patient care there needs to be further research using randomised controlled trials with consistent, standardised subjects using validated outcome measures.

The EWTD is a European law that seeks to protect the health and safety of workers, by limiting the number of hours that doctors are allowed to work over an average week. It was expected to improve the workforce environment and improve the quality of life of junior doctors. There is conflicting evidence to support an improvement in the quality of life of junior doctors in the current literature. To effectively assess the impact that the EWTD has had on the quality of life of junior doctors away from hospital, future research must focus on performing a workforce wide well-being assessment.

One of the major concerns regarding the EWTD is the impact it is likely to have on the training of junior doctors. A decrease in the quality of training may result in a generation of consultants that do not have sufficient experience to practice medicine safely. This is of significant interest to junior doctors, which can be demonstrated by the increased numbers of studies assessing the impact of EWTD on medical training. By analysing these studies it is clear that there is a quantifiable decrease in operating lists and caseload for trainee
anaesthetists and surgeons. There is a particularly apparent in sub speciality training caseload. However, there is some evidence to suggest that although working hours and operating list are reducing, if there is considerable commitment and innovative thinking in the way that junior doctors are trained, it may be possible to prevent a deterioration in the quality of training. Lim et al demonstrate that although training lists per month may reduce, actual monthly caseload can stay the same (Lim and Tsui, 2006). Future work should be aimed at testing new training models, and the impact that they have on training within a reduced working week.

There are also arguments regarding how we measure the quality of training. Training is changing from an experience based model to a proficiency based model. However, the way in which we are investigating the reduction in training opportunities for anaesthetists and surgeons is by identifying a reduction in caseload. If caseload should not be used to assess the competence of an individual doctor, then it should not be used as an outcome measure for quantifying training opportunities in a hospital. The quality of a training program can only be quantified in terms of its ability to produce competent doctors. This can only be measured using standardised, proficiency based assessment tools that assess both technical and non-technical skills. Future work should continue to develop proficiency based models and investigate the use of full simulation procedure suites that can quantifiably train and assess doctors’ performance. Only then can any change in training opportunities be accurately assessed.

It is vital to try and improve the efficiency of training, so that trainees can get more out of the finite time that they have. The practical specialities face a challenge to ensure that their trainees’ have the appropriate competencies by the end of their training to allow independent practice. Simulation, structured skills training curricula, simulated procedure suites and
Innovation in surgical training and its impact on healthcare
PhD thesis

dedicated training lists are some of these options. There also needs to be change in the way that medical teams and training programs are organised to optimise the training opportunities when they occur. Therefore, any changes in the structure of medical training must not come at the expense of patient care. We must ensure that training is integrated with sufficient service provision to ensure patient care is not affected. This requires a considerable commitment of time and effort by doctors of all levels.

The EWTD is now European Law, therefore trainers and trainees alike commit to improving postgraduate training. New approaches and innovation are required in the way in which we train junior doctors if we want to improve the efficiency of training on the job and maintain high standards of patient care.
3. **Advances in Surgical training**

3.1 Virtual Reality Simulation

It is no longer appropriate or acceptable to practice surgical procedures on patients (Aggarwal and Darzi, 2006). Therefore, it has been suggested that surgical training should start using simulation in the skills laboratory (Reznick and MacRae, 2006). Simulation can be defined as:

“the act of mimicking a real object, event or process by assuming its appearance or outward qualities” (Kneebone, 2003).

This allows a trainee to learn, practise and perfect the technical skills and clinical judgements required to be a surgeon. Simulation allows mistakes, which can be used as useful learning points. This can be done in a safe and controlled environment, in the skills laboratory, without detriment to the patient.

Simulation plays an important role in all specialities of surgery, but is increasingly important for general surgery, where the laparoscopic approach is becoming the gold standard for most traditional operations (Monson, 1993). There are considerable challenges for training in laparoscopic surgery, as the technical skills required are different to open surgery (Grantcharov et al., 2004). Many laparoscopic operations are technically difficult and have a long learning curve, with errors and complications more likely to occur with inexperienced surgeons operating at the start of the learning curve (Reissman et al., 1996).

Simulation for laparoscopic surgery can be broadly divided into mechanical simulation or box-training and virtual reality (VR) simulation.

Mechanical simulation requires the use of a laparoscopic box-trainer with a fixed camera that videos the movements of an individual’s laparoscopic instruments and replays them on a
computer screen. Box-trainers provide a useful method of practicing laparoscopic skills, and there is strong evidence demonstrating the acquisition of technical skills following use of a box trainer (Fried et al., 2004, Dauster et al., 2005, Korndorffer et al., 2006).

The term virtual reality can be defined as “a computer-generated representation of an environment that allows sensory interaction, thus giving the impression of actually being present” (Coleman et al., 1994). In 1994, Satava et al first advocated the use of VR simulation for teaching surgeons’ anatomy and technical skills (Satava, 1994). Since then VR simulation has been slowly adopted by the surgical community, despite the increase in use of simulation and attendance of skills laboratories (Figert et al., 2001). In recent years, there has also been significant improvement in the fidelity of VR simulators, as computer processing and graphical design have improved in the last 20 years. It is now possible to perform full length basic and advanced procedures in VR (Gallagher and Cates, 2004).

### 3.1.1 Types of VR-simulator

#### 3.1.1.1 MIST-VR

The first laparoscopic VR simulator developed for teaching technical skills was the Minimally Invasive Surgery Trainer-Virtual Reality (MIST-VR) (Mentice, Gothenburg, Sweden) in 1997 (Wilson et al., 1997). The MIST-VR is comprised of a laparoscopic interface with motion-tracking devices attached to mock laparoscopic instruments. This is attached to a computer that displays the movements of the instruments in real time on a computer monitor (Aggarwal et al., 2004). The simulator provides twelve psychomotor tasks that mimic important skills required for laparoscopic surgery in the operating room ranging from the basic “acquire place” to the more complex “stretch diathermy” (figure 6). The tasks can be performed on easy, intermediate and difficult settings. The computer can measure various parameters such as error scores, hand movements and path length (distance moved).
of each hand. This provides the user with immediate feedback of performance on each of the tasks. The MIST-VR was initially developed with assessment and examination of operative skill, not training (Wilson et al., 1997). However, it soon became evident that it would have a role in training as well. The MIST-VR only consists of abstract psychomotor tasks, which allows it to be used for training a wide range of surgical specialties in basic endoscopic techniques, including cardiothoracic, general and orthopaedic surgery. However, it does not allow training in specialist techniques that are provided by procedural and full length tasks on other simulators.
**Figure 6 – An example of the abstract tasks available on the MIST-VR simulator**

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acquire place</strong></td>
<td>The user is required to grasp a coloured ball and place it in a coloured box. Exercise alternates hands</td>
<td><img src="#" alt="Screenshot" /></td>
</tr>
<tr>
<td><strong>Transfer place</strong></td>
<td>The user is required to grasp a ball, transfer it from one hand to the next and drop it in a box. Exercise alternates hands</td>
<td><img src="#" alt="Screenshot" /></td>
</tr>
<tr>
<td><strong>Traversal</strong></td>
<td>The user is required to grasp a cylinder and pass it from one hand to the next moving down the cylinders length</td>
<td><img src="#" alt="Screenshot" /></td>
</tr>
<tr>
<td><strong>Withdraw insert</strong></td>
<td>The user is required to grasp a ball in one hand, touch the grasped ball with the other hand, then is required to withdraw the instrument fully and reinsert to touch the ball again</td>
<td><img src="#" alt="Screenshot" /></td>
</tr>
</tbody>
</table>
3.1.1.2 ProMIS

The ProMIS VR simulator (Haptica, Dublin, Ireland) was developed in 2002 and combined VR technology with traditional box trainer simulation. The laparoscopic interface is contained within a traditional torso shaped box trainer covered in neoprene (Figure 7).

The box trainer contains three separate cameras that track the motion of the laparoscopic instruments from three different angles (Van Sickle et al., 2005a). The ProMIS VR simulator has six modules designed to train laparoscopic skills such as: orientation, instrument handling, dissection, suturing, intracorporeal knot tying and diathermy (Figure 9)(Carter et al., 2005).
Figure 7 - The ProMIS VR simulator (Van Sickle et al., 2005b)
Figure 8 - Screenshot of ProMIS feedback (Haptica)

<table>
<thead>
<tr>
<th>Details</th>
<th>Your Score</th>
<th>Max Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of steps in which you avoided colliding with tissue</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Fixed targets achieved</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Moving targets hit</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Moving targets successfully held</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Bleeding targets hit</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Bleeding targets successfully stopped</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Your score</td>
<td>10</td>
<td>35</td>
</tr>
<tr>
<td>% score achieved</td>
<td>28</td>
<td></td>
</tr>
</tbody>
</table>
### Figure 9- An example of the tasks available on the ProMIS simulator (Haptica)

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laparoscope Orientation</strong></td>
<td>The user explores a virtual environment with a simulated Laparoscope. The aim is to follow the audio cues to find and hold steady on specified targets. The user has to deal with events such as fogging.</td>
<td><img src="image1" alt="Laparoscope Orientation" /></td>
</tr>
<tr>
<td><strong>Instrument Handling 1</strong></td>
<td>In a virtual environment, the user must touch and/or track a series of fixed and dynamic objects - while trying to avoid colliding with tissue. Audio cues and on-screen directions provide guidance.</td>
<td><img src="image2" alt="Instrument Handling 1" /></td>
</tr>
<tr>
<td><strong>Locating and Coordinating</strong></td>
<td></td>
<td><img src="image3" alt="Locating and Coordinating" /></td>
</tr>
<tr>
<td><strong>Instrument Handling 2 Object Positioning</strong></td>
<td>In a physical exercise, the user is asked to pick up a number of objects, transfer them from one hand to another and place them in a specified target area.</td>
<td><img src="image4" alt="Instrument Handling 2 Object Positioning" /></td>
</tr>
</tbody>
</table>
The ProMIS has both abstract and procedural tasks and analyses performance by tracking instruments in 3-dimensional space. This enables real-time measurement of instruments in use. All Tasks use validated metrics, including time taken, path length, economy of movement, hand dominance and task specific errors. On completion of each task, the user is given immediate feedback with summary of their metrics. (Haptica) (Figure 8) The trainee may also view a graphical replay or video of their performance, depending on the task selected (Van Sickle et al., 2005a).

### 3.1.1.3 LapSim

The LapSim (Surgical Science, Gothenburg, Sweden) laparoscopic simulator was developed in 2000. It was developed with more realistic tasks using tissue that could bleed and be manipulated. Tasks such as “clip and cut” and “suture” introduced tasks that are more relevant to a surgeon (Figure 10).

The Lapsim was one of the first VR simulators that allowed students to practice parts of operations such as laparoscopic cholecystectomy and gynaecological procedures (Table 11 and table 12). The Lapsim is used for training and assessment of both surgery and gynaecology trainees (Aggarwal et al., 2006b, Hart and Karthigasu, 2007).
Figure 10 – An example of basic tasks available on the Lapsim VR simulator (Science)

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Camera navigation</strong></td>
<td>This module introduces the trainee to camera navigation. The camera must be manipulated to visualize various objects.</td>
<td></td>
</tr>
<tr>
<td><strong>Instrument navigation</strong></td>
<td>The user must manipulate their instruments to touch various objects that appear in different positions. Allows the development of basic laparoscopic movements</td>
<td></td>
</tr>
<tr>
<td><strong>Coordination</strong></td>
<td>Using both hands in a coordinated manner, this task requires the trainee to control the camera in one hand and the laparoscopic instrument in the other, and must touch a number of objects in different positions.</td>
<td></td>
</tr>
<tr>
<td><strong>Suturing</strong></td>
<td>This exercise offers a choice between a synthetic and a realistic, video-based graphic environment, where a trainee must learn the basics of laparoscopic suturing.</td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Precision and speed</strong></td>
<td>This requires swift thinking, and dextrous movements. The trainee must touch various objects that appear at random, and move. Each object must be touched with the correct instrument to avoid error.</td>
<td></td>
</tr>
<tr>
<td><strong>Handling Intestines</strong></td>
<td>This module requires the measurement of a pre-defined length of small bowel.</td>
<td></td>
</tr>
</tbody>
</table>
### Figure 11 - Procedural tasks for general surgery on the Lapsim VR simulator

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
<th>Screenshot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cholecystectomy part 1</strong></td>
<td>This module provides the chance to perform the first section of a laparoscopic cholecystectomy, the dissection of Calot’s Triangle. The trainee must use graspers, scissors and diathermy to expose the cystic duct and artery before clipping and cutting the vessels.</td>
<td><img src="image1.png" alt="Screenshot" /></td>
</tr>
<tr>
<td><strong>Appendectomy</strong></td>
<td>This module provides the chance to perform a laparoscopic appendectomy using the loop technique. Different presentations of appendicitis may be explored.</td>
<td><img src="image2.png" alt="Screenshot" /></td>
</tr>
</tbody>
</table>

**GENERAL SURGERY**
Figure 12 - Procedural tasks for gynaecology on the Lapsim VR simulator

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tubal occlusion</strong></td>
<td>This module requires the trainee to use the camera in one hand and navigate toward the Fallopian tube. The other hand is used to cauterise and cut, to resect the Fallopian tube.</td>
</tr>
<tr>
<td><strong>Salpingectomy</strong></td>
<td>This module requires the use of both hands. The trainee must use suction and irrigation to expose the ectopic pregnancy before using graspers, bipolar and scissors to dissect and retrieve the foetus in an endoscopic basket</td>
</tr>
</tbody>
</table>


3.1.1.4 Lapmentor

The LAP Mentor surgery simulator (Simbionix, Chicago, USA) was developed in 2002. It divides modules into abstract tasks, procedural tasks and full length operations. (Figure 13). The full length operations range from intermediate to advanced procedures containing modules for laparoscopic cholecystectomy, laparoscopic colectomy and laparoscopic gastric bypass (Figure 14). The Lapmentor also combines the extensive range of procedures with advanced haptic feedback hardware that allows the simulator to transmit resistance when tissues or objects are encountered during a simulated task. Haptic feedback is an important part of simulation training as it is obviously present in the operating room. However, it is a feature that is lacking in many other computer-aided simulators (Andreatta et al., 2006). This enhances the realism of the simulator, and as such is used widely for training of surgical trainees (Aggarwal, 2009). The Lapmentor consists of abstract tasks, procedural tasks and full length procedures. The abstract tasks are measured by time, accuracy, number of camera movements, average camera speed, efficiency of instrument movement, path length of instruments, safe clipping and lost clips. The procedural and full length modules are assessed by time; safe clipping and cutting within defined distances; safe use and efficiency of cautery; accuracy; and safe dissection.
## Module Description

<table>
<thead>
<tr>
<th>Camera Manipulation</th>
<th>This module requires the trainee to manoeuvre a laparoscopic camera around a simulated environment to take “snapshots” of various objects.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clip applying</td>
<td>This module develops a trainee’s clip application skills. The subject must clip a number of “bleeding vessels” before they fill a pool full.</td>
</tr>
<tr>
<td>Two-handed manoeuvres</td>
<td>This module develops a surgeon’s bi-manual dexterity. The subject must move a deformable object with one hand before picking an object up and dropping it in a basket.</td>
</tr>
<tr>
<td>Hand Eye coordination</td>
<td>This module develops hand eye coordination with the trainee having to use precision movements to touch various objects with laparoscopic instruments.</td>
</tr>
<tr>
<td>Cutting</td>
<td>This requires bi-manual dexterity using a grasper and scissors to cut an object.</td>
</tr>
</tbody>
</table>

**Figure 13 - Range of basic tasks provided by the Lapmentor VR**
Figure 14 - Range of procedural tasks provided by the Lapmentor VR simulator

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laparoscopic cholecystectomy</strong></td>
<td>This module allows a surgeon to select from a patient library of different cases, each providing separate challenges, with different pathologies and anatomy. The user is required to perform a full length laparoscopic cholecystectomy.</td>
</tr>
<tr>
<td><strong>Laparoscopic ventral hernia repair</strong></td>
<td>This module allows a surgeon to develop the necessary skills required to perform a laparoscopic ventral hernia repair. The module is divided into learning adhesiolysis and handling and fixating intraperitoneal prosthetic mesh.</td>
</tr>
<tr>
<td><strong>Laparoscopic Roux-en-Y gastric bypass</strong></td>
<td>This module provides real-life visual and tactile simulation of the key stages of the Gastric Bypass procedure: simulations of internal organs and bodily fluids, manipulation of tools and tool-organ interaction and deformation, including tissue cutting and anastomosis using a linear cutter.</td>
</tr>
</tbody>
</table>
3.1.1.5 Other VR simulators

Other VR simulators are currently available that provide a platform for learning and practicing laparoscopic skills, but are not considered in further detail. (Schijven and Jakimowicz, 2003) Simsurgery (Norway) have developed a range of computer assisted simulators that are based on the Simsurgery Educational Platform (SEP) for teaching and training laparoscopic skills. They have four simulators

a) SEP Basic – for developing an practising basic laparoscopic skills

b) SEP Cholecystectomy – a learning module for removal of the gallbladder

c) SEP Ectopic Pregnancy – learning module for the removal of an ectopic pregnancy.

d) SEP Robot - for training robotic surgery.

Select-IT VEST Systems AG (Karlsruhe, Germany) produce the Virtual Endoscopic Surgery Training system (VEST). This provides two VR training platforms:

a) VSOOne Cho – for teaching and training laparoscopic cholecystectomy

b) VSOOne Gyn – for laparoscopic gynaecology training

The Xitact LS500 (Xitact SA, Morges, Switzerland) was a laparoscopic simulator that provided a modular training environment for basic laparoscopic skills and laparoscopic procedural skills. (Schijven and Jakimowicz, 2003)

3.2 Evidence for VR simulators

VR simulators measure and store various parameters and metrics of a subject’s performance which form the basis of an assessment. Before these can be used for surgical training or assessment, they must be objectively and vigorously tested to evaluate whether the
simulator is both scientifically reliable and valid (McDougall et al., 2006). Reliability can be defined as the reproducibility and precision of the test or testing device (Gallagher and Satava, 2002). Virtual reality simulation provides a good platform for simulation training and assessment as it combines a range of tasks that can be standardised for all subjects and are fully reproducible, providing an accurate way of assessing a surgeon’s dexterity (Gallagher et al., 2005). There are 5 levels of scientific validity that relate to the use of simulation for surgical training: Content, face, construct, concurrent and predictive validities ((McDougall, 2007) (Figure 15).
### Figure 15 - Qualities of the ideal surgical assessment tool (Aggarwal et al., 2007b)

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feasibility</td>
<td>Measure of whether something is capable of being done or carried out</td>
</tr>
<tr>
<td>Face Validity</td>
<td>Extent to which the examination resembles real life situations</td>
</tr>
<tr>
<td>Content validity</td>
<td>Extent to which the domain that is being measured is measured by the assessment tool – for example, while trying to assess technical skills we may actually be testing knowledge</td>
</tr>
<tr>
<td>Construct validity</td>
<td>Extent to which a test measures the trait it purports to measure; one inference of construct validity is the extent to which a test discriminates between various levels of expertise</td>
</tr>
<tr>
<td>Concurrent validity</td>
<td>Extent to which the results of the assessment tool correlate with the gold standard for that domain</td>
</tr>
<tr>
<td>Predictive validity</td>
<td>Ability of examination to predict future performance</td>
</tr>
<tr>
<td>Test-retest reliability</td>
<td>Measure of a test to generate similar results when applied at two different points</td>
</tr>
<tr>
<td>Inter-rater reliability</td>
<td>Measure of the extent of agreement between two or more observers when rating the performance of an individual</td>
</tr>
</tbody>
</table>
3.2.1 The MIST-VR

The MIST-VR was the first VR simulator to demonstrate reliability and validity for surgical skills training (Taffinder et al., 1998). The simulator evaluates technical skill through abstract tasks, therefore is not appropriate for face and content validation. Construct validity has been demonstrated in a number of studies that have confirmed significant differences in error scores, path length and hand movements between novice and experienced surgeons (Taffinder et al., 1998, Aggarwal et al., 2006b, Gallagher and Satava, 2002, McNatt and Smith, 2001). Concurrent validity has also been demonstrated for all of the abstract tasks implying that it is effective for both training and assessment of technical skills (Figure 16) (Grantcharov et al., 2001, Gallagher et al., 2001, Gallagher and Satava, 2002, Taffinder et al., 1998).

3.2.2 The ProMIS

The ProMIS VR simulator has been validated for construct validity with evidence demonstrating significant differences in performance between novice and expert surgeons (Broe et al., 2006, Van Sickle et al., 2005a, Ritter et al., 2007, Botden et al., 2007). There is also evidence supporting its concurrent validity (Figure 16) (Ritter et al., 2007).

3.2.3 The Lapsim

The Lapsim VR simulator has additional challenge to demonstrate its use as an effective training and assessment tool. The simulator combines both abstract tasks and procedural tasks and as such both need to demonstrate validity to be used for training and assessment. The abstract tasks have widely demonstrated construct and concurrent validity (Duffy et al., 2005, Woodrum et al., 2006, Carter et al., 2005). The procedural tasks for both laparoscopic cholecystectomy and laparoscopic gynaecology have been validated for face, construct and
concurrent validity (Figure 16) (van Dongen et al., 2007, Aggarwal et al., 2006a, Aggarwal et al., 2006b, Bajka et al.).

3.2.4 The Lapmentor

The Lapmentor is an advanced laparoscopic simulator that combines abstract and procedural tasks with full length procedures. There is extensive evidence to support its face validity and realism for procedural tasks (Hyltander et al., 2002, Aggarwal, 2009, McDougall et al., 2006). Construct, concurrent and face validity have all been demonstrated for the Lapmentor in a number of studies indicating its usefulness as a technical skills training and assessment platform (Figure 16) (McDougall et al., 2006, Aggarwal, 2009, Andreatta et al., 2006).
### Figure 16 - Summary of the validation of VR simulators

<table>
<thead>
<tr>
<th>VR simulator</th>
<th>Face validity</th>
<th>Content validity</th>
<th>Construct validity</th>
<th>Concurrent validity</th>
<th>Predictive validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIST-VR</td>
<td>-</td>
<td>-</td>
<td>Yes(^{(24)})</td>
<td>Yes(^{(30, 34, 36, 37)})</td>
<td>-</td>
</tr>
<tr>
<td>ProMIS</td>
<td>Yes(^{(46)})</td>
<td>-</td>
<td>Yes(^{(Broe et al., 2006, Van Sickle et al., 2005a, Ritter et al., 2007, Botden et al., 2007)})</td>
<td>Yes(^{(39)})</td>
<td>-</td>
</tr>
<tr>
<td>Lapsim</td>
<td>Yes(^{(van Dongen et al., 2007, Aggarwal et al., 2006a, Aggarwal et al., 2006b, Bajka et al., al.)})</td>
<td>Yes(^{(van Dongen et al., 2007, Aggarwal et al., 2006a, Aggarwal et al., 2006b, Bajka et al., al.)})</td>
<td>Yes(^{(van Dongen et al., 2007, Aggarwal et al., 2006a, Aggarwal et al., 2006b, Bajka et al., al.)})</td>
<td>Yes(^{(van Dongen et al., 2007, Aggarwal et al., 2006a, Aggarwal et al., 2006b, Bajka et al., al.)})</td>
<td>-</td>
</tr>
<tr>
<td>Lapment or</td>
<td>Yes(^{(Hyltander et al., 2002, Aggarwal et al., 2009, McDougall et al., et al., 2006)})</td>
<td>Yes(^{(Hyltander et al., 2002, Aggarwal et al., 2009, McDougall et al., et al., 2006)})</td>
<td>Yes(^{(McDougall et al., 2006)})</td>
<td>Yes(^{(McDougall et al., 2006)})</td>
<td>-</td>
</tr>
</tbody>
</table>
3.2.5 Predictive validity

There have been a large number of studies that have demonstrated the validation of VR simulators. This is very important when considering the use of a VR simulator for training technical skills. There is considerable evidence supporting the face and construct validity of VR simulation, with slightly less, but still sufficient evidence demonstrating the concurrent validity of VR simulation. On inspection of table 8, it is clear that there is a lack of evidence demonstrating the predictive validity of VR simulators. This is due to predictive validity being very difficult to demonstrate. Unlike concurrent validity, which shows a correlation between the simulator and the gold standard for assessment, predictive validity requires a long period of time between baseline testing and future testing. Concurrent validity can be measured on the same day, whereas predictive validity requires a longitudinal study with a gap of at least a year to demonstrate that a VR simulator can accurately predict the future performance in the operating room. It can be argued that predictive validity is not a very important validation type, but as surgical training changes towards improved efficiency, predictive validity would provide important information about the differing needs of individual surgeons. This would allow us to develop personalised training programs which are unique to the needs of the individual surgeon that would enhance the acquisition of technical proficiency.

3.3 Learning curves and skill acquisition

One aim for a laparoscopic VR simulator is that it can improve technical skills of surgeons. A learning curve can be defined as the rate of improvement of performing a task as a function of time. This means that learning curves can be used to demonstrate the acquisition of technical skills by a surgeon as they repeat a task. It is therefore important to analyse the learning curves of surgeons using various VR simulators to demonstrate that there is an
improvement in both the time taken and other dexterity parameters as a task is repeated. A learning curve is not a straight line with continued improvement on every repetition. For technical skills training, eventually the curve will reach a plateau of performance where there is a reduction in the rate of improvement. It is useful to know at what point the performance plateau occurs as it will provide useful information for planning training programs. Gallagher and Satava first reported data on skills acquisition and learning curve analysis for the MIST-VR in 2002 (Gallagher and Satava, 2002). They reported data on experienced, inexperienced and novice laparoscopic surgeons performing all tasks on the MIST-VR. There was a significant difference in performances between the groups on the first attempt. All groups improved performance with repeated attempts, with a plateau of skills acquisition at the fifth attempt, with most improvement by the novice and intermediate group. Further repeated practice improved the groups to the level of the experienced surgeons. This study demonstrates the effectiveness of the MIST-VR simulator for the acquisition of technical skills in surgeons. Further evidence of the learning effects of VR simulators has been demonstrated with learning curve analysis of novice and experienced surgeons on the Lapsim and Lapmentor VR simulators (Andreatta et al., 2006, Sherman et al., 2005).

3.4 Transfer to the operating room (OR)

Although there is considerable evidence presented on the validity of VR simulation for the acquisition of technical skills, the most important aspect of training should be the ability of a simulator to improve a subject’s performance in the operating room. If a simulator has concurrent validity, it informs us that the performance in the skills lab on VR may correlate with their current performance in the OR. Predictive validity can provide further information regarding how well a surgeon may perform in the future in the operating room. It can be argued that this is the most important form of validity, as it is an assessment of a surgeons
potential and predicts how well a surgeon will perform in the OR in the future. Compared to this face validity, the realism of a simulator, and construct validity, a difference between novice and experienced surgeons, seems less important. Currently there is no evidence supporting the predictive validity of VR simulation, as this can only be demonstrated by large scale, longitudinal “VR to OR” studies that assess surgeons in VR before analysing their performance in the operating room at a later date.

There have been a number of studies that have investigated the transfer of skills from “VR to OR”, but have not analysed the predictive validity of the simulators. There is evidence supporting an improvement in surgical performance following training on VR simulation. Seymour et al demonstrated that VR training on the MIST-VR improved OR performance with a decrease in errors and time taken when compared with a non-VR trained group (Seymour et al., 2002). Grantcharov et al confirm this finding with MIST-VR training, in addition demonstrating an improvement in economy of movement of the surgeons’ instruments (Grantcharov et al., 2004). In 2009, Larsen et al performed a randomised controlled study investigating the impact on OR performance after training on the Lapsim VR simulator. They demonstrated that the VR trained group had a significant improvement in OR performance with reduced operating time and better performance scores using two blinded assessors with validated scoring systems (Larsen et al., 2009). Further evidence can be found supporting an improvement in OR performance after training on the Lapsim VR simulator (Aggarwal et al., 2007d, Hyltander et al., 2002).

A number of studies report predictive validity, but in fact demonstrate concurrent validity. Ahlberg et al demonstrated a weak correlation between performance in the OR and VR for MIST-VR trained surgeons, although the assessment tools that were used were not validated (Ahlberg et al., 2002). This finding is supported by further studies that have shown
correlation between performance on the MIST-VR with the performance in the OR, for VR trained subjects (Ahlberg et al., 2007, Hart and Karthigasu, 2007, Grantcharov et al., 2004). However, these studies do not assess predictive validity. If a correlation is found between VR performance and OR performance, then the simulator has concurrent validity, not predictive validity. For a simulator to show predictive validity, a longitudinal study must take place that assesses a surgeon in VR, and after a considerable period of time, assesses their OR performance. These studies also have limitations which weakens the evidence. The studies use methods of assessment that are non-validated, which decreases the reliability of the findings. Two of the studies also assess the OR performance using a porcine model, which is not validated, and does not give an exact replication of OR performance. These studies also do not train the VR groups in a structured manner, they could be improved using validated training programs for the VR simulators (Aggarwal et al., 2006b, Aggarwal et al., 2006a).

Further work is required to demonstrate predictive validity of VR simulation, with large scale randomised controlled trials over a long period of time assessing surgeons from “VR to OR”.

3.5 Cost of VR simulation

One of the frequent criticisms of VR simulation is that the simulators are expensive, and not all hospitals can afford them. The MIST-VR and LapSim VR simulators are estimated at US$24,000 and US$40,000 respectively, and cost of the Lapmentor is in excess of US$100,000. The more expensive VR simulators also require an annual subscription for technical support and upgrades. Therefore, as VR simulation has demonstrated that it can decrease operating time, it can also reduce the costs of training in the operating room by improving efficiency (Ahlberg et al., 2007, Grantcharov et al., 2004). However, this economic evaluation does not take into account the cost of potential litigation that would
occur from trainees operating. This cost would also be decreased due to the reduction in medical error that can be demonstrated from prior VR training (Ahlberg et al., 2007).

### 3.6 Effectiveness of VR simulation

Surgeons in training have a finite amount of time in which they can train. It is therefore vital that they use the time they have as efficiently as possible. VR simulation provides a platform in which surgeons can learn and practice technical skills, and there is a great deal of published research demonstrating the realism and the validity of simulators in terms of skills acquisition compared to a control group. However, there are limited data that documents how effective each VR simulator is compared to other VR simulators. In the aviation industry, the transfer effectiveness ratio (TER) is used to measure how effective a simulator is (Rantanen EM, 2005). It is calculated as follows:

$$\text{TER} = \frac{Y_0 - Y_x}{X}$$

$Y_0$ is the median time required by the control group to reach performance criterion and $Y_x$ is the corresponding measure for the intervention group after having received a median of $X$ amount of training time on the simulator, which is also the denominator (Aggarwal et al., 2007d, Rantanen EM, 2005). When this is considered for VR simulation, $Y_0$ remains the time for a control group to reach proficiency in the operating room and $Y_x$ is the time for a VR trained group to reach proficiency in the operating room. Studies in the aviation industry report a TER of 0.5, which implies every hour spent training in a flight simulator is equivalent to 0.5 hours flying in a real plane (Rantanen EM, 2005). The only study investigating the TER of VR simulation was performed by Aggarwal et al (Aggarwal et al., 2007d). They randomised 20 novice laparoscopic surgeons to a control group and an
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intervention group trained on the Lapsim VR simulator. After cognitive training, all subjects performed three porcine laparoscopic cholecystectomies. By analysing the learning curve for dexterity parameters, the TER was calculated as 2.28. This implies that every hour of training on the Lapsim VR simulator is equivalent to 2.28 hours of training on the operating room. Although this figure is not as accurate as it would have been using time as the proficiency parameter, this remains the only study that assesses the transfer effectiveness of a VR simulator.

It is not feasible to have a simulator in every hospital in the country. Evidence is required to determine strategic venues for simulators, and to determine how many trainees are required to use each simulator. With a high rate of junior surgeons training on the simulators it would dramatically decrease the actual cost by giving a cost per trainee. Although it remains an expensive purchase, when it is compared with the cost of training surgeons in the operating room the initial outlay doesn’t seem too extravagant. The costs to a hospital may also be reduced, as VR simulation has been shown to reduce the operating time of surgeons in training. Therefore, by training surgeons in VR it will improve operating room efficiency and reduce the cost to the operating theatre. Further work should focus on the cost effectiveness of VR simulation in terms of the number needed to train on a VR simulator to make it cost effective.

3.7 Impact of VR

The impact of VR simulation can be assessed in a number of different ways. A new technology can only be as successful as the research that proves its worth. Therefore, by evaluating the number of research articles that are published in both editorials and peer review publications, it could be possible to assess the impact of VR simulation. It would be expected that as a product or surgical technology is increasing its penetration into the market,
it will have a higher impact by producing more articles for publication. Literature searches were performed for: (“MIST-VR” ”+”virtual reality”); (“Lapsim” ”+”virtual reality”); (“Lapmentor” ”+”virtual reality”); and (“Promis” ”+”virtual reality”).

The first laparoscopic VR simulator (MIST-VR) was introduced in 1996. Since 1996 there have been 718 publications in total on the MIST-VR, with a year by year increase, reaching a peak of 95 publications in 2006 and 2008, before dropping in 2009. It estimated that there will be 96 publications on the MIST-VR in 2010. (Figure 17)

A similar pattern was seen with the Lapsim after its introduction in 2000, with a gradual increase in yearly publication, reaching a peak of 112 in 2006. There have been 337 publications in total for the Lapsim. The Lapmentor was introduced more recently so has only 87 publications in total, but appears to be still increasing with a peak in 2009. At the current rate, it is estimated that there will be 72 publications on the Lapmentor in 2010. The ProMIS has only 76 publications, peaking in 2006 with 17 publications. (Figure 18) Although analysis of publications of VR simulation is a crude measure of market penetration, it provides an interesting evaluation of publication behaviour for VR simulation by surgeons over the past two decades.
Figure 17 – The cumulative level of publication for individual VR simulators from 1995-2010
Figure 18 – The levels of publication for individual VR simulators from 1995-2010
3.8 Discussion

It has been demonstrated that VR simulation can improve skills acquisition for surgical trainees. The VR simulators currently on the market for laparoscopic surgery have been widely validated for their use in surgical training and assessment. However, despite the fact that VR simulation has been established for well over a decade, it has been slowly adopted, and although there is evidence validating different VR simulators for use as training and assessment tools, there is limited evidence supporting the impact they will have on future OR performance. The most important aspects of VR simulation that need to be investigated further are:

1. An assessment of which simulators are the most effective at improving technical skills in the operating room
2. An assessment of the cost efficiency of training on simulation

Surgeons have a finite time to train in, therefore it is vital that they use the time they have as efficiently as possible. Further work on the TER of VR simulation would allow us to accurately state how efficient each simulator is for teaching technical skills, and therefore can recommend the use of the most efficient simulators for surgeons in training.

It is also important to analyse the cost to the healthcare system that VR simulation will have. VR simulators require a considerable financial investment to purchase them. Therefore to encourage hospital trusts and universities to acquire VR simulators, it is vital to be able to demonstrate that each hour of training in a VR simulator will reduce operating room costs by $X$ pounds. It would also be useful to evaluate how many students need to use a VR simulator and for how long, to make it cost efficient for an institution. This would define the “number needed to train” on each simulator to make them cost efficient.
The initial outlay for VR simulators is substantial, but the potential decrease in operating time combined with the decrease in medical error associated with VR simulation implies that it could reduce the overall cost of surgical training to the healthcare system. Further work should focus on the cost of simulation training modalities, and the effectiveness that they have in reducing training time in the operating room.

There are many studies looking at VR to OR performance, but there is a lack of evidence demonstrating the predictive validity of VR simulation. Every surgical trainee is different, and will have differing needs and training requirements. Predictive validity could identify the aptitude of individual surgeons, and allow the design of unique personalised training programs. This could ensure that each surgeon has reached a predefined proficiency level in fixed period of time.

VR simulation has been established as a valid method for teaching technical skills to surgeons. It is been slowly adopted by academic surgeons as demonstrated by the increase rate of publication for VR simulation. The initial criticism of VR simulation was that it was not realistic, is too costly and has no correlation to future OR performance. The is now considerable evidence demonstrating increased realism of simulators, but more work is needed to motivate and educate the surgical community in the effectiveness of VR simulation in terms of cost and future OR performance.
4. Technical skills curricula

4.1 Curriculum design

A curriculum is not a syllabus, and the development of a curriculum is far more than devising a list of topics and objectives that should be covered and setting outcomes to be achieved. It can defined as:

“A statement of the intended aims and objectives, content, experiences, outcomes and processes of an educational programme including:

- A description of the training structure [entry requirements, length and organisation of the programme including its flexibilities, and assessment system],
- A description of expected methods of learning, teaching, feedback and supervision

The curriculum should cover both generic professional and specialty specific areas.”

As McClusky et al describe in their excellent review, this definition of a curriculum demonstrates the need to produce a comprehensive framework for training. To design a curriculum that would stand up to scrutiny of the definition, it requires the establishment of a program, outlining the objectives and topics, the methods by which these topics will be taught and the development of objective assessments that demonstrate proficiency (McClusky and Smith, 2008). To be able to demonstrate proficiency, it is necessary that the design of a curriculum sets a bench mark that has been pre-defined by experienced surgeons’ performance which a participant can reach by completing the curriculum. In other words, a participant who completes the curriculum demonstrates proficiency. This is well established in knowledge and writing based curricula through the use of multiple choice questions (MCQ), extended matching questions (EMQ) and single best answer questions (SBA) (McClusky and Smith, 2008). These are widely used for the knowledge part of membership
examinations by the four Royal Colleges of Surgeons in the United Kingdom (Raftery, 1996), the Royal College of Physicians (Bessant et al., 2006) and the Royal College of Radiologists (McCoubrie and McKnight, 2008) as well as by the majority of medical schools in Great Britain (van der Vleuten, 2000). However, proficiency for technical skills in traditional training framework for surgeons is currently demonstrated by experience and numbers of cases. This is not the ideal way to demonstrate proficiency, furthermore, it is no longer feasible due to the reduction in training opportunities and patient safety (Aggarwal and Darzi, 2006).

The design of a successful curriculum involves using the framework which was devised in the 1960’s by Fitts and Posner. This theory suggests that complex skill should be taught in 3 sequential stages: a cognitive stage, an associative stage and an automated stage (Fitts P, 1967). The cognitive stage requires understanding of the theory behind the procedure. It is beneficial if the subject has a demonstration of the procedure, and instruction of what to do. The next stage involves integrating or associating the theory into musculoskeletal movements which allows the subject to translate theory into performance. The task performance is erratic, elongated and the outcome is often poor. The task is repeated, and with practice, movements become smoother and more efficient. The final stage is automated performance, in which a subject can complete the task fluidly and competently, without thinking of how to do it (McClusky and Smith, 2008). This theory can be used to define skills acquisition by surgical trainees. For example, Reznick and Macrae used the theory to define skills acquisition during simple procedure such as knot tying (Reznick and MacRae, 2006). During the cognitive stage, the subject must intellectualise the process. They need to know which type of knot is to be used, understand the mechanics of the specific knot, how to throw the knot, how the loops of material interact with each other and how their hands move to tighten the knot. The associative stage allows the subject to practice tying the knot. They still need to
think about their movements, but the performance is fluid with fewer interruptions. During the automotive stage, the subject knows how to competently throw the knot without thinking about their movements. This allows them to concentrate on more complex topics, such as, in theatre, operation planning, other technical and non-technical skills (Reznick and MacRae, 2006). This theory can be applied to the acquisition of both simple and complex skills by surgeons, and should be the cornerstone of the development of any surgical skills curriculum.

To successfully incorporate this theory the outcome of the curriculum needs to be defined. In other words, what benefit or level of skill will a trainee surgeon have on completion of the curriculum? Proficiency based curricula imply that proficiency in any given tasks has been reached. However it is much easier to develop proficiency levels for tasks (e.g. laparoscopic suturing) than for a full procedure (e.g. laparoscopic gastric bypass) or an overall program (e.g. laparoscopic bariatric fellowship) (McClusky and Smith, 2008). To develop a curriculum that enables a participant to be proficient in a procedure or fellowship, it needs to provide the platform to identify and master the skills needed and allow assessment of proficiency on completion.

By using Fitts and Posner's theory, we can try to create a framework that can make up the foundation of training and assessment of technical skills. The framework for systematic training and assessment of technical skills (STATS) has been developed to provide the opportunity for a trainee to learn and develop technical skills in the skills laboratory or in real life and enable reliable and objective assessment of these skills (Aggarwal et al., 2007c). The first step of developing a framework should be the acquisition of knowledge prior to attempting the practical aspects of a procedure or task. As previously mentioned, to successfully tie a knot, it is important that the trainee intellectualises the process, and is able to describe the procedure prior to attempting it. The second step is the practical element, in which a trainee develops their skills. The fundamental part of this step, the technical skills
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training program, is that a trainee should practise skills by following a structured training program with expert feedback and assessment, rather than practice individual tasks in an informal, haphazard manner. A step-wise, task based approach can be used, where the procedure is broken down into its constituent tasks (Aggarwal et al., 2007c). This allows the surgeon to concentrate on and perfect small identifiable steps of a procedure. There is however a great deal of variability as to how different surgeons perform the same procedure, so to be able to successfully define the key steps, it is important to watch a large number of different surgeons perform the same procedure. This can be done by recording the operation on video, before analysing the operation and splitting it into steps and sub steps. Task fragmentation has been published for laparoscopic cholecystectomy, laparoscopic Nissen fundoplication, and further work is being developed for laparoscopic Roux-en-Y gastric bypass and laparoscopic appendectomy (Cao et al., 1999, Joice et al., 1998). Using this method in the development of a step wise curriculum allows comparison between novice and experienced surgeon at different steps of a whole procedure.

Surgical trainees have a limited time to train. Therefore we should look at ways in which we can streamline training such that they do not waste time practising superfluous tasks. By analysing learning curves of various tasks on simulators, we can say that the longer the learning curve, the more difficult the task. By obtaining proficiency in the tasks with the longest learning curves, implies proficiency in the easier tasks with shorter learning curves and therefore the whole procedure (Payandeh et al., 2002). To use this successfully for training and assessment, the program and tasks within the program must be validated. If we are to break down a procedure and train and assess a surgeon in the separate tasks, we must be able to distinguish between an experienced surgeon and a novice performing the specific tasks (construct validity). This means that you can monitor a novice surgeon’s progress until they reach the level of the experienced surgeon. Completion of a technical skills training
program must also include some form of proficiency assessment. The assessment must be easy to perform, cheap, reliable and objective, and the trainee is not allowed to progress until they have reached a pre-defined level of proficiency. If a training model has been shown to be construct valid, proficiency can be determined from the parameters of an experienced surgeon's performance. The development of a technical skills curriculum should not only use time for assessment, but also global rating scales, error scores and parameters of manual dexterity. Expertise in the key tasks can be assessed by using the scores for these variables between novice and experienced surgeons performance. This method also allows us to identify key tasks within the procedure that are deemed integral to the process, these can then form the basis of the assessment (Payandeh et al., 2002, Aggarwal et al., 2007c). As with any training program, proficiency should be assessed and demonstrated at each level, before being able to move onto the next task.

Once the technical skills program has been defined, the trainee must develop their skills by repetitive practice. It is now considered unacceptable and inappropriate to practice on patients, exposing them to the increased risk of complications that are associated with novice surgeons’ performance. The skills laboratory provides an alternative, where a novice surgeon can practice on low fidelity plastic models to high fidelity VR simulators and develop their technical skills prior to entering the operating room. This theory can be incorporated into designing a framework that can be used for the development of a step wise curriculum for technical skills training (Aggarwal et al., 2007c).

4.2 Virtual reality simulators as training platforms

One problem we have with designing skills based curricula, is developing ways of accurately and consistently measuring metrics of technical performance. VR simulators provide a platform for being able to measure these metrics. The main criticisms of the
simulators have been that they lack fidelity and are not true to life. However, it is now likely that the main obstacle remains to be a lack of awareness, understanding and motivation by surgical educators (Aggarwal and Darzi, 2006). There have been many trials on VR simulators over the past few years that have had favourable outcomes on their realism and usefulness as a training modality (Blum et al., 2004, Grantcharov et al., 2004). However, the main criticism of these studies is the lack of a structured training program. The studies focus on the development of technical skills on a VR simulator, in which the participants were asked to repeat the set tasks on the simulator. However, more recent research into VR simulators has focussed not only on their use for skills acquisition as part of a training program, but into the development of separate training program on the simulator. Surgeons are able develop their skills on the simulators by following a structured, proficiency based curriculum. Completion of these curricula results in the attainment of proficiency purely in the skills laboratory, without risk to the patient. The objective is to give trainee surgeons the necessary technical skills prior to entering the operating room, thus reducing the learning curve and the risk to the patient (Aggarwal et al., 2006a, Aggarwal et al., 2006b).

VR provides a good platform for the development of a technical skills curriculum, but it is important that the design of a curriculum follows a number of rules:

i. Any training curriculum must be **reproducible** and **standardised** such that different trainees are able to perform and repeat the same tasks throughout the curriculum.

ii. The VR simulators also provide a good way of producing a program that enables trainees to perform simple tasks prior to attempting more complex tasks. A number of simulators allow the trainee to practice simple skills (camera manipulation) followed by more complex tasks (clipping and cutting), before progressing onto the
more challenging full procedures. This allows the design of a *step-wise* training curriculum.

iii. The simulators have different difficulty settings such that a trainee may develop skills on the easy levels before moving onto the medium and difficult levels. This provides an *incremental challenge* to the trainee as they progress through a curriculum.

iv. Training must be in a *distributed fashion*; massed training is not advised. It has been shown that skills acquisition is improved if training sessions are distributed into separate sessions (Magill, 2004).

v. Assessment is a vital part of any curriculum, and VR simulators allow accurate and reproducible assessment. Simulators provide *instant feedback* by giving scores for a number of parameters such as hand movements, path length, error scores and time. This allows a trainee to gauge their performance immediately after completion of a task. The simulator also allows *video review* by recording performances. This enables a trainee to be assessed by an experienced surgeon using global rating scores.

vi. Assessment should also demonstrate *proficiency*. Evidence based proficiency levels can be determined by evaluating experienced surgeons performances of the tasks. An experienced surgeon can be defined for assessment of basic skills, as one who has performed more than 100 laparoscopic cholecystectomies.

By following these rules, it is possible to develop an evidence based curriculum that enables the acquisition of basic technical skills by trainees. By completing the curriculum, a trainee can demonstrate proficiency levels as defined by experienced surgeons.
4.3 Evidence based curriculum for Mist-VR simulator

The first simulator that was widely used to demonstrate acquisition of skills in surgeons was the Minimally Invasive Surgery Trainer-Virtual Reality (MIST-VR) (Mentice, Gothenburg, Sweden). This is a basic VR simulator that has twelve basic tasks at 3 levels of difficulty (easy, medium and hard). For example, “Transfer Place” involves grasping a virtual sphere with a virtual laparoscopic instrument and transferring it to the opposite hand. As the difficulty levels increase, the size of the sphere reduces, and requires greater skill and dexterity. The exercises are split into two separate modules of six tasks. Each task in a module compliments the other, increasing in difficulty. The final task of the module incorporates parts of the other five tasks and requires the most skill. MIST-VR is the most widely validated VR simulator, with extensive research into the acquisition of skills by surgeons using the simulator for training (Moorthy et al., 2003). It has also been shown to significantly improve a surgeon’s technical skills performance in the operating room (Torkington et al., 2001b). The first evidence based curriculum for the acquisition of psychomotor skill on a VR simulator was produced for the MIST-VR (Aggarwal et al., 2006a). This was achieved by recruiting 20 medical students with no previous laparoscopic experience and 10 experienced surgeons to undergo a training program on the MIST-VR. The data collected allowed formulation of a curriculum which incorporates Fitts and Posner’s framework describing the three stages of motor skills learning (Posner M, 1967). For example, during the cognitive stage, the student gains knowledge from the explanation and demonstration of the simulator by the instructor. During the associative stage, the student can practise on the simulator and eliminate their errors. The instructor provides constructive feedback, and advice on error reduction. The automated phase implies that the student can perform the tasks in an automated manner, with little cognitive effort needed to complete the
task. Therefore, the easy level allows the students to familiarise themselves with the
simulator and tasks. The medium level allowed the students to refine their technique and
reduce their error scores, before progressing onto the hard task. At this point the trainee
demonstrates the automotive phase, with tasks performed as second nature, and no further
improvement in performance. The 3-stage curriculum enables the trainee to familiarize, train
and be assessed on the VR simulator. Trainee surgeons train through the different difficulty
levels, performing all 12 MIST-VR tasks on the easy levels in two separate sessions more
than one hour apart before repeating the tasks on the medium level. After completing these
levels, the trainee moves onto the difficult level and performs the two tasks, which were
deemed to be the most complicated as they were shown to have the longest learning curves.
The trainees continue to practise these two tasks until they perform the task to the level of the
experienced surgeon. Performance is assessed by looking at the experienced surgeons’ time,
error score and hand movements for the selected tasks. Once they have reached these scores
on two consecutive attempts (to rule out a fluke performance), they have developed
proficiency in laparoscopic psychomotor skill on the MIST-VR.

This curriculum demonstrates an evidence based approach to laparoscopic training,
allowing novice laparoscopic surgeons to train to proficiency in basic psychomotor
laparoscopic skills. One of the criticisms of this curriculum is that it may appear too basic for
a surgical resident, and that the basic psychomotor skills that are taught should already have
been learnt by a surgical trainee. Therefore, this curriculum may be more appropriate for
medical students or newly qualified doctors. The limitations of this study can be identified
using the rules that we have set for the design of a VR curriculum. The development of the
curriculum on the VR simulator means that it is standardised and reproducible. The
curriculum encourages distributed practice and does not allow massed practice, through 1
hour time limits for sessions, and a maximum of 2 sessions per day. Although the curriculum provides an *incremental challenge* with progression through difficulty levels, it does not provide a *step-wise* curriculum from basic tasks to procedural tasks to full procedures, as the MIST-VR does not provide these modules. Therefore it could be said that this VR simulator is better for learning generic technical skills for minimally invasive surgery, and would be beneficial to specialties such as gynaecology, orthopaedic or thoracic surgery, where learning how to perform a laparoscopic cholecystectomy is not vital! The software on the MIST-VR allows *proficiency based assessment* through both *instant feedback* and post-hoc *video review*. Proficiency based assessment means that completion of the curriculum is achieved by reaching pre-defined proficiency levels, and not by time taken or numbers of tasks completed. Time is irrelevant for completion of the curriculum; therefore, some students will develop proficiency quicker than others. However, the outcome on completion of the curriculum is a proficiency in basic psychomotor skills that will allow a novice surgeon to confidently assist in theatre, and learn how to operate on real patients further along the learning curve.

### 4.4 Competency based curriculum for Lapsim VR simulator

To be able to produce an evidence-based training curriculum it is vital to be able to use tools that enable structured training with objective measures of assessment. VR simulators provide this by allowing a student to develop skills in a safe and controlled environment. It provides the platform to develop skills in a graduated fashion and learn the basics of procedures that they may see in the operating theatre. By following a structured curriculum, students can train to proficiency in basic laparoscopic skills, prior to entering the operating room. The LapSim VR laparoscopic simulator (Surgical Science, Gothenburg, Sweden) provides an excellent platform to do this, combining basic laparoscopic tasks and procedural
based tasks. The simulator’s basic tasks module comprises 7 basic tasks ranging through 3 difficulty levels. The procedural aspect of the simulator involves a simulation of a laparoscopic cholecystectomy. The student can complete a dissection of Calot’s triangle to expose the cystic structures, prior to clipping and cutting them. These tasks have been previously demonstrated to be construct valid so the tasks show significant differences in performances between a novice and an experienced surgeon. (Duffy et al., 2005) This is a vital component of using a VR simulator for training, as it allows us to gauge a novice’s performances against an experienced surgeon, whilst training on the simulator. It is also possible to plot learning curves for novices with repeated performance of the tasks demonstrating skills acquisition, with a plateau effect towards the experienced surgeon’s performance.

By using similar methodology to the development of the MIST-VR curriculum, it has allowed the design of a structured curriculum for the LapSim VR simulator. (Aggarwal et al., 2006b) Unlike the MIST-VR, the LapSim VR simulator allows a curriculum to be established for training in specific VR procedures, for example laparoscopic cholecystectomy. This framework allows a trainee to learn the basics for laparoscopic surgery, such as depth perception, hand-eye co-ordination and the fulcrum effect, without wasting time practising tasks that would not benefit their training. This was achieved by training 10 experienced surgeons and 11 novice surgeons through the modules and analysing their learning curves.

The curriculum was designed such that the novice completes 2 sessions of all 7 tasks at easy and medium levels. To ensure distributed training, each session must be at least an hour apart, with no more than two sessions per day. The novice then progresses onto the difficult level, where they only perform the two most difficult tasks as defined by the learning curve analysis (“lifting and grasping” and “clip applying”). It is likely that these tasks
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demonstrated the longest learning curves as, unlike some of the other tasks, they require coordination of both hands. They are further complicated by the use of two different tools, and require the trainee to learn different techniques to correctly use the instruments in each hand. The novice surgeon then practises these two tasks until they achieve the proficiency level for path length, error score and time taken as defined by the experienced surgeons’ performance on these tasks. It is assumed that gaining proficiency in the most complicated tasks infers proficiency in the easier tasks. Progression from the task based module to procedure based module is only permitted once proficiency levels are met. The final step is completing the procedural task of dissection of Calot’s triangle. Again, the novice surgeon must practice this module in a distributed manner until they can successfully reach the pre-defined benchmark criteria for proficiency.

The important aspect of the development of this curriculum is that it is proficiency based, in that a student cannot advance from one level to the next until they obtain the pre-defined proficiency benchmark. All tasks are standardised and demonstrate construct validity and learning curve analysis showed that performance improves with repetitive practice, although it encourages distributed practice, and prevents massed practice. The curriculum is designed such that it provides a step-wise program with an incremental challenge, training through simple tasks, procedural tasks and full length tasks at different difficulty levels. Unlike the curriculum for the MIST-VR, the Lapsim curriculum involves procedure based tasks, with the trainee practising the skills needed to perform a laparoscopic cholecystectomy. For this reason, it could be used for junior general surgeons, who can learn the relevant skills, the anatomy of the hepato-biliary structures and the individual steps required to perform a laparoscopic cholecystectomy. By altering the structure of the curriculum, it may also be useful and relevant for trainee gynaecologists for the development of basic skills. The Lapsim
VR simulator provides a number of procedural tasks for laparoscopic gynaecology. The module for laparoscopic salpingectomy has been shown to improve a trainee gynaecologist’s technical skill. It has also been shown to demonstrate construct validity, with significant differences between the performance of an experienced and novice gynaecologist (Aggarwal et al., 2006c). Therefore, it may be possible to substitute the laparoscopic cholecystectomy module for a laparoscopic salpingectomy module in the Lapsim VR curriculum. This would allow a proficiency based VR curriculum that is useful and relevant for a trainee gynaecologist. It may however, have less relevance for other trainees in other surgical specialities, such as orthopaedics and thoracic surgery, where in depth knowledge of Calot’s triangle is not essential for progression. Proficiency is demonstrated in the LapSim curriculum, by reaching the same level of skill as an experienced surgeon, on two consecutive attempts on each difficulty setting, this eliminates the attainment of proficiency level by chance. (Grantcharov et al., 2004, McClusky et al., 2004). By following this curriculum on the LapSim VR simulator, trainee surgeons and gynaecologists could acquire the relevant laparoscopic skills needed to perform basic laparoscopic tasks, which reduces the learning curve, and could improve their performance in the operating room.

4.5 Structured training curriculum for Lapmentor VR simulator

VR simulators are now well recognised for providing a platform for technical skills training. Simulators like the MIST-VR and LapSim have been validated for training basic laparoscopic skills in a safe and controlled environment. To enhance a trainee surgeon beyond the basics skills of laparoscopy, it is important to train the necessary skills needed for specific procedures in a particular speciality. As previously described, evidence based curricula have been developed for basic laparoscopic skills on the MIST-VR (Aggarwal et al., 2006a) and for basic skills and procedural skills on the LapSim VR simulator (Aggarwal et
As technology has advanced surgical procedures, it has also improved the VR surgical simulators. The Lapmentor VR simulator has been comprehensively validated for face, content and construct validity (McDougall et al., 2006). It has also been shown that training on the Lapmentor simulator improves a surgeon’s performance on real tasks and procedures in the operating room (Gallagher and Cates, 2004, Andreatta et al., 2006, Gallagher et al., 2005).

A structured curriculum for the Lapmentor has been designed to enhance the quality of its content. It has resulted in an evidence-based training curriculum for basic and procedural laparoscopic skills (Aggarwal, 2009). To be able to develop this curriculum, 57 surgeons of varying experience were recruited to follow specific training programs on the Lapmentor VR simulator. Learning curves were plotted and analysed, and individual tasks were assessed for construct validity. The curriculum that was developed requires a novice surgeon to complete the modules on the Lapmentor in a step-wise manner, progressing from basic tasks to procedural tasks to full length procedures. One of the greatest strengths of the curriculum is that it is proficiency-based. The novice is not permitted to move along the steps until they have completed the assessments to the level of an experienced surgeon. The proficiency level is pre-defined by the experienced surgeon’s time taken, path length number of movements of each hand when completing the tasks. The novice is asked to complete all basic tasks in two separate sessions on the same day. They are then asked to repeat the two most difficult tasks as defined by learning curve analysis. Through repetitive practice they must continue to perform these tasks until they reach the experienced surgeon derived proficiency levels.

Another advantage of the curriculum is that it encourages all training to occur in a distributed manner, with a maximum of two sessions per day, with at least a 1 hour break between sessions. This form of distributed training has been shown to improve skills retention by
surgeons in training (Magill, 2004). Once they have reached the proficiency levels for the basic tasks, they may move onto the procedural tasks. Again they must perform all 4 procedural tasks in two separate sessions on the same day, before practising the two most difficult tasks until they reach the proficiency level as defined by the experienced surgeons' performance. Once achieved, the novice may progress onto the full length VR laparoscopic cholecystectomy. Completion of the training curriculum is achieved once the novice surgeon is able to perform the full length procedure to the level of an experienced surgeon in terms of hand movements, time and path length. However, to ensure it has not been achieved by fluke, the proficiency levels must be reached on two consecutive performances. As the Lapmentor demonstrates an accurate version of the gallbladder, the curriculum is most relevant for general surgical trainees to develop their technical skills and learn how to perform a full length laparoscopic cholecystectomy, and has a limited use for other surgical speciality trainees.

The strongest point of this curriculum is that its structure has been devised purely using a scientific methodology. Only tasks that showed construct validity were included in the curriculum, such that task selection is completely evidence based. Only tasks with the longest learning curves were used for repetitive practice, as they were deemed the most complicated, and obtaining competence in these tasks infers competence in the simpler tasks. To complete these tasks, performance is only evaluated using the parameters which have demonstrated validity. Assessments are, as previously described, proficiency based, by comparing to experienced surgeons performance on the valid parameters of the valid tasks. The result is the development of an evidence based curriculum that demonstrates proficiency on completion (Aggarwal, 2009).
4.6 Discussion

The evolution in surgical training has already started with increased attendance to technical skills laboratories, and increase accessibility to VR simulators (Haluck and Krummel, 2000). Surgical educators must now use validated educational concepts to efficiently use simulation to provide the optimum way of training technical skills. The development of evidence-based VR simulator curricula can enhance the development of technical skills, and should now be fully incorporated into surgical residency programs. However, one of the frequent criticisms of VR simulation is that the simulators are expensive, and not all hospitals can afford them. The MIST-VR and LapSim VR simulators are estimated at US$24,000 and US$40,000 respectively, and cost of the Lapmentor is in excess of US$100,000. The more expensive VR simulators also require an annual subscription for technical support and upgrades. It is therefore not feasible to have a simulator in every hospital in the country. However, a large number of junior surgeons training on the simulators would dramatically decrease the actual cost by giving a cost per trainee. Although it remains an expensive purchase, when it is compared with the cost of training surgeons in the operating room the initial outlay is not too extravagant. If you also add the potential cost of litigation that could occur with the increased risk of complication due to inexperienced surgeons learning in the operating room, purchasing a VR simulator can be regarded as a cost efficient way of training. Future work on VR curricula should look at developing curricula on different VR simulators. The validation and development of VR skills curricula for intermediate laparoscopic procedures such as laparoscopic ventral hernia repair and more complicated procedures such as laparoscopic Roux-en-Y gastric bypass and laparoscopic colorectal surgery would allow us to create a tiered training program. Surgeons may train and develop their skills on the more basic curricula such as the MIST-VR curriculum or
Lapmentor curriculum, before progressing onto the intermediate and advanced curricula that
could be developed.

However it is vital that the any future development of curricula follows the rules that we
have previously discussed. They should be standardised, reproducible, step-wise,
incrementally challenging, provide both instant feedback and the means to video review, and
most importantly should be proficiency based. However, to further enhance the evidence
basis of a curriculum, the following steps, as previously described in the scientific methods
for development of a curriculum for the Lapmentor VR simulator, should be used. Task
inclusion in curricula should only use tasks that have been validated, using only the
parameters for that task that also demonstrate validity. If repetitive practice is required,
selecting tasks that have the longest learning curve provides an efficient way to train.
Assessment of proficiency should be demonstrated by comparing an experienced surgeon’s
performance on the valid parameters of the valid tasks. This set of rules provides a
framework for the development of an evidence based curriculum that can be used for any VR
simulator.

Further research into VR curricula should focus not only on the design and development
of a skills curriculum itself, but importantly on how to incorporate these frameworks into a
fully established educational program. Program directors must provide the time to allow a
surgeon to attend skills laboratories and use VR simulators. Training on the simulators should
be structured, with trainees learning through deliberate repetitive practice, which is essential
for performance improvement. Distributed practice has been shown to enhance skills
acquisition more than massed practice (Magill, 2004). Therefore, sessions must be structured
and occur with regularity, to ensure that optimal skills acquisition with a balance between
service provision and training. If a VR curriculum is to be successfully incorporated into a
surgical residency program, it is vital that the participants are able to complete the curriculum in the time that is available. As previously discussed, completion of a proficiency based VR curriculum is not based on time. Therefore some residents may take longer than others to complete the curriculum. It has been shown that baseline testing of technical skills can predict how quickly a subject can complete a skills curriculum. For a skills curriculum to function in an academic year, baseline testing may be used to identify subjects that may need more time to complete the curriculum. Therefore, the numbers of sessions needed for training curricula can be modified to ensure that all participants can reach proficiency in an academic year (Stefanidis et al., 2006). Once proficiency has been reached, it is vital to maintain and enhance levels of technical skills with overtraining. It has been shown in one study that students who over train following completion of a skills curriculum have improved skills than those who just complete the curriculum (Aggarwal et al., 2006b). Therefore, following demonstration of proficiency, skills maintenance sessions should be incorporated into the residency programmes every 1-3 months (Stefanidis and Heniford, 2009). However despite all these measures to ensure successful skills training, to be able implement a VR training curriculum into a residency program, requires the motivation of both student and surgical trainer. One aspect of VR that needs to be explored in detail is the role of performance parameters. Currently, performance on the simulators is assessed by looking at the time, numbers of hand movements and the path length of each hand. However, are these enough? These do not give an idea of the quality of the performance. Therefore, it is important to develop rating scores that we can use to assess performance. Global rating scores have already been developed for laparoscopic skills, but procedure specific rating scales need to be developed for each surgical procedure. By using video review, we can objectively assess a trainee’s general laparoscopic skill, and their specific skills to that procedure. This would also allow the use of VR simulators for certification of surgeons in training, to ensure that they
have developed the necessary skills needed to be competent. It is conceivable that a junior surgeon would not be allowed to perform laparoscopic surgery in their hospital until they have been certified on a VR simulator. Further development could lead to the possibility of using VR simulators for re-validation of senior surgeons, as they provide a standardised platform that accurately assesses a surgeon’s technical skill.

The perfect way of teaching technical skills has not yet been developed. Educators must constantly evolve their ideas and the ways in which skills training is delivered. A VR simulator curriculum must be a dynamic entity, such that it changes from year to year to improve itself, and is flexible enough that it moulds its structure to allow for the inherent differences between trainee surgeons ability and rate of learning. This would allow a structured, evidence-based VR simulator curriculum to be successfully incorporated into an established surgical residency program.
5. **Current training methods – the surgical masterclass**

5.1 **Current training methods**

Current training methods use a variety of educational theory and training platforms to enhance technical skills and improve operative performance. A structured, step-wise training curriculum provides a reproducible training structure that allows a standardised approach to training of large numbers of trainees. An ideal training curriculum would give a trainee the knowledge, skills and attitudes required to start performing certain procedure independently. The role of the adoption of a technique by a surgeon is a complex process that is not fully understood (Lewis et al., 2011a).

5.2 **The adoption of advanced surgical techniques**

The adoption decision is a term given by researchers in the diffusion of innovation, to the moment a person agrees to use a new technology or innovation (Greenhalgh et al., 2005). When a surgeon decides to adopt a new technique, operation or technology, the decision will be influenced by a number of different parameters. First and foremost is the ability of the surgeon to provide the patient with the best possible operation, and give the optimal outcome in terms of operative time, trauma, post-operative pain, length of hospital stay and long term follow up (Wilson, 2006). The surgeon may also be swayed by an intrinsic desire to be the best, and to perform the most advanced and modern surgical procedures. Other external factors include economic considerations of the hospital trust, peer pressure and competition with other surgeons and of course pressure from the patient, who since the introduction of the internet have become increasingly aware and educated in terms of innovations in healthcare (Riskin et al., 2006). As yet, there are no regulations in place to ensure that surgeons have the technical skills to be able to perform the procedures safely (McCulloch et al., 2009).
Currently, we must rely on the honesty and diligence of individual surgeons and surgical department audit within hospitals to ensure that each patient gets the best possible operation by a surgeon who has the appropriate competence, without detriment to their safety (Wexner, 2009).

In the United Kingdom, on completion of specialized surgical training a surgeon receives their Certificate of Completion of Training (CCT), where they are then able to practise as a substantive or honorary consultant in the National Health Service (NHS) (Nel and Kent, 1994). They are also obliged to register with the General Medical Council (GMC) on the specialist register. At this point, a consultant surgeon will perform operations that lie within the sub-speciality, and may adopt more complex operations at their discretion. As there is a learning curve associated with individual operations, there is also a learning curve for operations within a sub-speciality (Aggarwal et al., 2007a). A fully trained bariatric surgeon would gain proficiency in basic and intermediate techniques such as laparoscopic cholecystectomy and laparoscopic Nissens fundoplication before independently performing advanced laparoscopic techniques such as laparoscopic Roux-en-Y gastric bypass (LRYGB)(Aggarwal et al., 2007a, Schlachta et al., 2001). Advanced surgical techniques such as LRYGB and laparoscopic colorectal procedures are not performed by all colorectal and bariatric surgeons (Sarr, 2008). One of the reasons that some surgeons do not perform these operations is due to technical skills training (Lublin et al., 2005, Schauer et al., 2003). If a surgeon works in hospital without peers performing advanced techniques, it is not always possible to have the opportunities to develop the skills necessary to perform these operations. Therefore, many senior surgical trainees or consultants will seek other avenues to enhance and develop advanced laparoscopic technical skills in order to have the proficiency to adopt a complex surgical technique into their clinical practice (Rattner et al., 2001).
Currently there are two main avenues that a senior surgeon may follow to develop surgical skills and learn advanced laparoscopic operations; the surgical fellowship and the surgical masterclass. Surgical fellowships have traditionally been an effective way of gaining the appropriate experience and competence to perform advanced operations (Kothari et al., 2005). Surgeons may take up a fellowship at the end of their training prior to commencing as a consultant surgeon. This can be a highly valuable way of allowing a surgeon to perform large numbers of operations with sufficient supervision and develop their technical skills ensuring that they reduce their learning curve as an independent practitioner (Oliak et al., 2004). However, they are highly competitive, especially at specialist centres with a high flow of patients. They can also be costly, with a decrease in salary and the associated high costs for relocation. As a result many surgeons are unable to gain entry a fellowship program (Cottam et al., 2007). Another popular training method is the attendance of a surgical masterclass. A masterclass may last 3 to 7 days, where a surgeon is immersed in both the theoretical and practical aspects of advanced operations (MacIntyre and Munro, 1990). In a number of facilities in Europe and the United States, surgeons may attend a masterclass, where they are able to learn operations and develop their skills on a live anaesthetised porcine simulator (Hamdorf and Hall, 2000).

Surgeons do not adopt a new technology or surgical technique without ensuring they have the technical skills to perform the operation safely (Wilson, 2006). Traditionally, surgical masterclasses have been used by a large number of surgeons to develop the necessary technical skills to perform new techniques and operations (Renwick et al., 2005). However, there is only one study that demonstrates the effectiveness of surgical masterclass in providing a surgeon with enhanced technical skills. This study showed that following attendance of a laparoscopic bariatric masterclass, surgeons improved their technical skills by
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using a validated cadaveric porcine assessment tool (Aggarwal et al., 2007a). However, there is limited data that demonstrates that this equates to an improvement in operating room performance. Moreover, there is limited data to show that a surgeon is more likely to adopt a new surgical technique into their practice if they attend a surgical masterclass.

This chapter aims to investigate the efficacy of surgical masterclasses in terms of the adoption of the operations that they teach when surgeons return to their local hospitals. It also aims assess the optimal methods for teaching technical skills to doctors of all grades.

5.3 Methods and Materials

A web based questionnaire study was developed which covered a number of different topics including demographics, training history, masterclass attendance, operative experience prior to masterclass attendance, adoption of techniques following attendance of the masterclass, impressions on masterclass, opinions and training methods. An electronic mail was sent to 137 surgeons who have attended a surgical masterclasses at Elancourt (Covidien, Elancourt, France) in either laparoscopic colorectal or bariatric surgery from 2004 until 2009. The electronic mail contained an invitation letter describing the purpose of the study along with a hyperlink to the web page for the questionnaire. Two further reminder emails were sent at 2 and 4 four weeks following the initial email. The email also contained a surgeon information sheet with information about the study including a privacy statement. The questionnaire was voluntary, and those who wished not to be included were advised to ignore the email. The questionnaire was devised to maintain anonymity, and no information could be attributed to individuals completing it. Results were obtained and analysed by the online web program Survey Monkey (www.surveymonkey.com). The results obtained were analysed to assess the levels of adoption of advanced surgical techniques with traditional training following attendance of a surgical masterclass. The data were further analysed with
the Statistical Package for Social Science version 17.0 (SPSS, Chicago, Il, USA) using the Wilcoxin non-parametric test for paired data. A p value <0.05 was considered as statistically significant.

5.4 Results

The survey was sent to 137 surgeons, of which 34 were sent to old or closed email accounts, and received immediate rejection of the email. Emails were successfully delivered to 103 surgeons with 49 completing the survey (response rate of 47.6%). The age of surgeons responding ranged from 30-35 to >50, with a median age of 36-40 (n=15) and 41-45 (n=15). 25% (n=12) of surgeons were from the United Kingdom (UK). 16% (n=8) were from both Sweden and Denmark. Other countries included South Africa, Romania, Portugal, Netherlands, Austria, Croatia, Estonia and Turkey (figure 19). There was no response from surgeons from Spain, France and Italy. 67% (n=33) of surgeons were sub-specialised in colorectal surgery with 29% (n=14) in upper gastro-intestinal surgery. Surgeons attended a surgical masterclass between 2005 and 2009. 67% (n=33) attended a colorectal masterclass, with 33% (n=16) attending a bariatric masterclass. 67% (33) attended the masterclass with another surgeon that they knew, 52% of which were not from the same institution. 78% (n=38) of the surgeons did not attend any further training masterclasses. 76% (n=37) currently perform the operation that they practised at the surgical masterclass. 18% (n=9) do not currently perform the operation that they learnt, with 6% (n=3) choosing to skip the answer. 23% (n=11) have performed 1-10 procedures with 18% (n=9) having performed between 51-100 procedures since the masterclass.

For colorectal surgery, 33% (n-11) had performed advanced colorectal laparoscopic surgery prior to attending the course, with 79% (n= 26) adopting the procedures following the masterclass. By comparing the number of surgeons performing laparoscopic colorectal surgery.
procedures before the masterclass with the number of surgeons performing the procedures after the masterclass, there was a significant increase in adoption of the technique, (p=0.00011) (figure 19).

For bariatric surgery, 27% (n=4) of surgeons performed LRYGB prior to attending the masterclass, with 66% (n=10) of surgeons adopting the technique following attendance of the masterclass. By comparing the number of surgeons performing LRYGB before the masterclass with the number of surgeons performing the operation after the masterclass, there was a significant increase in adoption of advanced bariatric surgery, (p= 0.014) (figure 19).
Figure 19 - The percentage of surgeons from each country practising the operation before and after the masterclass

<table>
<thead>
<tr>
<th>Country</th>
<th>Percentage of surgeons before masterclass</th>
<th>Percentage of surgeons after masterclass</th>
<th>Total no:</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>4</td>
<td>8</td>
<td>n=4</td>
</tr>
<tr>
<td>Turkey</td>
<td>2</td>
<td>8</td>
<td>n=2</td>
</tr>
<tr>
<td>Croatia</td>
<td>1</td>
<td>1</td>
<td>n=1</td>
</tr>
<tr>
<td>Austria</td>
<td>4</td>
<td>1</td>
<td>n=1</td>
</tr>
<tr>
<td>Estonia</td>
<td>1</td>
<td>8</td>
<td>n=4</td>
</tr>
<tr>
<td>Portugal</td>
<td>1</td>
<td>8</td>
<td>n=4</td>
</tr>
<tr>
<td>Netherlands</td>
<td>12</td>
<td>8</td>
<td>n=12</td>
</tr>
<tr>
<td>UK</td>
<td>8</td>
<td>8</td>
<td>n=8</td>
</tr>
<tr>
<td>Denmark</td>
<td>8</td>
<td>8</td>
<td>n=8</td>
</tr>
<tr>
<td>Sweden</td>
<td>2</td>
<td>8</td>
<td>n=2</td>
</tr>
</tbody>
</table>

The diagram shows the percentage of surgeons before and after a masterclass, with countries listed from left to right in descending order of total number of surgeons.
5.4.1 Opinions on training and adoption of advanced surgical techniques

Surgeons were asked questions regarding their opinions of training methods and potential barriers to training and the adoption of advanced techniques by surgeons. Each participant was asked to score the question using a 7 point Likert scale, with 1 being not useful/not important and 7 being very useful/very important. The greatest barrier to the adoption of innovation and advanced operations was economic constraints, with 33% scoring it “extremely important”, and a mean score of 5.59/7. Technical skills of the surgeon were the most significant barrier to adoption, with 34% regarding it “extremely important” with a mean score of 5.74/7. Other important barriers included time constraints, local and national guidelines, and local managers medical knowledge. On questioning what was the most important barrier to the adoption of advanced surgical techniques, most responded that a lack of supervision and inexperience prevented successful adoption (figure 20).
Figure 20 - The importance of various factors influencing the adoption of advanced surgical techniques by a surgeon
5.5 Discussion

The surgical masterclass has traditionally been a way in which a surgeon can augment their technical skills and develop the technical skills required to perform advanced surgical techniques (Aggarwal et al., 2007a). To date this is the first study that attempts to assess the efficacy of the surgical masterclass in terms of adoption of operative techniques. The results of this chapter demonstrate that on completion of a surgical masterclass, there is an increase in the number of surgeons performing the operations. Therefore, the surgical masterclass increases the adoption of advanced surgical procedures. This was apparent for both laparoscopic bariatric and colorectal masterclasses. The masterclass provides the platform for senior surgeons to practice complex procedures in a safe and controlled environment, where errors can be accepted and learnt from. The use of live anesthetised porcine simulators allows surgeons to develop the necessary technical skills to perform complex procedures on living tissue that handles and bleeds like human tissue. Although there are some anatomical differences between the porcine model and the patient, it provides high fidelity simulation for complex operations.. Not only can a surgeon learn advanced techniques, and develop their technical skills, it can help to provide the confidence that is necessary to adopt the technique into their surgical practice. This was confirmed in the survey that rated the anaesthetised porcine model as realistic (score 5.69/7), with the majority of surgeons recommending it highly as a training modality for all grades of surgeon (recommend for consultants average score 5.43/7; for senior trainees 5.67/7 and for junior trainees 6.17/7). The masterclass itself was rated very highly by all surgeons enrolled, as 100% of the surgeons would recommend it to a colleague for learning advanced surgical techniques.

Further questioning on matters regarding surgical training revealed some interesting results. The majority of surgeons felt that technical skills were the most important aspect of
introducing a new operation into a hospital. Along with economic constraints, they also felt that a lack of experienced supervision by colleagues would prevent successful adoption of an advanced technique into their surgical practice.

This study has a number of limitations that could have had an impact on the results. It has been designed as a retrospective questionnaire based study, therefore provides a subjective opinion of surgical training and barriers to surgical training. Also, the primary outcome of the study is the adoption of an operation following attendance of a masterclass. It does not make an assessment of the quality of the operations performed. It could be improved by assessing the acquisition of technical skills using validated technical skill assessments. It would also be of interest to investigate objective patient outcome measures such as morbidity, mortality, length of stay and re-intervention rates that were associated the adopted operations. These improvements would demonstrate both an improvement in operative technique and more importantly patient outcome. An important limitation to this study is the inability to compare the results with a control. This would give us a more accurate measure of the adoption directly as a result of masterclass attendance. It could be argued that the surgeons that were questioned self-select themselves. It is likely that surgeons who attend a surgical masterclass are more likely to adopt a new technique as they are demonstrating commitment and desire to improving their technical skills and career. A control group would have reduced this limitation. The study could also have been improved if there had been a higher response rate. The response rate for this study was 47.6%, which could have influenced the result. This can be accounted for by the selection of countries that were included in the study. Surveys were sent to surgeons from Spain, Italy and France, with a 0% response rate from these countries. This may be explained by the survey being written in English, which could have created a language barrier preventing a higher response rate. The response rates from
the other countries that sent at least one response was between 60% and 100%, which is more acceptable.

The results of this study can conclude that a three day surgical masterclass is an effective way of teaching surgeons advanced surgical techniques, with a significant increase in the number of surgeons performing the operations after the masterclass than before. The masterclasses are useful for all levels of surgical trainees, and are a realistic way of improving technical skills and learning and perfecting different stages of an operation. The results demonstrate that the surgical masterclass is an important factor for increasing the adoption of advanced operative procedures.

Surgical training is in a period of change. With the reduction in opportunities for developing technical skills and learning how to operate, there needs to a paradigm shift in the way surgeons are trained. Technical skills training must start in the skills laboratory to reduce the inherent risks that are associated with the procedural learning curve. This is true for both junior surgeons learning basic laparoscopic tasks and senior surgeons learning advanced laparoscopic techniques. Therefore, it is important to match the fidelity of the simulator with the experience level of the surgeon. The anaesthetised porcine model is one of the highest fidelity simulator available, as such should be the simulator of choice for a senior trainee.

The effectiveness of surgical masterclasses can be explained by the way in which they are structured. Effective technical skills training should encompass 3 stages: cognition, association and automation (Aggarwal et al., 2007c). It is vital to have a cognitive element to technical skills training, prior to the learning, and perfecting the practical aspects. Although a masterclass traditionally lasts 2-3 days it is unlikely to be as effective in terms of skills acquisition as a long term structured, proficiency based training curriculum. However, it is a useful method of improving surgeons’ technical skills, and could be constructively integrated into local or national surgical training programs.
The introduction of the National Training Programme in Laparoscopic Colorectal Surgery (LAPCO) has recently been developed to increase the level of consultant surgeons performing routine colonic resections using a laparoscopic approach. (M, 2009) The training program provides cognitive and technical skills training to develop proficiency in laparoscopic colorectal surgery. LAPCO already uses a masterclass model using cadaveric simulators. It could be envisaged that national training programs are developed for other surgical subspecialties that focus on advanced surgical training for experienced surgeons wishing to adopt new complex operations. The surgical masterclass could be used within new national training programs to augment skills training delivery for advanced surgery.

Simulation based training has advanced considerably to incorporate teaching and training of complex procedures. Therefore, surgeons can learn advanced surgical procedures on live porcine models, where they can practice procedures, and mistakes are permitted. As innovation in surgery progresses, new operations, techniques and instruments are developed. Therefore, surgical simulation platforms must evolve to allow surgical trainees to use simulation to learn new advanced surgical techniques and procedures. New surgical techniques such as robotic surgery or single incision laparoscopic surgery are considered to be advanced surgical approaches, which require surgeons to have considerable experience. The technical skills required to perform these procedures are thought to be very different to traditional laparoscopic surgery, and it is not clear whether surgeons should undergo specific training in these surgical approaches prior to using them on patients.
6. **Innovations in surgery and the impact on training methods**

6.1 Single Incision Laparoscopic Surgery

Innovation in surgery is an important aspect of ensuring improvement in both quality of healthcare delivery and enhancement in surgical technology (Darzi, 2008, Lewis et al., 2012a). The development of laparoscopic surgery in the early 1990’s has been heralded as one of the most important advances in the surgical speciality, providing patients with the benefits associated from reduced tissue trauma (Velanovich, 2000). Laparoscopic surgery has been demonstrated to be an effective approach to many general surgery operations, and results in smaller wounds, less post-operative pain, shorter length of hospital stay and earlier return to normal function with an improved cosmetic appearance (Reza et al., 2006, McCormack et al., 2005, Kuhry et al., 2008). Single Incision Laparoscopic Surgery (SILS) aims to enhance these effects by allowing access to the abdominal cavity through one single manufactured port placed in the umbilicus (Chow et al., 2010c). It has been widely demonstrated that SILS can be used for appendectomy, cholecystectomy, gastric banding, sleeve gastrectomy and right hemi-colectomy (Chow et al., 2010c, Chow et al., 2010b, Reavis et al., 2008, Oltmann et al., 2009, Bucher et al., 2008).

The technical skills required to perform traditional multi-port laparoscopic surgery are different to those required to perform open surgery (Rosser et al., 1997). When laparoscopic surgery was introduced, patients were at risk at the early stage of the learning curve, as surgeons learned the required technical skills (Hawasli and Lloyd, 1991, Sariego et al., 1993). The introduction of SILS provides surgeons with a similar challenge (Tacchino et al., 2009). The techniques used to perform SILS are different to those that are required to perform traditional laparoscopic surgery (Cox et al., 2011). SILS techniques force the surgeon to pass all instruments through one port, which can make movements awkward and technically
challenging. To overcome this, surgeons can either operate using one instrument, or use specialised instruments that can be articulated and rotated (Chow et al., 2010a). This can increase the challenge by reversing the orientation of the surgeon’s instruments, such that his right hand controls the left instrument and vice versa. Both these techniques are challenging and require considerable practice to be used confidently and safely on a patient. Therefore, it can be suggested that there may be a SILS learning curve similar to that seen at the advent of traditional laparoscopic surgery regardless of the open or laparoscopic experience of the surgeon (Chow et al., 2009, Schlachta et al., 2001).

To overcome the inherent risks associated with the procedural learning curve, the American College of Surgeons developed the Fundamentals of Laparoscopic Surgery (FLS) training curriculum. The FLS is a technical skills training curriculum that allows surgical trainees to learn and develop technical skills in the skills laboratory by completing basic tasks in a box trainer. Each task has a proficiency score that provides a goal for training such that the trainees must repeat tasks until they develop proficiency. The FLS has been validated for improving laparoscopic technical skills and is now mandatory for completion of a surgical residency program (Fried et al., 2004, Ritter and Scott, 2007).

As SILS provides a very different challenge in terms of technical skills that are required, it could be suggested that specific and separate technical skills training programs should be available for surgeons that wish to learn SILS both at a junior level, and at a senior level where an established surgeon aspires to extend their practice. Currently there are no specific technical skills training programs for SILS that are available to all surgeons. As FLS is currently the gold standard for teaching and training laparoscopic surgery, potentially it could be modified to be used as an appropriate training platform to learn SILS.
This chapter aims to investigate the impact that previous laparoscopic surgical experience has on the ability to perform SILS. The secondary aim is to investigate whether current laparoscopic technical skills training curricula can be modified and used to teach SILS by demonstrating construct validity of the modified FLS tasks.

### 6.2 Methods and Materials

This study was performed by recruiting 18 surgeons of varying laparoscopic and SILS experience. Twelve novice surgeons (surgeons that had performed <5 laparoscopic cholecystectomies and <5 SILS cholecystectomies); four intermediate surgeons (surgeons that have performed >25 laparoscopic cholecystectomies but <5 SILS cholecystectomies); and two experienced surgeons (surgeons that have performed >25 laparoscopic cholecystectomies and >25 SILS cholecystectomies).

#### 6.2.1 Technical skills assessment

Surgeons were asked to complete four tasks from the validated Fundamentals of Laparoscopic Surgery (FLS) training curriculum: peg transfer, precision cutting, endoloop and intra-corporeal suture. Extra-corporeal suture was not completed as it is not routinely used at our institution. Each task was explained and demonstrated, but no practise was allowed prior to attempting the tasks. The FLS box was modified to allow placement of a SILS port, and allow tasks to be performed using a SILS approach. All participants were asked to complete tasks using both a traditional multiport laparoscopic (LAP) approach and a SILS approach. Standard graspers and graspers that allow articulation and rotation, scissors, endoloops and needle holders were supplied to the participants. The study was designed using a randomised crossover design, such that half the participants performed the tasks using a
SILS approach first and half the participants’ performed the tasks using a LAP approach first. This was to alleviate any learning effect that could occur by repeating tasks.

6.2.2 Assessment of performance

Participants were assessed for quality of performance and for dexterity whilst performing the tasks. Quality was assessed using FLS performance parameters, measuring time and error scores for each task. Dexterity analysis was performed using the Imperial College Surgical Assessment Device (ICSAD). ICSAD requires motion tracking sensors to be placed on the dorsum of the surgeon’s hands and can accurately measure their dexterity whilst performing a task, giving parameters for hand path length and total number of hand movements. ICSAD has been widely validated as a surgical assessment tool (Hayter et al., 2009).

6.2.3 Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences version 18.0 (SPSS, Chicago, IL). The data analysed was non-parametric. Unpaired data was assessed using the Mann-Whitney U test and paired data with the Wilcoxon signed rank test.

6.3 Results

The novice group performed two tasks (precision cutting and intra-corporeal suture) significantly better using a LAP approach than a SILS approach in all parameters (p<0.05) (figure 21). The two other tasks (peg transfer and endoloop) were performed significantly better with a LAP approach than SILS for time and dexterity only (p<0.05), but not for error score (peg transfer error score, p=0.257), (endoloop error score, p=0.128).

The intermediate group demonstrated no significant difference in performance using a LAP approach or SILS approach for any of the four tasks for time, dexterity analysis or FLS
error score (p>0.05). This was reciprocated by the experienced group, with no significant difference in performance between LAP approach and a SILS approach for any of the tasks in any performance parameters (p>0.05)(figure 22 and 23).
Figure 21 – The difference between SILS and laparoscopic performance for novice on precision cutting (p=0.002)
Figure 22 – The difference between SILS and laparoscopic performance for Intermediate group on precision cutting (p=0.109)
Figure 23 – The difference between SILS and laparoscopic performance for expert group on precision cutting (p=0.18)
To demonstrate construct validity, novice performance is compared to experienced performance. Three of the SILS tasks demonstrated significant differences between novice and experienced surgeons performance (p<0.05). SILS precision cutting demonstrated significant differences for time (median 191.9 - 609.5s, p=0.028), Error score (median 1.5 - 7.5, p=0.027) and path length (median 11.08 - 53.45m, p=0.028), but not for hand movements (p>0.05). SILS peg transfer demonstrated significant differences between novice and experienced surgeons performance for time (median 180.9 - 462.4s, p=0.028) and path length (median 14.96 - 34.99m, p=0.029), but not for error score or hand movements (p>0.05). SILS intra-corporeal suture demonstrated significant differences for time (median 709.9 – 992.1s, p=0.045) and error score (median 0 – 7.5, p=0.035), but not for path length or hand movements (p>0.05). The SILS endoloop did not demonstrate construct validity, with no differences found between the novice and experienced group in any parameter (p>0.05).

Further intergroup analysis demonstrated significant differences in performance between novice and intermediate groups for three SILS tasks. The SILS peg transfer had significant differences for time only (median 280.3 - 462.4s, p=0.029), but not for error score, path length or hand movements (p>0.05). SILS endoloop demonstrated significant difference for time (median 105.2 – 224.1s, p=0.018) and error score (median 0 – 1.5, p=0.018) but not for path length or hand movements (p>0.05). SILS intra-corporeal suture demonstrated significant differences for time only (median 661.5 – 992.1s, p=0.045), but not for error score, path length and hand movements (p>0.05).

There was no significant difference in performance on any SILS task for any parameter between the intermediate group and the experienced group.
Figure 24 – The difference in performance between all groups on peg transfer for time (p=0.017)
Figure 25 – The difference in performance between all groups on precision cutting for time (p=0.067)
Figure 26 – The difference in performance between all groups on endoloop for time

\( p = 0.028 \)
Figure 27 – The difference in performance between all groups on intra-corporeal suture for time (p=0.02)
6.4 Discussion

In this study we conclude that novice laparoscopic surgeons perform basic SILS tasks worse than basic laparoscopic tasks. However, as laparoscopic experience increases, surgeons are able to perform basic SILS tasks to a similar level as they perform basic laparoscopic tasks. This implies that surgeons that are trained and proficient in laparoscopic surgery can perform basic SILS tasks to a similar level as traditional laparoscopic tasks. In addition, they can perform basic SILS tasks to a similar level as an experienced SILS surgeon. This is an important finding as it provides evidence that despite the differences in technical skills that are required for traditional laparoscopic surgery and SILS, the skills that are developed to perform competent laparoscopic surgery provide surgeons with the skills necessary to perform SILS.

The secondary aim of this study was to analyse whether current laparoscopic training curricula may be used to learn SILS. Before a simulator can be used for teaching and training, it must be validated. Construct validity is an important form of validity, demonstrating that a simulator can distinguish between novice and experienced surgeons performances. This allows proficiency criteria to be set, allowing novice surgeons to practice tasks until they can perform them to the level of an experienced surgeon. This study demonstrates that construct validity has been established in three of the SILS FLS tasks (peg transfer, endoloop and intracorporeal suture), with significant differences demonstrated between novice and experienced performances on the tasks. This implies that with modification to the FLS box to allow entry of the SILS port, the FLS tasks are valid for SILS training. However, it must be mentioned that this would only be appropriate for inexperienced laparoscopic surgeons, as it is clearly shown that the benefit to experienced laparoscopic surgeons is minimal.
Previous research in this field demonstrates conflicting results to the ones demonstrated in this chapter. Santos et al performed a similar study to assess the impact that previous laparoscopic experience has on the ability to perform SILS. (Santos et al., 2011) The authors used medical students, surgical residents and attending surgeons, and analysed laparoscopic performance followed by SILS performance on the FLS tasks. The authors demonstrated significant differences between SILS and laparoscopic performance on all tasks. The conclusions of Santos et al differ from those provided in this chapter. (Santos et al., 2011) This may be explained by the difference in participant selection, with this chapter only analysing qualified doctors rather than medical students. In addition, Santos et al only analysed total FLS score, whereas this study also analysed the dexterity that is required to perform the tasks, this could also explain the discrepancy in findings.

The results of this study could suggest that the development of a dedicated SILS training program is pointless, as laparoscopic surgical training using current methods will provide the technical skills that are required to perform SILS. However, surgical trainees have already had a reduction in training opportunities that are available to them due to the reduction in working hours. Therefore, as the number of SILS cases increase, by limiting SILS procedures to experienced laparoscopic surgeons, it will further decrease the number of potential training opportunities that are available to surgical trainees. This study demonstrates that novice surgeons can perform basic tasks better using a laparoscopic approach compared to a SILS approach. However, as there is no difference in laparoscopic and SILS performance for the intermediate group, it can be suggested that training in laparoscopic surgery should give the necessary dexterity to perform basic SILS tasks. As basic operations are increasingly performed using a SILS approach by experienced surgeons it is important to develop dedicated SILS training curricula to allow enhancement of SILS technical skills in the skills.
laboratory prior to entering the operating room. This would increase the number of training opportunities available to junior trainees.

Despite the positive finding in this study, there are a number of limitations that should be discussed. The study clearly demonstrates construct validity of three of the FLS tasks. However, this is based on an experienced group of two surgeons, which is very small. At the time of the data collection for the study, there were only two experienced SILS surgeons available at our institution. It would have been beneficial to have more surgeons, and potentially have equal numbers of surgeons in each group. This could have increased the significance of the findings. Another limitation of this study is the selection of tasks. One of the aims was to establish construct validity of the FLS training tasks. However, the disadvantage of using the FLS tasks is that they are only basic laparoscopic tasks, and may not provide enough of a challenge to experienced laparoscopic surgeons. Although the intermediate group (experienced laparoscopic, inexperienced SILS surgeons) performed laparoscopic tasks and SILS tasks to a similar level, it could be suggested that by increasing the complexity of the task, it would begin to demonstrate differences between laparoscopic and SILS performances. In addition, the FLS tasks are not as challenging as performing a SILS cholecystectomy or appendectomy. Therefore, although this study concludes that experienced laparoscopic surgeons can perform laparoscopic and SILS tasks to a similar level, it does not imply that they can perform a laparoscopic cholecystectomy to a similar level as a SILS cholecystectomy.

Another limitation of this study is the validation process of the tasks. Although the study establishes construct validity, it does not attempt to establish any other forms of validity. Content validity is an important form of validation, which is established by experts and assesses the appropriateness of a simulator as a teaching modality. The FLS was
designed for traditional laparoscopic surgery, and it may be that the individual tasks are not appropriate for SILS. For example, intra-corporeal suture may not be performed in a SILS manner, as specific suturing instruments may be used instead. Another limitation is that this study only analysed one attempt at the tasks. Therefore, it only assesses the ability to perform SILS, with no inference about learning potential. It would be useful to analyse learning curves for the tasks, assessing how long and how often trainees should perform the tasks to reach the level of an experienced surgeon.

SILS is a new and innovative advancement in the provision of general surgery. SILS is challenging, and there are many differences between the technical skills required to perform traditional laparoscopic surgery and SILS. Although experienced laparoscopic surgeons have the manual dexterity to perform basic SILS tasks to a similar level as laparoscopic tasks, this is not the case for novice surgeons. Inexperienced surgeons did not have the dexterity to perform SILS tasks to a similar level as laparoscopic tasks, with more error. Simulation is routinely used for traditional laparoscopic surgical training, to enhance skills in the skills laboratory and make junior surgeons safer when they enter the operating room. This should be reciprocated for SILS training to improve dexterity and minimise errors. Therefore, if junior surgeons wish to take part in SILS operations, as the primary or assistant surgeon, it should be compulsory to complete some form of basic SILS training.

In addition, this study demonstrates that three of the FLS tasks have construct validity and could be used for teaching and training. However, more work needs to be done to identify what are the key, important techniques that are required to perform SILS operations, and how they can be incorporated into a specific training curriculum. Additional future work should also focus on the impact on SILS performance by experienced laparoscopic surgeons when the complexity of task is increased and the subsequent learning curve in the operating room.
7. **The effectiveness of VR simulation for advanced surgical training**

7.1 Simulation for advanced techniques

The previous chapters have investigated the use of simulation for teaching new innovations such as single incision laparoscopic surgery, and for teaching advanced techniques such as laparoscopic bariatric surgery. As discussed, to use simulation for single incision surgery, current laparoscopic training modalities require considerable modification and further validation studies prior to use. Advanced techniques such as laparoscopic bariatric surgery require expensive simulation modalities, such as live porcine simulation, which requires dedicated facilities and has a number of ethical concerns also. In addition, live porcine simulation is not permitted in the United Kingdom.

It would be useful to establish alternative forms of simulation for teaching advanced operations. Virtual reality (VR) simulation has been demonstrated as an effective form of simulation for teaching and training basic surgical techniques and procedures, but it has not been established as a method for teaching advanced techniques such as laparoscopic Roux-en-Y gastric bypass (LRYGB). This chapter aims to validate VR simulation for the teaching advanced surgical techniques (Lewis et al., 2012b).

7.2 The role of obesity surgery

There has been an explosion in the worldwide incidence of obesity over the past two decades (Yanovski and Yanovski, 2002) It is estimated that there will be 700 million people who are defined as obese (body mass index (BMI) greater than 30) by 2015 (National Task Force for Obesity, 2000). The failure of conservative approaches to manage morbid obesity, such as dietary programmes and pharmacological interventions, has led to advances in weight loss or bariatric surgery. It is now standard practice to consider weight loss surgery, to avoid
or reverse the significant co-morbidities that are associated with morbid obesity (Buchwald and Williams, 2004, Colquitt et al., 2003). The most common bariatric surgical procedures undertaken are LRYGB and laparoscopic adjustable gastric banding (LAGB) (Tice et al., 2008). LRYGB is the commonest bariatric surgery performed in the USA and is now considered the standard procedure for bariatric surgery. However, despite an increase in LRYGB in the UK in the past five years, LAGB is still more frequently performed (Tice et al., 2008, Buchwald and Williams, 2004, Santry et al., 2005, Burns et al., 2010). One of the reasons for this is that LRYGB is a highly challenging operation that demands extensive experience before attempting. This is due to the complexity of both the operative procedure, and the technical skills that are needed to complete the operation. LRYGB requires the surgeon to work in more than one abdominal quadrant and perform complicated tasks including Roux limb formation, complex anastomosis and gastric pouch formation (Suter et al., 2010). The surgeon also needs to develop advanced skills for manipulation of bowel, laparoscopic suturing and master the use of complex equipment including laparoscopic staplers, high energy devices (Higa et al., 2000). The learning curve associated with has been quoted as 75-100 cases (Schauer et al., 2003, Higa et al., 2000). During this time, there is a significant increase in complication rate and need for converting to an open procedure, compared to an experienced bariatric surgeon (Schauer et al., 2003, Oliak et al., 2003, Aggarwal et al., 2007a). It would be beneficial to the patient if the early part of the learning curve, where the most mistakes are made, could be transferred to the skills laboratory.

The traditional way of training surgeons to perform LRYGB has been the apprenticeship model, where a surgeon practises the procedure on real patients under supervision (Aggarwal and Darzi, 2006). The surgeon can develop their skills through patient exposure and experience, learning from their mistakes. However, this method is no longer tenable, as it
takes a long time, is expensive, and can result in significant complications of morbidity and mortality, which do not benefit the patient (Moorthy et al., 2003). As opportunities for training through patient contact are decreasing, more importance is being placed on bench top and virtual reality (VR) simulation to develop skills (Satava, 1999, Aggarwal et al., 2006b). Simulation can improve basic laparoscopic skills and reduce the learning curve when a trainee enters the operating room. However, it is not clear whether this can be translated to teach advanced surgery, where a senior surgeon who has basic laparoscopic skills would like to develop competence in advanced laparoscopic procedures such as LRYGB. Usually, the surgeon would attend a technical skills course learning and developing skills on cadaveric tissue. However, this has a number of limitations, including a lack of realism or bleeding tissue. An enhancement in training can be sought by attending an industry sponsored surgical masterclass, where the full length operation can be performed on live anaesthetised porcine models, allowing the surgeon to learn from their mistakes (Lewis et al., 2011d). However, access to these masterclasses can be difficult, as they are dependent on industry invitation, and due to legal issues in the United Kingdom, it requires travel to Europe to attend.

Currently, VR simulation is limited to training junior surgical trainees’ basic laparoscopic skills, or basic procedures such as laparoscopic cholecystectomy. It is not currently used for teaching advanced surgery. As simulator technology has advanced, some VR simulators now have the processing power and intricacy to contain modules for full length intermediate and advanced laparoscopic procedures such as laparoscopic ventral hernia repair, laparoscopic colectomy and LRYGB. To establish whether VR simulation can be used for advanced surgical training and assessment, it is important to demonstrate the validity of an individual simulator. Important validities to demonstrate are face, content, construct and concurrent validity.
This study aims to investigate whether VR simulation is appropriate to be used to teach experienced surgeons advanced surgical techniques for bariatric surgery by demonstrating the validity of the simulator.

7.3 Methods and Materials

Twenty surgeons were recruited during a technical skills training course at Imperial College NHS trust. The participants were divided into expert, intermediate and novice groups depending on their previous laparoscopic surgical experience. Novice laparoscopic surgeons were defined by performing less than 75 basic laparoscopic procedures (laparoscopic cholecystectomy/appendectomy). Intermediate surgeons were defined by performing more than 75 basic laparoscopic procedures and more than 50 intermediate laparoscopic procedures (laparoscopic ventral hernia repair, Nissens Fundoplication). Expert surgeons had performed more than 100 advanced laparoscopic procedures (LRYGB). Novice and Intermediate surgeons were asked to perform a laparoscopic jejuno-jejunostomy on both cadaveric tissue and a VR simulator.

7.3.1 VR simulated jejuno-jejunostomy (VRJJ)

All participants were asked to perform a VRJJ using the LRYGP module of the Lapmentor VR simulator (Simbionix, Chicago, IL, USA). The module requires the surgeon to choose their preferred position of bowel, complete the enterotomy using an energy device, position and engage a stapling device and review the results. The module does not require a laparoscopic stay suture, or closure of the enterotomy. Each participant’s performance was recorded using a video camera.
**7.3.2 Cadaveric porcine jejuno-jejunostomy (CPJJ)**

Novice and Intermediate surgeons were asked to perform a laparoscopic jejuno-jejunostomy on cadaveric porcine tissue in a standard box trainer and laparoscopic stack. The CPJJ model was used in accordance with a previous study demonstrating the construct validity of the CPJJ model as an assessment tool (Aggarwal et al., 2007a). A 50cm section of cadaveric porcine small bowel was filled with thickened fluid (Thick and Easy, Hormel Foods, Austin, MN, USA) and tied at both ends using 3-0 vicryl hand suture material. The fluid filled bowel was pinned to a generic cork board and placed in a U-position inside the box trainer. The CPJJ was performed by placing a laparoscopic intracorporeal stay suture, followed by enterotomies in each limb of bowel with a harmonic scalpel. A linear stapler was fired between the two sections of bowel and the procedure was completed by closing the enterostomy with a running laparoscopic suture.

**7.3.3 Assessment of performance**

Videos of both the CPJJ and the VRJJ were assessed post hoc by a blinded expert assessors with extensive experience of video rating scales. Each performance was assessed using validated Objective Structured Assessment Tools (OSATS) global rating scales (GRS) for assessment of general laparoscopic skill, and modified OSATS procedure specific rating scale (PSRS) for assessment of the laparoscopic jejuno-jejunostomy (Martin et al., 1997, Aggarwal et al., 2007a). All surgeons completed a post-test questionnaire focusing on the realism and appropriateness of different simulation modalities for technical skills training. These were measured on a seven point Likert scale.
7.3.4 Statistical analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences version 18.0 (SPSS, Chicago, IL). The data under analysis is non-parametric, non-paired data and was analysed with the Mann Whitney U test. Correlation analysis between performances was assessed with Spearman rank correlation. All p-values less than 0.05 were considered significant.

7.4 Results

Twenty surgeons of varying experience were recruited, 10 novice, 5 intermediate and 5 expert laparoscopic surgeons.

Construct validity was established by demonstrating a significant difference in performance of jejuno-jejunostomy on the VR simulator between the novice and the expert groups. This was demonstrated for both GRS (median 11-15.5; p=0.017) and PSRS (median -11-13; p=0.003). This was reciprocated between intermediate and expert surgeons, with significant difference in performance for GRS (median 12-15; p=0.017) and PSRS (median 11-13; p=0.017). There was no significant difference between novice and intermediate performances for GRS (median 11-11; p=0.702) or PSRS (median 11-12; p=0.752).

Content validity of the VR simulator was also established using a validated method of assessment, with surgeons describing the bariatric module as very useful for training (mean Likert score 4.45/7) and would highly recommend its use by surgical trainees (mean Likert score 5/7).

Concurrent validity for the VR simulator was not established with no correlation found between surgeons performance on the VRJJ with the CPJJ. This was for both GRS (correlation coefficient 0.002, p=0.995) and PSRS (correlation coefficient 0.054, p=0.85).
Face validity was also not established, with its realism described as average (mean Likert score 3.7/7).

7.5 Discussion

The challenges faced by junior trainees trying to learn and develop laparoscopic technical skills are reciprocated for senior surgeons who have not had enough exposure to laparoscopic techniques. Simulation and in particular VR simulation has been heralded as potential adjunct to training for junior surgeons wishing to learn basic laparoscopic procedures (Peters et al., 2004b, Spiteri et al., 2010). However, it is yet to be embraced for advanced surgical training. One of the reasons for this is the previous lack of evidence that demonstrates the validity of VR simulation as a training modality for advanced surgical training. It is vital for this to be established, before VR simulation could be recommended for training surgeons complex procedures. This could be for both junior surgical trainees pursuing a career in bariatric surgery or senior surgeons who wish to expand their current practice to include laparoscopic bariatric procedures.

This chapter establishes construct validity of the VR jejuno-jejunostomy module with significant difference in performance demonstrated between the novice and the expert groups. Content validity was also established with the surgeons recommending that the VR bariatric module had appropriate content for advanced surgical training and was useful for training technical skills. This implies that the VR simulation could be used for advanced surgical training for laparoscopic bariatric surgery.

Concurrent validity and face validity were not established. Despite this, it can still be recommended for training as construct validity was established. However, it is not
recommended for assessment of technical skills as it does not demonstrate concurrent validity.

For a simulator to be used for surgical training, the most important validity to establish is construct validity. This is a vital quality for a simulator to have as it allows a trainee to demonstrate improvement in performance along a learning curve, towards the level of an expert. In addition to construct validity, there were significant differences between intermediate and expert performance, but no significant difference between novice and intermediate performance. This suggests that the level of the VR bariatric module is set at a sufficient difficulty and complexity, such that surgeons with a reasonable amount of laparoscopic experience are still able to demonstrate improvement along a learning curve. Therefore it is appropriate for advanced surgical training. The results from this chapter recommend that VR simulation could be used to train a surgeon, but to assess advanced laparoscopic skills the cadaveric porcine model should be used.

Traditional surgical training through the apprenticeship model is no longer a viable method for training surgeons alone. Surgical training at a junior level has already adapted and has embraced simulation to enhance skills outside of the operating room. This is particularly obvious in the United States, where it is now mandatory for surgical residents to complete the Fundamentals of Laparoscopic Surgery (FLS) training curriculum prior to completing their residency program. (Peters et al., 2004b) However, this needs to be reciprocated at a senior level, with an enhancement in the acceptance and use of simulation. Currently there are limited options for senior surgeons who wish to expand their practice to included advanced laparoscopic techniques such as LRYGBP or laparoscopic colorectal procedures. (Wilson, 2006) The traditional method would be to ask an experienced colleague to act as a mentor to teach the skills and supervise the learning curve. However, this option is not always
available, and colleagues may be unwilling or unavailable to help in this manner. Other options would be to attend cadaveric tissue courses or surgical masterclasses utilising live anesthetised porcine models, to gain the technical skills that are required to be able to independently practice complex laparoscopic operations (Lewis et al., 2011d). This may not always be possible, and can be very expensive. In the United Kingdom, this issue is being addressed for colorectal surgery by the National Training Programme in Laparoscopic Colorectal Surgery (LAPCO). LAPCO provides a cognitive and technical skills training curricula followed by mentorship and validated assessments prior to be accredited for laparoscopic colorectal procedures (Miskovic et al., 2011). However, a similar training curriculum is not available for advanced laparoscopic bariatric surgery, so alternative methods of training are being sort.

This study provides the first evidence that VR simulation is a valid and appropriate training modality for advanced laparoscopic training such as laparoscopic bariatric surgery.
8. **The development and assessment of the training value of surgical simulators**

**8.1 Aims**

The primary aim of this chapter is to define the “training value” of surgical simulation. This will be performed by comparing the effectiveness of different evidence based training curricula for the acquisition of laparoscopic skills and their ability to transfer skills to the simulated operating room (OR). The second aim was to assess differences between the rate of learning in the OR due to these skills curricula, and third to develop a new tool for assessing the effectiveness of a simulator’s ability to enhance OR performance called the training value. This allows the recommendation of a simulated training curriculum to junior trainees that require the most efficient adjuncts to their formal training programs.

**8.2 The importance of defining training value**

Surgical trainees have a finite amount of time in which they are able to develop the technical skills required to be a safe and competent surgeon. As training opportunities in the operating room are reduced, it is more important to make the most of each opportunity when it arises. It is beneficial to both the patient and the trainee to transfer learning of technical skills to the skills laboratory. Technical skills, manual dexterity and basic procedures can be taught on simulators, such that when the trainee enters the operating room, they already have a basic level of proficiency, so instead of learning how to manipulate a laparoscopic instrument, they can learn other skills such as decision making and operative planning.

Bench top and virtual reality (VR) simulators have been validated in this thesis and the literature for their use for technical skills training (Kneebone and ApSimon, 2001). However, it is not clear which are the most effective simulators at teaching technical skills. As previously mentioned, the working hour restriction limits the time a doctor can spend in
hospital, so efficient forms of training are required to obtain the required technical skills to be an independent practitioner. Although simulation can be used outside of working hours, it is still important to identify which simulator improves performance in the operating room the most, and which simulator subsequently increases the rate of learning when training is transferred to the operating room.

It is therefore important to be able to ascertain the value of different types of simulation in terms of their effectiveness for developing technical skills. This would allow a trainee to choose which training modality they should use to be able to train as efficiently as possible in the time that they have left. It would also allow deaneries and training bodies to identify which simulators should be supported and purchased for their trainees.

8.3 Materials and Methods

24 subjects were recruited that had observed a maximum of five laparoscopic cholecystectomies (LC) with no laparoscopic experience, either as primary surgeon or as an assistant and randomised to three equal groups using a closed envelope method. Subjects were randomised to a task based VR simulation group, a procedure based VR simulation group or a box trainer group. All subjects underwent cognitive training by watching a video consisting of instructions for basic laparoscopic skills and an introduction to laparoscopic instruments. This was followed by a video of a VR simulated laparoscopic cholecystectomy, and a video of a real life laparoscopic cholecystectomy both performed by an experienced surgeon (>100 LC). Cognitive training was followed by technical skills training.
8.3.1 Technical skills training

8.3.1.1 Task based VR group

Subjects underwent formal technical skills training on the Minimally Invasive Surgery Trainer-Virtual Reality (MIST-VR) (Mentice, Gothenburg, Sweden) simulator using a previously validated proficiency based training curriculum (Aggarwal et al., 2006a). The subjects were required to perform 12 abstract psychomotor tasks in a step-wise manner. Completion of training was established on repeating the two most difficult tasks until they reach expert-derived performance scores. This validated training curriculum is discussed in more detail in chapter 4.

8.3.1.2 Procedure based VR group

Subjects completed a validated training curriculum for the LAP Mentor surgery simulator (Simbionix, Chicago, USA) (Aggarwal, 2009). This curriculum requires subjects to perform 9 abstract tasks, 4 procedural tasks and 1 full length procedure on the VR simulator. Progression to the next stage is only permitted when proficiency criteria are reached for each task. Completion of the curriculum occurs when the subject performs a full length VR LC within the expert derived proficiency parameters. This validated training curriculum is discussed in more detail in chapter 4.

8.3.1.3 Box trainer group

Subjects underwent technical skills training using a standard box trainer. They completed two tasks from the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills (MISTELS) program, peg transfer and pattern cutting. These tasks have been validated as a training and assessment tools and now form the basis of the Fundamentals of Laparoscopic Surgery (FLS) training curriculum (Vassiliou et al., 2006). Peg transfer uses a
standard peg board and requires the trainee to grasp six pegs, transfer the peg in mid-air to the non-dominant hand and place back on the pegboard. Errors are scored if pegs are dropped. The process is then reversed. Pattern cutting requires the subject to cut a circular shape out from a piece of surgical gauze. Errors are recorded for deviating from the marked line. Both tasks were completed to pre-defined proficiency scores. The FLS tasks three to five, the endoloop, intra-corporeal and extra-corporeal suturing were not used, as they were deemed too difficult for naive laparoscopic surgeons to perform in the time period of the study.

8.3.2 Cadaveric porcine laparoscopic cholecystectomy assessment

On completion of technical skills training, all groups performed five cadaveric porcine laparoscopic cholecystectomies (CPLC) in a simulated OR. Porcine gallbladders attached to livers were placed in the anatomical position into a box-trainer and the LC was performed as a standard case with a 4-port technique. The procedures were completed in a distributed manner with at least one hour’s break between attempts. Subjects were provided with standard straight-toothed grasping forceps, clip applicator, curved scissors and diathermy. Performance of the CPLC was assessed using a motion tracking device for surgical dexterity called the Imperial College Surgical Assessment Device (ICSAD). ICSAD can be used to measure the subjects hand movements, path length and time whilst they perform an operation. It has been widely validated as a surgical assessment tool. Measurement of dexterity commenced from the initial entry of the endoscope into the box-trainer until the complete detachment of the gallbladder from the liver bed.
Figure 28 - Methods for the assessment of the training value of each simulator

22 Subjects

Randomised
- Box trainer
- Task based VR
- Procedure based VR

Technical skills training
- FLS tasks
- MIST VR curriculum
- Lapmentor curriculum

Technical skills assessment in simulated OR
- 5 CPLC
- 5 CPLC
- 5 CPLC

Assessment of performance with ICSAD

Defining the ‘Training Value’
8.3.3 Proficiency level

Proficiency on the cadaveric porcine model was determined using experienced surgeons performance. Three experienced surgeons were asked to perform two consecutive cadaveric porcine laparoscopic cholecystectomies using the same methods as this chapter. ICSAD was used to measure the path length, hand movements and time taken to complete the procedure. The median scores for each parameter were used on the second attempt. These were deemed as the benchmark for proficiency for the chapter and equated to 765 seconds for time, 506 total number of hand movements and 73.0m total path length (Aggarwal et al., 2007d).

8.3.4 Statistical analysis

Statistical analysis of the performance of the five CPLCs were conducted using the Statistical Package for the Social Sciences version 17.0 (SPSS, Chicago, IL). The data under analysis was paired & non-parametric and was assessed using the Wilcoxin signed rank test. Analysis was based on total time taken, path length and number of movements. All p-values less than 0.05 were considered significant.

8.3.5 Defining value of training

Technical skills assessment took place in a simulated OR, with participants completing five CPLCs assessed using ICSAD. This allowed participants to develop a learning curve over the five CPLCs, with the aim to reach the proficiency level as set by the experienced surgeons. To make these targets more relevant as a training model, the expert scores were defined as 100%, with each performance by the subject given a percentage of the expert surgeons score. As the parameter scores that were used would decrease as the subjects improved (i.e. Time would reduce, hand movements would become fewer and path length would reduce as performance improved), to be able to define the score as a percentage of the
expert, all scores were inverted ($x^{-1}$). This would mean the worse the performance, the lower the score, but still retaining the relationship between expert and novice performance. The subjects score can then be defined as a percentage of proficiency for each dexterity parameter. This would allow performance to monitored along the learning curve, with the rate of improvement in the OR calculated from the first to the fifth CPLC. This allows the development of a new tool for assessing how well different simulation modalities enhance your OR performance in the early stages of the operative learning curve. This will be termed the “training value”. The training value is defined by analysing the change in percentage of proficiency from the first to the fifth CPLC for each parameter, and taking the mean change in percentage to give an overall training value for a simulator. The training value allows an objective assessment of improvement in combined dexterity parameters along the learning curve. Each parameter has been converted to percentages to allow them to be combined in a training quotient.

$$\text{Training value} = \frac{[\Delta\text{(PP of time)} + \Delta\text{(PP of HM)} + \Delta\text{(PP of PL)}]}{3}$$

PP – Percentage of proficiency
HM – Hand movements
PL – Path length

8.4 Results

8.4.1 Training

Twenty four subjects were recruited, with twenty two who took part in the study. Two subjects were unable to complete the study due to financial and time constraints. Eight participants completed the task based VR group with a median of 13.6 hours to complete the curriculum (range 4.6 – 17.7). Seven subjects completed the procedure based VR curriculum
with a median of 14.4 hours (range 6.3-21.5) Seven participants completed the box trainer group with a median of 8.1 hours for basic training (range 6.5-12.9).

8.4.2 Learning curve analysis

The box trainer group performed five CPLC in a distributed manner. The box trainer group did not achieve improvements in performance from first to fifth CPLC for time (median 1796.7s to 1721.8, p=0.176) hand movements (median 1845 to 1832, p=0.866) or for path length (median 269.3m to 279.2m, p=0.612) (Figure 28) These scores were inverted (x^{-1}) and converted to a percentage of the expert derived proficiency parameters (Figure 30). This demonstrated changes from 42.59% to 44.43% of proficiency in time taken, from 27.43% to 27.62% for hand movements and 27.10% to 26.15% in path length, which equates to a mean training value of 0.36% (Figure 31). This means that the combined improvement along the learning curve for all dexterity parameter equates to 0.36%.
Figure 29 - ICSAD dexterity parameters for performance on CPLC1 and CPLC5

<table>
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<tr>
<th></th>
<th>Time taken (seconds)</th>
<th>p-value</th>
<th>Hand movements</th>
<th>Hand movements p-value</th>
<th>Path length (metres)</th>
<th>Path length p-value</th>
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<td>p=0.176</td>
<td>1845</td>
<td>p=0.866</td>
<td>269.3</td>
<td>p=0.612</td>
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<tr>
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<td></td>
<td>1832</td>
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<tr>
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<td>1501</td>
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<td>169.02</td>
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<tr>
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<td></td>
<td>1786</td>
<td></td>
<td>270.43</td>
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Figure 30 - Proficiency percentage of experts for CPLC and novices for CPLC1 and CPLC 5

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<th>Path length</th>
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<td>MIST LC 1</td>
<td>35.09%</td>
<td>21.38%</td>
<td>35.43%</td>
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<td>MIST LC 5</td>
<td>58.67%</td>
<td>33.71%</td>
<td>43.19%</td>
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<tr>
<td>Lapmentor LC 1</td>
<td>42.95%</td>
<td>24.90%</td>
<td>25.95%</td>
</tr>
<tr>
<td>Lapmentor LC 5</td>
<td>63.81%</td>
<td>28.33%</td>
<td>26.99%</td>
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</table>
Figure 31 – The training value of each VR simulator

<table>
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<th>Simulation modality</th>
<th>Parameter</th>
<th>Percentage of proficiency</th>
<th>Change in percentage proficiency</th>
<th>Training value</th>
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<td></td>
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<td>CPLC1</td>
<td>CPLC5</td>
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<td>Time</td>
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<td>44.43%</td>
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<tr>
<td></td>
<td>PL</td>
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<td>26.15%</td>
<td>-0.95%</td>
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<tr>
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<td>33.71%</td>
<td>12.33%</td>
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<tr>
<td></td>
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<td>28.33%</td>
<td>3.43%</td>
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<td></td>
<td>PL</td>
<td>25.95%</td>
<td>26.99%</td>
<td>1.04%</td>
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</table>
The MIST-VR group performed five CPLC, and demonstrated significant improvements in performance from first to fifth CPLC for time (median 2180.2s to 1303.9s, \(p=0.025\)) and hand movements (median 2367 to 1501, \(p=0.050\)), although not for path length (median 206.05m to 169.02m, \(p=0.263\)) (Figure 31). These scores were inverted \((x^{-1})\) and converted to a percentage of the expert derived proficiency parameters. This demonstrated an improvement from 35.09% of proficiency to 58.67% of proficiency in time taken; an increase from 21.38% to 33.71% of proficiency in hand movements with an increase in proficiency percentage from 35.43% to 43.19% in path length. This equates to a mean training value of 14.56% for the MIST-VR group (Figure 30). This means that the combined improvement along the learning curve for all dexterity parameter equates to 14.56%.

The Lapmentor group demonstrated significant improvements in performance from first to fifth CPLC for time (median 1781.0s to 1198.8s, \(p=0.043\)) and hand movements (median 2032 to 1786, \(p=0.028\)) though not for path length (median 281.34m to 270.43m, \(p=0.128\)) (Figure 28). These scores were inverted \((x^{-1})\) and converted to a percentage of the expert derived proficiency parameters. This demonstrated an improvement from 42.95% of proficiency to 63.81% of proficiency in time taken; an increase from 24.9% to 28.33% of proficiency in hand movements with an increase in proficiency percentage from 25.95% to 26.99% in path length. This equates to a mean training value of 8.44% for the box trainer group (Figure 30). This means that the combined improvement along the learning curve for all dexterity parameter equates to 8.44%.
8.5 Discussion

Innovations in surgical training have led to the development of VR as a valid training adjunct, especially for minimally invasive surgery. The results of this study demonstrate that if used correctly, simulation can enhance performance in the OR. By calculating the training value of each simulator, it is clear that simulation is beneficial, with all three groups demonstrating improvement in performance proficiency. However, both VR groups improved their performance on the CPLC to a greater extent than the box trainer group. This study has demonstrated that there was a 14.56% improvement in performance proficiency for the task based VR simulator and 8.44% increase for the procedure based VR simulator with only a 0.36% improvement for the box trainer. One can conclude that the task based VR and procedure based VR simulators are 45 times and 30 times more efficient respectively than the box trainer in terms of technical skill gained. However, it is important to state that this rate of improvement in OR technical skills performance is only likely to occur at the start of the learning curve. This study assessed surgeons performing their first five CPLC. This would be the steepest part of their learning curve, and therefore the greatest rate of improvement in performance. If the surgeons first 20 CPLCs were studied, the rate of improvement would be different.

This study demonstrates that simulation can improve technical skills and operative performance on real tissue, with both VR groups improving performance to a greater extent than the box trainer group. However, it is apparent that simulation must be used correctly to ensure that surgeons train efficiently and gain the optimal benefit of simulation. Both VR groups completed validated proficiency based training curricula that allowed structured training with learning in a step wise manner. Progress was only permitted once proficiency levels were achieved. Although the MISTELS tasks are validated technical skills tasks, this
study further enhances the evidence that step wise and proficiency based training curricula can improve a surgeon’s technical skill development and performance on real tissue.

What is not clear from this study is whether this will be enough? It is not possible to train solely in VR simulation and translate that to being completely proficient in the OR at a certain operation. However, if properly trained in the VR lab, a surgeon can enter the OR with basic laparoscopic skills which will make them more effective than if they hadn’t trained previously. This allows them to use the OR to learn more complex manoeuvres or the intricacies of the operation rather than learning how to hold an instrument or overcoming the fulcrum effect. By the end of an operation, they would have progressed further along the learning curve than if they had not been previously trained in VR. This is the most important training factor of simulation.

In the United Kingdom, it requires more encouragement from senior surgeons and training boards for trainees to use simulation to improve their technical skills. It is clear that simulation is effective, and can improve patient safety, so it could be foreseen that completing simulation curricula for laparoscopic surgery becomes compulsory at a junior level before they enter the OR. This already occurs to some extent in the United States of America, where surgical residents must complete a laparoscopic training programme called the Fundamentals of Laparoscopic Surgery prior to completing their surgical residency. If it were made compulsory for surgeons to complete a technical skills program prior to entering the OR, it could improve patient safety and improve the efficiency of surgical training, which in turn could begin to reduce the deficit in training hours that we currently face.
9. The cost of training in the operating room – A systematic review

9.1 Aims

The previous chapters have analysed the effectiveness and efficiency of various simulation modalities in terms of improving technical skills. Despite this, one of the main criticisms of simulation based training is the substantial cost for setting up skills centres. However, training in the operating room in itself has significant financial costs. This chapter aims to systematically review the literature to analyse the costs of training practical procedures in the operating room and procedure suite.

9.2 Introduction

A global economic downturn has resulted in governments around the world cutting costs and reducing funding to many departments and public sectors (Simms, 2009). In the UK, healthcare is seen as one of the most important sectors, and its financing has been ring-fenced to prevent detrimental effects on patient care (Pollock et al., 2011). Despite this, hospital trusts and health care authorities are under pressure to reduce waste and ensure hospital departments are run with efficiency in mind, without detriment to the quality of service provided. This is especially true in the practical specialities such as surgery, anaesthetics and gastroenterology, where operating room or procedure room efficiency is vital (Cima et al., 2011). Inefficiency in patient turnover results in cancelled patients and significant costs to a hospital trust (Overdyk et al., 1998). One of the areas of practical specialities that may be seen as inefficient is the time taken during a procedure for teaching or training. A fully trained, board certified surgeon, anaesthetist or endoscopist is likely to perform a procedure quicker and more effectively than an unsupervised trainee. In addition, the supervision of a junior trainee, with the consultant allowing them to perform all or part of the procedure is
likely to take even longer (Bridges and Diamond, 1999). Furthermore, cases that traditionally were seen as training operations, such as elective hernia repair, are routinely place on staff surgeon lists, or waiting list initiatives which trainees often do not have access to (Bagley, 1996). Specific training lists are seen as expensive and inefficient, however, the benefits of the training list is that they can be the most effective method for teaching trainees how to perform procedures (Feldman and Nasmyth, 2005). As costs are cut, and departments are under pressure to improve efficiency, there is a possibility that training time could be identified as “luxury”, and that it should be limited. However, additional reductions in training time or opportunities will further decrease the levels of competence of clinicians on completion of their training, which will result in a generation of consultants that are not proficient.

9.3 Methods and Materials

9.3.1 Inclusion criteria

Randomised Controlled Trials (RCT) in the English language were selected that investigated the costs of teaching or training practical procedures to junior surgeons in the operating room and procedure suite. Studies were included that directly analysed the costs of a trainee or junior surgeon with a fully trained, board certified surgeon or clinician. Included studies had to contain outcome data including costs in terms of: money, time and patient outcome (specific procedure results, complications, length of stay and time in the intensive care unit).

9.3.2 Search Strategy

Two investigators, TL and IH, independently searched the databases of Pubmed (MEDLINE), Embase, Web of Knowledge, Cochrane libraries and Google scholar with the
MeSH terms: ("Costs and Cost Analysis" OR "Cost-Benefit Analysis" OR "Efficiency" OR "Transfer (Psychology)") AND ("Education" OR "Education, Medical") AND ("General Surgery" OR "Surgical Procedures, Operative" OR "Motor Skills"). The databases were accessed on the 31<sup>st</sup> May 2011. Individual journals (American Journal of Surgery, Annals of Surgery, Archives of Surgery, British Journal of Hospital Medicine, British Journal of Surgery, Journal of Gastrointestinal Surgery, Journal of the American College of Surgeons, Surgery, Surgical Endoscopy, World Journal of Surgery) were searched for relevant studies not yet in print. References of the identified trials were also searched to identify further relevant trials. The two authors independently reviewed the literature for inclusion and exclusion criteria, extracted the data for author, year of publication, speciality, procedure assessed, cost outcome data, results and study quality.

Any discrepancies between the two investigators were accessed in full and reviewed together, with a consensus decision made and agreed by both.

9.3.3 Data Extraction

Data were extracted for analysis individually by both investigators. Results of data extraction were not combined, as many of the studies had different outcome measures. Data for time was extracted and converted, where possible, to minutes; Monetary costs were extracted and converted to United States Dollars (US$). Where possible, costs were converted using the currency rate stated in the literature at the time of publication, otherwise they were converted using a freely available online currency converter (www.XE.com).

9.3.4 Details of Studies

A total of 3460 studies were accessed from the initial database search, Pubmed (MEDLINE)(n=722), Embase (n=1760), Web of knowledge (n=928), Cochrane database
(n=19) and Google scholar (n=31). 562 duplicates were eliminated resulting in 2898 study abstracts accessed for analysis. 2807 abstracts were rejected as they did not meet inclusion criteria for the systematic review. 91 full papers were accessed for further assessment. Three additional studies were included from review of the selected studies references. The two investigators rejected 58 further studies for not fulfilling the inclusion criteria. (Figure 32)
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Stage 1

Electronic databases: search using the following parameters:

MEDLINE (722), EMBASE (1760), Web of Knowledge (928), Cochrane Library (19), Google scholar (31)

Preprint: search the following journals for relevant studies not yet in print:
- American Journal of Surgery (0)
- Annals of Surgery (2)
- Archives of Surgery (0)
- British Journal of Hospital Medicine (0)
- British Journal of Surgery (17)
- Journal of Gastrointestinal Surgery (0)
- Journal of the American College of Surgeons (0)
- Surgery (0)
- Surgical Endoscopy (0)
- World Journal of Surgery (0)

Duplicates: 562

Stage 2

Reject those meeting exclusion criteria: 468 +
- Letters, comments, reviews
- Animal or in vitro studies
- Non English studies
- Not published between January 1980 and May 2011
- Unpublished

Discrepancies between two researchers: 135

Stage 3

Select those meeting inclusion criteria:
- Cost of training in the OR/procedure suite (55)

91 full papers
Reject those meeting exclusion criteria:
<18 years old of age
<10 participants
Without outcomes of interest – (needs to include outcomes for one or more of the following):
- cost in terms of money/economics, time, patient outcome, effectiveness or training, skills acquisition
Without extractable outcomes
Duplicates

Further studies included:
Reference search (55)
In total, 36 relevant studies were included, with a total of 456,657 overall cases. One study did not describe the number of cases that they included. The length of data collection and analysis varied widely between the 36 studies, from one case to a 14 year period of cases. Studies included analysis of trainees vs. consultants, or hospitals with trainees vs. hospitals without trainees. (Figure 33) The studies covered eight specialties, with 17 papers focusing on general surgery, five papers on orthopaedics and trauma, three papers on medicine, three papers on anaesthetics, three papers on cardiothoracic surgery, two papers on gynaecology, one paper on otolaryngology, one paper on maxillary facial surgery and one paper on urology. Data were extracted for the cost of training surgeons and anaesthetists in the operating room and endoscopists in the procedure suite. Cost of training was measured in monetary terms, operating/procedure/anaesthetic induction time, surgical success and accuracy, morbidity and mortality, complications length of stay, patient satisfaction and trainee experience (Figure 33)

9.3.5 Quality of studies

Quality of studies was assessed by an adapted risk of bias tool, analysing whether studies were designed prospectively using surgeons of similar experience and ability; whether included cases had strict inclusion criteria; whether studies were standardised for difficulty of case/morbidity of patient and if studies were influenced by withdrawn cases. Studies were given a score out of 5, with 0 conferring poor quality (high risk of bias) and 5 conferring high quality (low risk of bias)

Thirteen studies were designed prospectively; Twenty one studies used surgeons of similar experience; thirty studies had defined inclusion criteria that used specific procedures; thirty two studies were not influenced by withdrawn or excluded cases and only eight studies standardised the cases used by morbidity or difficulty of case. (Figure 33)
**Figure 33 – Studies included for data extraction**

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</tr>
<tr>
<td>Traverso et al (1997)</td>
<td>Time</td>
<td>359</td>
<td>1</td>
<td>0</td>
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</tr>
<tr>
<td>Wang et al (2001)</td>
<td>Time, procedural performance</td>
<td>100</td>
<td>0</td>
<td>1</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>Wang et al (2009)</td>
<td>Monetary, time, procedural performance</td>
<td>71</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Woolson et al (2007)</td>
<td>Time</td>
<td>347</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 34 – Studies arranged by type of cost analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Speciality</th>
<th>Outcome data</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgical</td>
<td>Surgery, Pathological</td>
<td></td>
<td>Auerbach et al (2008), Shepherd et al (1992),</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------------------------</td>
<td>------------------------------------------</td>
<td>----------------------------------</td>
</tr>
</tbody>
</table>
9.4 Results

9.4.1 Operating room efficiency

A total of 22 studies were included that assessed the impact of training on the efficiency of operating room function in terms of additional time taken. Two studies were assessed as being of high quality (Davis et al., 2006, Schuster et al., 2008) (Figure 35). Eighteen studies demonstrated significant increase (p<0.05) in operating room time due to teaching or the presence of trainees, with only four studies demonstrating no significant difference in OR time (p>0.05).

Opit et al performed one of the first studies that analysed the impact that teaching had on operating time, by retrospectively analysing the operating room logs for 1024 general surgery cases taking place during a four month period at a district general hospital (Opit et al., 1991). Consultants performed 297 procedures, with 488 by registrars and 239 by senior house officers. The authors analysed a large number of different cases, and organised them by complexity of case into four groups: minor, intermediate, major and major plus procedures. They demonstrated that teaching cases that were performed by SHOs were significantly longer than when the consultant performed them for minor cases (5 minutes per case, p<0.01) and for intermediate cases (18 minutes longer, p<0.01). SPRs performed more major and major plus cases, with non-significant increases in time for major cases (9 minutes longer) and for major plus cases (1 minute). Although there are some limitations to the study in terms of accuracy of data collection, and no analysis of case turnover time, the authors provide moderate evidence for the increase in time taken for minor and intermediate cases when they are performed by junior trainees as teaching cases. These results were confirmed by Babineau et al, who analysed specific general surgery cases and performed a retrospective analysis of operating room times for four common general surgery procedures with or without a
resident (Babineau et al., 2004). All four procedures demonstrated increased operating times when a post graduate year (PGY) three resident was present during the case. However, there were only significant increases in operating time for hernia repair (median 38 vs. 46; p=0.03), laparoscopic cholecystectomy (median 63 vs. 86; p=0.002) and carotid endarterectomy (median 124 vs. 168, p<0.001). Partial colectomy demonstrated increased operating time of 60 minutes when the resident was present, however, this was not significant (median 115 vs. 175, p=0.08) due to a relatively small N and large standard error. Although this study was a retrospective analysis, data was recorded prospectively, with participants unaware that the data was being collected, preventing any manipulation of the times, providing moderate evidence of the increase in OR time as a direct result of teaching. The evidence for increased operating time in general surgery due to teaching is supported by Jain et al (Jain et al., 2005) who demonstrated an increase of 6 minutes per case for laparoscopic cholecystectomy; Martin et al (Martin et al., 1989) demonstrated an increase of 19 minutes per thyroidectomy; Traverso et al (Traverso et al., 1997) demonstrated an increase of 26 minutes per laparoscopic cholecystectomy. For cardiothoracic surgery Bakaeen et al (Bakaeen et al., 2009) demonstrated an increase in operating time for coronary artery bypass graft of 40.5 minute for PGY1 residents and 13.8 minutes for PGY2 residents; which was supported by Haan et al (Haan et al., 2007) who demonstrated an increase in perfusion time of 6.75 minutes per case and increase in cross clamp time of 5.66 minutes. For orthopaedic surgery, Woolson et al (Woolson and Kang, 2007) demonstrated an increase in time for total hip replacement of 12 minutes and total knee replacement of 13 minutes. For maxillary-facial surgery, Shepherd et al (Shepherd et al., 1992) demonstrated an increase of 2.5 minutes per case for third molar extraction.
Teaching in the operating room occurs both for trainee surgeons and trainee anaesthetists. There were three studies demonstrating an increase in operating time as a result of anaesthetic teaching, two of which were assessed as being of high quality (Davis et al., 2006, Schuster et al., 2008). Davis et al (Davis et al., 2006) analysed the additional time taken during a case when an attending is present to teach a trainee. They estimated that 75% of 1559 operations had some element of training, which resulted in an increase in anaesthetic induction time of 4.5 minutes per case. They also demonstrated that there was an increase in teaching time, and therefore induction time, if the case was more difficult. Despite this increase in time due to teaching, the authors also point out that the increase in OR time due to teaching is a very small increase in proportion to the total length of the operation (3% of the mean total operating time). Schuster et al (Schuster et al., 2008) confirmed these findings and that the complexity of the case increased teaching time by demonstrating that teaching time increased if a central venous line had to be placed with a 15.9 minutes increase in time per case (p=0.033) compared to if a consultant performed alone. This result is supported by Eappen et al (2004)(Eappen et al., 2004) who demonstrated a similar increase in induction time as a direct result of teaching. However, they also demonstrated that this time was made back, with no significant decrease in OR room turnover and efficiency; concluding that although teaching is time consuming, it can still take place within an efficient OR. Davis et al and Schuster et al performed studies that were assessed of being of high quality, providing strong evidence for the increase in operating room time due to teaching and training.

As previously discussed, further evidence demonstrating the additional time for teaching and training in the operating room is supplied by Bridges et al (Bridges and Diamond, 1999) (net operating time increase over four years of 2050 hours); Depew et al (Depew et al., 2010) (17.5 minutes longer per case (PGY4) (p<0.001), 14.7 minutes longer per case (PGY5)
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(p<0.001); Farnworth et al (Farnworth et al., 2001) (42.47 minutes longer per case
(p<0.001)); Harrington et al (Harrington et al., 2007)(43.7 minutes longer per case); Koperna
et al (Koperna, 2004) (9 minutes longer per case, 18.5 minutes longer per case); McCashland
et al (McCashland et al., 2000) (2-6 minutes longer per case, 5-16 minutes longer per case);
and Wang et al (Wang et al., 2009) (35.4 minutes longer per case (p<0.0001)).

Conflicting evidence regarding the impact of teaching and training on operating room
efficiency, demonstrating no significant increase in OR time, is supplied by Auerbach et al
(Auerbach et al., 2008) who demonstrated that there was no significant increase in operating
time for posterior spinal surgery by residents (p>0.05). Although the same study did
demonstrate significant increases in time for anterior spinal surgery, combined
anterior/posterior spinal surgery and video assisted thoroscopy (p<0.05); Schroeck et al
(Schroeck et al., 2008) demonstrated a non-significant increase in operating time of 12
minutes for robot assisted prostatectomy with residents present (p=0.512) which was
supported by Wang et al (Wang et al., 2009) with a non-significant increase in operating time
for laparoscopic cholecystectomy of 11.4 minutes (p=0.2). Rudkin et al (Rudkin et al., 1997)
did not specifically look at technical skill or operative training, but whether the presence of
medical students unscrubbed in the OR influenced operating time, and demonstrated no
impact on operating time (p=0.16).
### Figure 35 – Studies analysing operating room efficiency and time

<table>
<thead>
<tr>
<th>Study</th>
<th>Procedure</th>
<th>Cost in terms of time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auerbach et al (2008)</td>
<td>Spinal surgery:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anterior spinal surgery -</td>
<td>33 minutes longer per case (p=0.01)</td>
</tr>
<tr>
<td></td>
<td>Video assisted thoroscopy -</td>
<td>48 minutes longer per case (p=0.0004)</td>
</tr>
<tr>
<td></td>
<td>Combined Ant/Post. Surgery –</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior spinal surgery -</td>
<td>34 minutes longer per case (p=0.0063)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 minutes longer (p&gt;0.05)</td>
</tr>
<tr>
<td>Babineau et al (2004)</td>
<td>Hernia -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Laparoscopic cholecystectomy -</td>
<td>8 minutes longer per case (p=0.03)</td>
</tr>
<tr>
<td></td>
<td>Carotid endarterectomy -</td>
<td>23 minutes longer per case (p=0.002)</td>
</tr>
<tr>
<td></td>
<td>Partial colectomy -</td>
<td>44 minutes longer per case (p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 minutes longer per case (p=0.08)</td>
</tr>
<tr>
<td>Bakaeen et al (2009)</td>
<td>Coronary artery bypass graft</td>
<td>40.5 minutes longer per case (Post graduate year (PGY) 1) (p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td>(CABG)</td>
<td>13.8 minutes longer per case (PGY2) (p&lt;0.001)</td>
</tr>
<tr>
<td>Bridges et al (1999)</td>
<td>62 different general surgery procedures</td>
<td>512.5 longer hours per year</td>
</tr>
<tr>
<td>Davis et al (2006)</td>
<td>Anaesthetic induction time</td>
<td>4.5 minutes longer per case</td>
</tr>
<tr>
<td>Depew et al (2010)</td>
<td>Colonoscopy</td>
<td>17.5 minutes longer per case (PGY4) (p&lt;0.001)</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Study</th>
<th>Procedure</th>
<th>Time Difference</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eappen et al (2004)</td>
<td>Anaesthetic induction time - Operating room turnover time</td>
<td>14.7 minutes longer per case (PGY5)</td>
<td>(p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.5 minutes longer per case (p=0.047)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 minute longer per case (p=0.907)</td>
<td></td>
</tr>
<tr>
<td>Farnworth et al (2001)</td>
<td>Anterior Cruciate Ligament reconstruction</td>
<td>42.47 minutes longer per case</td>
<td>(p&lt;0.001)</td>
</tr>
<tr>
<td>Haan et al (2007)</td>
<td>CABG: Perfusion time - Cross clamp time</td>
<td>6.75 minutes longer per case</td>
<td>(p&lt;0.0001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.66 minutes longer per case</td>
<td>(p&lt;0.0001)</td>
</tr>
<tr>
<td>Harrington et al (2007)</td>
<td>Laparoscopic Roux-en-Y gastric bypass</td>
<td>43.7 minutes longer per case</td>
<td></td>
</tr>
<tr>
<td>Jain et al (2005)</td>
<td>Laparoscopic cholecystectomy</td>
<td>6 minutes longer per case</td>
<td>(p=0.001)</td>
</tr>
<tr>
<td>Koperna et al (2003)</td>
<td>Laparoscopic cholecystectomy - Open hernia repair</td>
<td>9 minutes longer per case</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.5 minutes longer per case</td>
<td></td>
</tr>
<tr>
<td>Martin et al (1989)</td>
<td>Thyroidectomy</td>
<td>19 minutes longer per case</td>
<td>(p=0.0025)</td>
</tr>
<tr>
<td>McCashland et al (2000)</td>
<td>Colonoscopy – Oesophago-gastro-duodenoscopy</td>
<td>2-6 minutes longer per case</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5-16 minutes longer per case</td>
<td></td>
</tr>
<tr>
<td>Opit et al (1991)</td>
<td>Minor ops – Intermediate ops – Major ops</td>
<td>5 minutes longer per case</td>
<td>(p&lt;0.01)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18 minutes longer per case</td>
<td>(p&lt;0.01)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 minutes longer per case</td>
<td></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>Procedure Details</th>
<th>Additional Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudkin et al (1997)</td>
<td>Vasectomy, Inguinal hernia repair, ingrown toenail removal, carpal tunnel decompression and colonoscopy</td>
<td>No significant increase in operating time (p=0.16)</td>
</tr>
<tr>
<td>Shepherd et al (1992)</td>
<td>Third molar extraction</td>
<td>2.5 minutes longer per case</td>
</tr>
<tr>
<td>Schroek et al (2008)</td>
<td>Robot assisted prostatectomy</td>
<td>12 minutes longer per case (p=0.512)</td>
</tr>
<tr>
<td>Schuster et al (2008)</td>
<td>Anaesthetic induction time: With central line placement - With laryngeal mask placement -</td>
<td>15.9 minutes longer per case (p=0.033) 4 minutes longer per case (p=0.015)</td>
</tr>
<tr>
<td>Traverso et al (1997)</td>
<td>Laparoscopic cholecystectomy</td>
<td>26 minutes longer per case (p&lt;0.01)</td>
</tr>
<tr>
<td>Wang et al (2001)</td>
<td>Laparoscopic cholecystectomy</td>
<td>11.4 minutes longer per case (p=0.2)</td>
</tr>
<tr>
<td>Wang et al (2009)</td>
<td>Tympanoplasty Type I</td>
<td>35.4 minutes longer per case (p&lt;0.0001)</td>
</tr>
<tr>
<td>Woolson et al (2007)</td>
<td>Total hip replacement – Total knee replacement -</td>
<td>12 minutes longer per case (p&lt;0.0001) 13 minutes longer per case (p=0.0028)</td>
</tr>
</tbody>
</table>
9.4.2 Operative performance

Operative performance and surgical success is difficult to objectively assess if not using patient outcome measures. Three studies analysed surgical performance as a cost of training. Shepherd et al (Shepherd et al., 1992) performed the first study looking at the impact of training on surgical performance (Figure 36). The primary aim of the study was to analyse the time taken for each step of an extraction of the third molar, with the secondary outcome analysing how the trainees performed the operation. By deconstructing the procedure into individual tasks, Shepherd et al demonstrated that trainee surgeons performed worse than experienced surgeons and missed significantly more steps of the procedure. Wang et al (Wang et al., 2001) analysed surgical performance for a laparoscopic cholecystectomy by analysing the affect that trainees had on pathological acuity of the sample removed, demonstrating no significant difference between consultants and trainees. Wang et al (Wang et al., 2009) demonstrated that residents had a lower surgical success rate than board certified surgeons (81.82% vs. 96.43%) when performing type I tympanoplasty. Surgery was considered successful if there was no tympanic membrane perforation or retained debris.

Intraoperative performance is difficult to assess objectively or in a retrospective manner. These studies provide weak evidence to the detrimental impact of trainees on surgical performance.
Figure 36 - Studies analysing cost in terms of operative performance

<table>
<thead>
<tr>
<th>Study</th>
<th>Procedure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shepherd et al (1992)</td>
<td>Third molar extraction</td>
<td>Junior surgeons missed significantly more steps of the procedure.</td>
</tr>
<tr>
<td>Wang et al (2001)</td>
<td>Laparoscopic cholecystectomy</td>
<td>No difference in pathological acuity</td>
</tr>
<tr>
<td>Wang et al (2009)</td>
<td>Tympanoplasty Type I</td>
<td>Trainees had lower surgical success (81.82% vs. 96.43%)</td>
</tr>
</tbody>
</table>
5.1.1 Patient outcome

A procedural learning curve is inevitable when a trainee enters the OR, which can have inherent risks to the patient. Eleven studies analysed the impact that teaching and training has on patient outcome (Figure 37). Five studies demonstrated no change in mortality (Offner et al., 2003, Hwang et al., 2008, Goodwin et al., 2001, Haan et al., 2007, Bakaeen et al., 2009); five studies demonstrated no impact on post-operative complications or morbidity (Auerbach et al., 2008, Bakaeen et al., 2009, Hwang et al., 2008, Imhof et al., 2002, Schroeck et al., 2008); two studies demonstrated no change in length of stay in the intensive care unit (Bakaeen et al., 2009, Goodwin et al., 2001). However, there was conflicting evidence about total hospital length of stay, with three studies demonstrating increased length of stay (Chang et al., 2003, Hwang et al., 2008, Hwang et al., 2010), four studies demonstrating no change in total hospital length of stay (Auerbach et al., 2008, Bakaeen et al., 2009, Goodwin et al., 2001, Imhof et al., 2002), with one study demonstrating that the presence of residents actually reduced length of stay (Offner et al., 2003). Only one study demonstrated a detrimental effect on patient outcome with Imhof et al (Imhof et al., 2002) demonstrating a significant increase in minor complications, but the same study showed no change in major complications, morbidity and mortality.
### Figure 37 - Studies analysing cost in terms of patient outcome

<table>
<thead>
<tr>
<th>Study</th>
<th>Procedure</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auerbach et al (2008)</td>
<td>Spinal surgery</td>
<td>No difference in spinal curve correction, transfusion rate, length of stay or complication rates</td>
</tr>
<tr>
<td>Bakaeen et al (2009)</td>
<td>Coronary artery bypass graft (CABG)</td>
<td>No change in mortality or major morbidity, intensive care stay or hospital length of stay</td>
</tr>
<tr>
<td>Chang et al (2003)</td>
<td>Laparoscopic-assisted vaginal hysterectomy</td>
<td>Increased length of stay</td>
</tr>
<tr>
<td>Chang et al (2005)</td>
<td>Laparoscopic-assisted vaginal hysterectomy</td>
<td>Increased number of follow up out-patient appointments</td>
</tr>
<tr>
<td>Goodwin et al (2001)</td>
<td>CABG</td>
<td>No change in mortality, intensive care stay or hospital length of stay</td>
</tr>
<tr>
<td>Haan et al (2007)</td>
<td>CABG</td>
<td>No change in mortality</td>
</tr>
<tr>
<td>Hwang et al (2008)</td>
<td>Bowel resection, laparoscopic cholecystectomy, hernia, mastectomy, and appendectomy</td>
<td>No change in complications or mortality. Increased length of stay</td>
</tr>
<tr>
<td>Hwang et al (2010)</td>
<td>Bowel resection, laparoscopic cholecystectomy, hernia,</td>
<td>Length of stay increased with residents (3.3 vs. 4.6 days)</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Procedure</th>
<th>Technique</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mastectomy, and appendectomy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No change in major complications, conversion to open rate, reoperation rate and length of stay</td>
</tr>
<tr>
<td>Offner et al (2003)</td>
<td>Trauma cases</td>
<td>No change in mortality ER time reduced,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Length of stay reduced</td>
</tr>
<tr>
<td>Schroek et al (2008)</td>
<td>Robot assisted prostatectomy</td>
<td>No change in complications</td>
</tr>
</tbody>
</table>
9.4.3 Patient satisfaction and trainee experience

Feldman et al (Feldman and Nasmyth, 2005) produced the only study that went beyond the usual methods for analysing cost and surgical success by also investigating the impact that trainees have on patient satisfaction and trainee experience. The authors developed a study looking at the impact of regular training lists. They demonstrated that patients were agreeable to this, with no difference in patient satisfaction using a validated patient satisfaction survey. They also demonstrated that using a dedicated training list, they increased trainees surgical experience and exposure compared to traditional operating lists.

9.4.4 Monetary cost

Seventeen studies were included that analysed an economic cost of training in the operating room, five studies were deemed to be of high quality (Figure 38) (Botha et al., 1995, Bridges and Diamond, 1999, Depew et al., 2010, Harrington et al., 2007, McCashland et al., 2000).

Botha et al performed a retrospective study of the laparoscopic appendectomies performed at a hospital over an 11 month period (Botha et al., 1995). Although the aim of the study was to analyse the cost effectiveness of a laparoscopic training program for laparoscopic appendectomy, they also analysed the operative costs of teaching and training junior surgeons in the operating room. The senior trainee (SPR) was permitted to perform laparoscopic appendectomy unsupervised, whereas the junior trainee (SHO) was permitted to perform diagnostic laparoscopy under supervision. Over the 11 month period, the SHO performed 33 open appendectomies compare to five open appendectomies performed by the SPR. The results of the study demonstrated that an open appendectomy costs £152 more than a laparoscopic appendectomy, resulting in an additional cost of £4642.90 ($7,426.83) per
year per trainee for one procedure (£152 x 28 open appendectomies in 11 months). This study was of high quality, with strict inclusion criteria and using the same surgeon for comparison. However, although it demonstrates an increase in costs, with the junior trainee performing more open appendectomies than the senior trainee, it does not describe whether the open operations were performed purely because the junior trainee was present, or whether the cases were unsuitable for a laparoscopic procedure. It would also be of interest to see the figures of the consultant as well as the senior trainee. Despite this, it provides strong evidence documenting the additional costs of training junior surgeons in the operating room.

Bridges et al (Bridges and Diamond, 1999) investigated the cost of training residents in the operating room, by analysing the operating times for procedures performed by an attending alone, compared with procedures with a resident present. They estimated that 95% of the procedures where a resident was present, the resident actually performed the operation. Over a four year period, 62 procedures were selected, with a total of 14,452 cases, 9,733 with a resident present and 4,719 without a resident. This resulted in a net increase in operating time of 123,024 minutes as a direct result of a resident being present. The cost per minute of operating room functioning was demonstrated as $429/minute (which includes salaries, wages and benefits of employees). The total cost for “lost time” was $527,772.96, which equates to $47,979 per resident over a 4 year period, or $11,994.75 per resident/year. This study provides strong evidence towards the costs of training surgeons in the operating room. The structure of the surgical department was such that it allowed a direct comparison between operations performed by an attending surgeon with operations performed by residents. The study was set over a four year period, which provided a large amount of cases to be analysed. By analysing such a breadth of different procedures it allows the authors to look at large numbers of cases. However, the study does have some limitations. By grouping major and
minor surgeries together, it does not take into account the proportion of the operation performed by the residents. It would be expected that a resident would perform a larger proportion of excision of a cyst than they would for an abdominal aortic aneurysm repair. Therefore the cost of an operation performed in its entirety by the resident is likely to cost more than a procedure that only had 10% of the operation performed by the resident. Another criticism of this study is the assessment of cost of operating room time. The authors have used the wages, salaries and benefits of the operating room staff only. Operating room expenses also include the cost of anaesthetic and surgical salaries, equipment used, electricity and sterilisation services. If these costs were included it would increase the resulting cost of operating room time. In addition, this study does not mention the level of experience of all the residents who performed operations, as this would vary depending on postgraduate year, and would influence the results obtained. Despite these limitations, this study has a low risk of bias and provides strong evidence of the additional costs to a hospital for teaching and training in the operating room.

A number of studies have used similar methods to Bridges et al., by calculating the additional time taken by training residents in the OR compared to an attending operating alone, and then attaching a price per unit time (Farnworth et al., 2001, Harrington et al., 2007, Koperna, 2004, Wang et al., 2009). Farnworth et al demonstrated a significant decrease in anaesthetic and operating time when an attending was present for arthroscopic anterior cruciate ligament (ACL) reconstruction, with the increased cost of training equating as $228.73 for anaesthetic cost and $661.85 for total operating costs. (Farnworth et al., 2001) Harrington et al demonstrated that by allowing a resident to perform part of a laparoscopic Roux-en-y gastric bypass, there was an increase in operating time or “educational time” of 43.7 minutes which equated to $45.52 per case and $45,601 per resident per year. (Harrington
Koperna et al demonstrated longer operating room times when residents or junior consultants operated compared to senior consultants. These costs were increased by €54 for residents and €200 for junior consultants per laparoscopic cholecystectomy and €106 for residents and €153 for junior consultants per hernia repair. This total was €8,370 ($11,947) per resident per year and €22,922 ($32,711) per junior consultant per year (Koperna, 2004). Wang et al (2009)(Wang et al., 2009) demonstrated that residents performed type I tympanoplasty significantly longer than attending surgeons (35.4 minutes), which equated to $40.36 per case and $4036 per resident per year.(Wang et al., 2009) (Figure 38)

As colonoscopy is a common procedure with a large number performed per hospital per year, it is vital that endoscopy lists are run efficiently. The additional costs of training in the procedure suite have been analysed in two studies (Depew et al., 2010, McCashland et al., 2000). Depew et al performed a retrospective study analysing the case load of residents with experienced endoscopists practising alone. Over a 14 year period, 17,948 colonoscopies were analysed from both general surgery and gastroenterology procedure lists. The authors demonstrated that mean endoscopy times were significantly shorter for experienced endoscopists than for trainees. Procedure time increased from 31.6 (± 15.6) minutes to 47.3 (±19.1) minutes. This is equivalent to 1.05 cases per hour for trainees compared to 1.43 cases per hour for experienced endoscopists, which equates to a loss of $85.45 per hour. If this was extrapolated to a six hour weekly endoscopy list, the total cost of training one resident endoscopy over a year would be $26,660.4 ($85.45 x 6 hours x 52 weeks). This study demonstrated similar results to McCashland et al who analysed endoscopy times for clinicians in private practice, university hospitals and veteran’s affairs hospitals. Both the university hospital and veterans’ affairs hospitals had endoscopies performed by both
experienced endoscopists and trainees. 17,948 endoscopies were analysed over a one year period in all institutions. They demonstrated that an endoscopy with a trainee present added 2-6 minutes per oesophago-gastro-duodenostomy (OGD) and an additional 5-16 minutes per colonoscopy. By analysing the rate of caseload per hour, a financial cost was $500,000-$1,000,000 per 4000 cases.

Both Depew et al and McCashland et al analysed the costs of training in the endoscopy suite for a large number of cases. However, Depew et al only looked at one centre over a fourteen year period, which could influence the findings of the study. This implies that the endoscopy times of residents in 1997 could be compare with the experienced endoscopists times in 2009, which would not take into account the improvement in times seen by new technologies and procedure suite resources. In addition, they analysed both general surgery trainees and gastroenterology trainees, and noted that there was a discrepancy between the time for training for the different speciality trainees. Despite this, they still used all of the data collected to make the conclusions.

McCashland et al compared different institutions rates of endoscopy. Although this provided a useful way of comparing solo endoscopists with trainees, the comparison of different institutions could also influence the results. Private practice hospitals are likely to run more efficiently, especially in between cases where a lot of time can be lost. In addition, it is likely that they were comparing endoscopists practising solo with different endoscopists teaching. It would have been better to compare an experienced endoscopist practising solo with the same endoscopist teaching a resident, to get an accurate measurement of the additional teaching time. Despite these criticisms, both of these studies have used large numbers of cases and provide strong evidence of the additional costs that occur when teaching takes place in the procedure suite.
Further evidence for the additional cost of training residents is provided by Blewett et al ($146,765 per resident per year) (Blewett et al., 2001); Chang et al (NT$7141/US$210 per case = $7561 per year) (Chang et al., 2003); Feinstein et al ($232,726 for one institution) (Feinstein et al., 2011); Feldman et al (Increased cost per patient of £69 = £10764 ($17,177) per year (£69 x 3 patients x 52 weeks)) (Feldman and Nasmyth, 2005); Hwang et al ($3,455 per patient) (Hwang et al., 2008); Hwang et al ($3,245 per patient) (Hwang et al., 2010); Jones (Breast $269, vascular $5291, gynaecology $105 and joint surgery $726) (Jones, 1985) and Kane et al ($1,085,000 net per year for an institution for surgery) (Kane et al., 2005). (Figure 38)
### Figure 38 - Studies analysing cost in financial terms

<table>
<thead>
<tr>
<th>Study</th>
<th>Procedure</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botha et al (1995)</td>
<td>Laparoscopic appendectomy</td>
<td>$7,426.83 per trainee/ year for one procedure</td>
</tr>
<tr>
<td>Bridges et al (1999)</td>
<td>62 general surgery procedures</td>
<td>$11,994.75 per resident/year</td>
</tr>
<tr>
<td>Chang et al (2005)</td>
<td>Laparoscopic-assisted vaginal hysterectomy</td>
<td>$210 per case = $7561 per resident per year</td>
</tr>
<tr>
<td>Depew et al (2010)</td>
<td>Colonoscopy</td>
<td>$85.45 per residents/hour = $26,660.4 per resident/year</td>
</tr>
<tr>
<td>Farnworth et al (2001)</td>
<td>Arthroscopic ACL reconstruction</td>
<td>$661.85 per resident/case</td>
</tr>
<tr>
<td>Feinstein et al (2011)</td>
<td>30 procedures</td>
<td>$232,726 per year for one institution</td>
</tr>
<tr>
<td>Feldman et al (2005)</td>
<td>Inguinal hernia, Para umbilical hernia, varicose vein high tie and strip, circumcision and Zadeks procedure</td>
<td>$17,177 per resident per year</td>
</tr>
<tr>
<td>Goodwin et al (2001)</td>
<td>Coronary artery bypass graft</td>
<td>No significant increase in cost</td>
</tr>
</tbody>
</table>
### Table 1: Cost Analysis of Surgical Procedures

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Procedure Description</th>
<th>Cost(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hwang et al (2008)</td>
<td>Bowel resection, laparoscopic cholecystectomy, hernia, mastectomy, and appendectomy</td>
<td>$3,455 per patient</td>
</tr>
<tr>
<td>Hwang et al (2010)</td>
<td>Bowel resection, laparoscopic cholecystectomy, hernia, mastectomy, and appendectomy</td>
<td>$3,245 per patient</td>
</tr>
<tr>
<td>Jones (1985)</td>
<td>Breast, Vascular Surgery, Gynaecology, Joint Surgery</td>
<td>$269 per clinician, $529 per clinician, $105 per clinician, $726 per clinician</td>
</tr>
<tr>
<td>Kane et al (2005)</td>
<td>Surgery costs</td>
<td>$1,085,000 net per year for an institution for surgery</td>
</tr>
<tr>
<td>Koperna et al (2003)</td>
<td>Laparoscopic appendectomy and laparoscopic cholecystectomy</td>
<td>$11,947 per resident/year, $32,711 per junior consultant/year</td>
</tr>
<tr>
<td>McCashland et al (2000)</td>
<td>OGD + colonoscopy</td>
<td>$500,000-$1,000,000 per 4,000 cases.</td>
</tr>
<tr>
<td>Wang et al (2009)</td>
<td>Type 1 Tympanoplasty</td>
<td>$4,036 per resident/year</td>
</tr>
</tbody>
</table>
9.5 Discussion

In the United Kingdom, healthcare delivery requires a high quality service at a reasonable cost. To provide this, it is vital that hospital trusts and departments cut cost by ensuring efficient service delivery. An experienced surgeon or clinician is likely to perform a task quicker, more efficiently and with higher quality than a trainee. As a result, it could be foreseen by hospital administrators that healthcare authorities should be providing a consultant delivered service therefore improving operating room efficiency and patient outcome. However, this would be to the detriment of the current generations of trainees by further reducing the training opportunities that are available.

Surgical training is expensive and time consuming. The results of this study demonstrate that one individual resident costs an institution between $4,046 and $45,601 per single specific operation (Harrington et al., 2007, Wang et al., 2009). As it is unlikely that a resident would only perform one type of operation per year, these costs are likely to be higher, with Blewett et al suggesting it would be $146,765 per trainee per year (Blewett et al., 2001). In addition, many institutions are likely to have more than one resident, so costs will be even higher, with Feldman et al suggesting it would cost $232,726 and McCashland et al suggesting between $500,000 and $1,000,000 per year for an individual institution to have residents (Feldman and Nasmyth, 2005, McCashland et al., 2000). Furthermore, these costs are additional costs as a direct result of teaching in the operating room. They do not take into account normal operating room costs, the salaries of the trainees, costs of study leave, annual leave or sick leave. As a result, the costs of training in the operating room and procedure suite are extremely high. However, this cost is vital to provide junior surgeons with the technical skill and experience that is required when they complete their training. Any reduction in costs
would be a direct reduction in training opportunities and consequently a reduction in competence of the next generation of surgical consultants.

Although the financial cost of training is high, and it is difficult to see how to reduce those costs, one area that could be identified to reduce is the time it takes for a trainee to perform operations. With operating room efficiency in mind, it is clear that there is strong evidence that teaching and training in the operating room increases operating room time, with colonoscopy being between 6 and 17.5 minutes longer per case, (Depew et al., 2010, McCashland et al., 2000) laparoscopic cholecystectomy being between 6 and 26 minutes longer (Jain et al., 2005, Traverso et al., 1997) and hernia repair being between 8 and 18.5 minutes longer per case (Babineau et al., 2004, Koperna, 2004). However, a number of studies demonstrated that there is an association between operating time and the seniority of the trainee, with a more junior trainee taking longer to perform the same procedure (Bakaeen et al., 2009, Depew et al., 2010, Opit et al., 1991). Therefore, a number of methods could be used to improve operating room efficiency whilst maintaining teaching time:

a) Surgical training programs and program directors need to have more structure at identifying which cases should be performed by a junior trainee, a senior trainee and a consultant.

b) Common training cases should be deconstructed into individual tasks with trainees performing part of a task and then the experienced surgeon performs that rest of the operation.

c) Once the trainee is competent at one task, he performs the next task to proficiency, until they are able to perform all tasks proficiently. This would be far more efficient than asking a trainee to perform all of an operation for the first time.
d) In addition, complex cases could still be used as training cases, with trainees performing one simpler task within a more complex case. This would increase the total number of training opportunities available to the trainee.

e) Simulation should be used by all trainees so that when they enter the operating room, they are not learning a new operation, but perfecting what they have already learnt.

f) Operating room turnover should be improved, reducing the waiting time between cases, such that any additional time that occurs due to teaching can be made back with efficient handover teams.

Teaching and training in the operating room has been previously suggested to be detrimental to patient safety, with mistakes and errors more likely to be made at the start of the procedural learning curve (Hasan et al., 2000). Although not the primary aim of this study (and was not considered within our search term strategy), there was evidence to suggest that training in the operating does not impact perioperative patient outcome. There was no significant increase in in mortality (Offner et al., 2003, Hwang et al., 2008, Goodwin et al., 2001, Haan et al., 2007, Bakaeen et al., 2009); major complications or morbidity (Auerbach et al., 2008, Bakaeen et al., 2009, Hwang et al., 2008, Imhof et al., 2002, Schroeck et al., 2008) or change in length of stay in the intensive care unit (Bakaeen et al., 2009, Goodwin et al., 2001). Only one study demonstrated an increase in minor complications, but this study did not demonstrate any consequent impact on morbidity, major complications, mortality or length of stay. In addition, this study had a high risk of bias. Therefore there is strong evidence supplied by studies with a low risk of bias, to support that training in the operating room does not affect peri-operative patient outcome. However, there is conflicting evidence for the effect of training on hospital length of stay, with different specialities having different results. The studies that demonstrated an increase in length of stay were two for gynaecology
and one for major general surgery, with cardiothoracic surgery, day-case general surgery and orthopaedic surgery demonstrating no change in length of stay. An increase in length of stay would have a two fold increase in cost for the hospital or institution involved, with the cost of extra bed days, and the increased risk of immobility associated complications such as infection and thromboembolism (McAleese and Odling-Smee, 1994). Therefore, with an inter-speciality discrepancy for length of hospital stay, it would be prudent to analyse how and when teaching occurs for the specialities that do not increase length of stay with teaching in the operating room to further improve the efficiency of training in the operating room.

The healthcare system faces considerable challenges over the next ten years, with a constant demand for innovative treatments and new technologies or drugs, with reduced waiting times, exemplary patient safety, all to be done within budget. Training in the operating room is expensive and time consuming, and may be seen as an unnecessary luxury by hospital management, striving to provide exceptional healthcare delivery in a cost efficient manner. However, reducing costs of training by reducing training time may have a financial benefit in the short term, but it is certainly going to be costly in the long term. It would lead to generation of fully qualified, board certified surgeons that are not competent. Cost reduction for surgical training can occur if there is innovative thinking in the way that training is structured and delivered. Simulation has been heralded as an effective adjunct to improve technical skills in the laboratory such that on entering the operating room, trainees are further along their learning curve, so operating times are reduced. (Scott and Dunnington, 2008) Future work in this area should look at the effectiveness of simulation in terms of providing trainee surgeons with the appropriate technical skills, but in a cost effective manner.
10. Simulation is cost efficient and reduces hospital costs

10.1 Introduction

In the United States, simulation training has been fully incorporated into the national training programme. It is now mandatory for all surgical residents must complete the Fundamentals of Laparoscopic Surgery training curriculum before finishing their residency program (Peters et al., 2004a). This allows a structured laboratory based simulation curriculum to be incorporated into the national surgical training program for all trainees (Fried et al., 2004). This is not the case in the UK, with the majority of surgical trainees undertaking training courses, such as basic surgical skills and basic laparoscopic skills, externally to their formal training programs (Torkington et al., 2001a).

Current research should not aim to investigate whether simulation is effective (Cook et al., 2011). It is clear from the literature, and from the evidence provided in this thesis, that simulation is effective; from low-fidelity bench top simulation, to computer based virtual reality (VR) simulation, to live anesthetised porcine simulation to whole team simulated operating suites (Kneebone, 2003, Aggarwal et al., 2006b, Aggarwal et al., 2007a, Arora et al., 2011). These forms of simulation have demonstrated improvements in technical skills, trainee confidence, operating room (OR) performance and decreased technical error and thus improved patient safety (Gallagher and Satava, 2002, Nishisaki et al., 2007, Grantcharov et al., 2004, Aggarwal et al., 2006a). Simulation should be utilised by all surgical trainees to enhance their technical skills in a safe and controlled environment, where mistakes are permitted, and can be used as learning points. Therefore, the question arises as to why simulation has not been fully adopted by the international surgical community? Previously, criticisms regarding simulation focused on the lack of realism for simulation (Satava, 1993). However, as simulation technology progresses with improved computer processing powers
and graphics, VR simulation in particular has dramatically increased the realism and fidelity of the simulations. Full length procedures can be performed on excellent computer reproductions of anatomical structures. Bleeding and the use of high energy devices or staplers further increase the realism of a full procedure in the virtual world. Previously, a surgical trainee would be limited to basic psychomotor tasks in VR, now they can perform full length complex procedures in a virtual environment. They can learn develop and perfect technical skills that are required for many different operations. This allows the trainee to enter the OR further down the learning curve.

As simulator technology advances, there is a reciprocal increase in the costs of the simulators, which has always been another criticism of VR simulation. VR simulators have always required a considerable upfront cost, but also may require yearly servicing costs and dedicated staff available to teach and maintain the simulators. A basic laparoscopic VR simulator, such as the Minimally Invasive Surgical Trainer – Virtual Reality (MIST-VR) (Mentice, Gothenburg, Sweden), may cost in excess of £35,000, with the more advanced simulators with better graphics, haptic feedback and full length procedures such as the Lapmentor (Simbionix, Gothenburg, Sweden) costing in excess of £100,000. In this age of austerity, where hospitals and institutions are looking for cost savings and efficiency of processes, a large outlay on a VR simulator could be considered a luxury. A large teaching hospital may have as many as 10,000 employees, with only 0.4% being surgical trainees. Therefore, regardless of cost saving initiatives, simulation requires a large outlay for such a small number of people that are able to use it.

However, it is vital that the surgical trainees have adequate training facilities and dedicated time to utilise them. Without simulation, it would imply that all surgical training takes place in the OR on patients. This in itself can be very expensive. In 1999, Bridges et
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*all(Bridges and Diamond, 1999)* analysed the cost of training in the OR for all trainees at an institution. They calculated the additional time taken by trainees learning in the OR, and allocated a cost per minute to that time. They concluded that the direct impact of training in the OR resulted in an increase in cost of $47,979 per trainee.

By learning basic skills and procedures in the skills laboratory, it could reduce the time taken in the OR to reach proficiency in specific operations. By entering the OR further along the learning curve, it would decrease operating times, and could improve OR efficiency. A surgical trainee cannot develop proficiency in an operation by practising in the skills lab alone. However, they can ensure that they learn the basic technical skills, anatomy and operative planning outside of the OR, therefore removing the most dangerous part of the learning curve from the patient. This would create safer, more efficient trainees that in turn would reduce OR costs.

A useful method of quantifying how much simulation is required outside of the OR is by assessing the transfer effectiveness (TER). The TER is an assessment tool commonly used by the airline industry to assess the effectiveness of a simulator in terms of technical skills taught. In the airline industry, the gold standard for a simulator is a TER of 0.5, which implies that each hour spent on the simulator is the equivalent of 0.5 hours spent in the airplane. The only study to analyse the TER for a surgical simulator is by Aggarwal et al, who demonstrated a TER of 2.28, implying every hour on a simulator was equivalent to 2.28 hours in the OR (Aggarwal et al., 2007d). The TER and its calculation is discussed in more detail in chapter 3.6.

Establishment of the transfer effectiveness of a simulator allows an accurate method for assessing how much OR costs can be reduced by a trainee using that simulator prior to entering the OR. By learning and practising basic skills in the skills lab, The TER would
imply an equivalent time in the OR that would be removed from a trainee’s OR learning curve. This would consequently reduce OR costs by improving OR efficiency. This could make the purchase of an expensive simulator by a hospital more viable. In addition, many institutions have large numbers of surgical trainees, all of whom increase operating times when training, which increases hospital costs. Therefore, the more trainees that use simulation before entering the OR, the larger the savings to a hospital due to increased OR efficiency.

The aims of this chapter were to assess the how effectively different forms of simulation improve OR performance in a simulated OR, and whether training on simulation can be cost efficient to an institution by reducing OR times. This would allow the determination of a “number need to train” on a simulator in order to make it a cost efficient purchase for an institution or hospital.
10.2 Methods and Materials

10.2.1 Study participants

Thirty qualified doctors with limited laparoscopic experience were recruited to take part in the study. All participants had no previous simulation experience. The study consists of baseline testing of technical skills, cognitive training, technical skills training and OR technical skills assessment. A control group followed the same protocol, but had no technical skills training. All recruits were trainees on surgical training programs or expressed an interest in a career in surgery but had performed less than five laparoscopic cholecystectomies as primary surgeon. Participants were randomised into three groups using the closed envelope technique: a control group, a box training group and a virtual reality training group. Each participant was consented to take part in the study.

10.2.2 Baseline testing

All participants completed a baseline assessment of technical skills. Recruits were asked to complete three tasks from the MIST-VR simulator (Mentice, Gothenburg, Sweden). The MIST-VR simulator is one of the first commercially available VR simulator that has been extensively validated as a surgical assessment and training tool. The tasks were “withdraw/Insert”, “Diathermy” and “Manipulate Diathermy”. Each task was demonstrated by a faculty member, before being performed twice each by the participants. Performance was assessed by analysing validated performance metrics on the second attempt. These metrics were time, economy on motion and error score. Further details of the validity of the MIST-VR simulator can be found in chapter 3.1.3.
10.2.3 Cognitive training

All participants underwent cognitive training prior to technical skills training. Cognitive training consisted of watching a 30 minute video explaining the basics of laparoscopic surgery, laparoscopic instruments and common pitfalls of using a laparoscopic approach. Participants then watched a full length virtual reality LC and a full length real patient LC, with expert commentary of surgical technique, both performed by an experienced surgeon (>100 LC’s).

10.2.4 Technical skills training

The control group received no technical skills training, and progressed to OR technical skills assessment.

10.2.5 VR training group

The VR training group trained using the Lapmentor VR simulator. Participants completed a validated, proficiency based training curriculum which has a step wise design, with progression through the modules only permitted once expert derived proficiency parameters have been reached for each task (Aggarwal et al., 2009). The training curriculum requires participants to complete basic tasks, procedural tasks and a full length laparoscopic cholecystectomy to validated proficiency parameters. Completion of the curriculum requires performance of a full length laparoscopic cholecystectomy to proficiency on two consecutive attempts. Full explanation of this training curriculum is described in chapter 4.5.

10.2.6 Box trainer group

The box trainer group trained using the Fundamentals of Laparoscopic Surgery (FLS) box and curriculum. The FLS is a widely validated technical skills training curriculum that
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Involves completion of five tasks: peg transfer, precision cutting, endoloop, extra-corporeal suture and intra-corporeal suture (Scott et al., 2008). Participants are required to complete each task to an expert derived proficiency score on two consecutive attempts before progressing to the next task (Scott et al., 2008). Extra-corporeal suture is not routinely performed at our institution, so this task was omitted from technical skills training. Further information regarding the FLS training curriculum has been described in chapter 8.2.1.

10.2.7 OR technical assessment

On completion of technical skills training, OR performance was assessed in a simulated OR using cadaveric porcine tissue. A cadaveric liver with gallbladder was fixed to a cork board and placed in an anatomical position in a traditional box trainer. Participants were provided with real OR instruments including diathermy. Participants were required to perform a laparoscopic cholecystectomy, with assessment taking place from the insertion of the instruments until complete excision of the gallbladder from the liver bed. Assessment was performed by analysing time, dexterity and quality of performance. Dexterity was analysed using a motion tracking surgical assessment tool called the Imperial College Surgical Assessment Device (ICSAD). ICSAD accurately measures time, total path length and number hand movements of each hand, and has been extensively validated as a surgical assessment tool (Hayter et al., 2009). This is a validated method of technical skills assessment within a simulated OR (Aggarwal et al., 2007d).

10.2.8 Cost analysis

One of the aims of this chapter is to assess how effective simulation training is at reducing the learning curve in the operating room. Training in the operating room is expensive, so a reduction in time spent in the operating room, would improve operating room
efficiency and reduce costs. The transfer effectiveness allows an accurate quantification of how much simulation training reduces operating room time. This would allow an assessment of cost savings that are made by training in the skills prior to the operating room. The following steps would allow assessment of the number needed to train (NNT) to make simulation training cost efficient (Figure 39).

1. Literature review of the number of laparoscopic cholecystectomies required before reaching proficiency (i.e. the learning curve), to allow assessment of the total length of the learning curve in minutes.
2. Assessment of the cost per minute of operating room function.
3. Assessment of the total cost of the learning curve in the operating room.
4. Assessment of the TER and therefore the amount of time saved in the operating room by prior simulation training.
5. Assessment of the costs of training in the skill laboratory.
6. Assessment of cost of learning curve in the OR with prior simulation training.
7. Training costs are made up of fixed training costs and variable training costs that reduce depending on the number of trainees that use the facilities.
8. Assessment of the change in training costs by increasing numbers of trainees.
9. Assessment of how many trainees are required to save enough money to purchase simulator.
10. This is performed by plotting a graph of decreasing costs against increased numbers of trainees (figure 40), and by stipulating the total cost of traditional training in the OR, it would allow us to define the number needed to train on the simulator to make it cost efficient.
Figure 39 - flowchart demonstrating methodology for assessing the number needed to train (NNT)

Assessment of cost of training

Cost of training in OR per minute (£OR)  |  Cost of training in VR per minute (£VR)

Transfer effectivenss quantifies the reduction in total OR time (vOR)

Total time for learning curve (tOR) = (VR time x TER) + vOR time
Therefore: vOR = tOR - (VR time x TER)

Assessment of total cost of learning curve

Without VR training: tOR x £OR  |  With VR training: (VR time x £VR) + (vOR x £OR)

If VR is cost efficient, Total OR training cost must equal VR cost +vOR cost

If: Total OR training cost = (VR time x £VR) + (£OR x vOR); and: vOR = tOR - (VR time x TER)
Therefore: Total training cost = (VR time x £VR) + (£OR x (tOR - (VR time x TER)))

Assessment of maximum cost allowance to make VR cost efficient (£VRmax)

For cost efficiency: Total training cost (tOR x £OR) = (VR time x £VRmax) + (£OR x (tOR - (VR time x TER)))
Therefore: £VRmax = (tOR x £OR) - (£OR x (tOR - (VR time x TER)))

VR cost (£VRmax) is variable depending on how many trainees use VR

£VRmax = fixed training costs + variable training costs
Variable costs = simulator costs (£sim)/ Number of trainees (N)

Number of trainees (N) needed to make VR cost efficient

N = £sim / (£VRmax - fixed training costs)

Number needed to train = £sim / [(tOR x £OR) - {tOR + (VR time xTER) x £OR}] - fixed training costs
Figure 40 – Example of chart plotting cost of simulation training per trainee and the assessment of the number needed to train

Change in cost per trainee

As simulation training reduces total cost of the learning curve; by analysing the total cost of the learning curve *without* simulation training - the number needed to train on simulation can be defined
10.2.9 Statistical analysis

Statistical analysis of the learning curves were conducted using the Statistical Package for the Social Sciences version 18.0 (SPSS, Chicago, IL). Learning curves were analysed with Friedman’s test. Group performance data under analysis is of non-parametric nature. Paired data was assessed using the Wilcoxon signed rank test and non-paired data with the Mann Whitney U test. All p-values less than 0.05 were considered significant.
10.3 Results

10.3.1 Study participants

30 surgeons were recruited and randomised into three groups. Five surgeons requested to withdraw during the study due to time constraints. This resulted in nine surgeons in the control group, nine surgeons in the VR group and seven surgeons in the FLS group.

10.3.2 Baseline testing

Each participant completed three tasks on the MIST-VR simulator at the easy level, “withdraw-insert”, “Diathermy” and “Manipulate-diathermy”. Performance was assessed on the second attempt of “Manipulate diathermy” using the metrics of time, economy of motion and error score, as they have been previously validated as a performance metrics (Aggarwal et al., 2006a). There was no significant differences in performance for manipulate diathermy between all three groups for time (median: control 49.4, VR 49.95, FLS 50.8; p = 0.894), economy of motion (median: control 7.75, VR 4.6, FLS 4.6; p = 0.524) and error score (median: control 277.95, VR 156.8, FLS 190.2; p = 0.434)

10.3.3 Technical skills training

The VR group had a median training time of 273.33 minutes (range = 190 – 295 minutes), and the FLS group had a median training time of 173.92 minutes (range = 67.25 – 287 minutes).

10.3.4 Learning curve analysis

Learning curves were plotted for each group’s performance on five CPLC’s. The control group demonstrated no significant improvement in time from CPLC 1 to CPLC 2 (median 3375.6 vs. 2728.5, p= 0.214). There was no significant improvement by the third
CPLC (median 3375.6 vs. 2403.65, p= 0.197), or the fourth CPLC (median 3375.6 vs. 2353.6, p=0.07). Significant improvement in time was reached by the fifth CPLC (median 3375.6 vs. 2354.9, p=0.095) (Figure 41). There was no significant improvement in performance along the learning curve from CPLC 1 to 5 for both path length and hand movements (p<0.05) (Figure 42 and 43).

The VR training group demonstrated no significant improvement in time for any of the five CPLC. CPLC 1 to CPLC 2 (median 1781.0 vs. 2192.7, p=0.953); CPLC 1 to CPLC 3 (median 1781.0 vs. 1643.7, p=0.717); CPLC 1 to CPLC 4 (median 1781.0 vs. 1783.9, p=0.769); and CPLC1 to CPLC5 (median 1781.0 vs. 1797.3, p=0.525) (Figure 41). This was reciprocated for path length and hand movements, with no significant improvement in performance along the learning curve from CPLC1 to CPLC5 (p<0.05) (Figure 42 and 43).

The FLS group demonstrated no significant improvement in time from CPLC1 to CPLC2 (median 2853.6 vs. 2180.9, p=0.735). There was significant improvement in time by the third CPLC (median 2853.6 vs. 2081.9, p=0.018). There was further significant improvement in time by CPLC 4 (p=2853.6 vs. 1423.3, p=0.029). There was no further significant improvement by CPLC5 (median 2853.6 vs. 1454.1, p=0.066) (Figure 41). There was no significant improvement in performance for path length and hand movements along the learning curve from CPLC1 to CPLC5 (p<0.05) (Figure 42 and 43).
Figure 41 – Learning curves for all groups for time
Figure 42 – Learning curves for all groups for path length
Figure 43 – Learning curve for all groups for hand movements
Kruskal Wallis analysis was performed to identify significant differences in performance between the groups for each CPLC. There was a significant difference in performance between the groups for time for CPLC1 (median - control 3375.6, VR 1781.0, FLS 2853.6 seconds, p = 0.019) (Figure 44). There was no significant difference in time between the groups for CPLC2 (median - control 2728.5, VR 2192.7, FLS 2728.5, p=0.287) or CPLC3 (median – control 2403.65, VR 1643.7, FLS 2081.8, p=0.519); and CPLC 4 (median – control 2353.6, VR 1783.9, FLS 1423.3, p=0.294). However, by CPLC5, there was a significant difference in performance between the three groups (median – control 2504.9, VR 1797.3, FLS 1454.1, p=0.015) (figure 45). There was no significant difference in performance between the three groups for path length or hand movements for CPLC1, CPLC2, CPLC3, CPLC4 or CPLC5 (p<0.05) (figures 42 and 43).

Intergroup analysis for each CPLC demonstrated that CPLC 1 had significant differences in performance for time between the control group and VR group (median control 3375.6, VR 1781.0 seconds, p=0.007). There was no significant difference in time for CPLC 1 between the control group and the FLS group p (median – control 3375.6, FLS 2853.6 seconds, p = 0.101).There was also no significant difference in performance between the VR group and the FLS group (median – VR 1781.0, FLS 2853.6 seconds, p=0.368) (Figure 44).

As previously discussed there were no significant differences between the groups for time during CPLC 2, CPLC 3 or CPLC 4, therefore further intergroup analysis was not performed. For CPLC 5, there was a significant difference in time between the control group and the VR group (median - control 2504.9, VR 1797.3 seconds, p =0.02) There was also a significant difference in time for CPLC 5 between the control group and the FLS group (median - control2504.9, FLS 1454.1 seconds, p=0.011). There was no significant difference
in time for CPLC 5 between the VR group and the FLS group (median – VR 1797.3, FLS 1454.1 seconds, p =0.56). As previously discussed, there were no significant differences between the three groups for path length or hand movements for any of the five CPLC’s (p>0.05), therefore further intergroup analysis was not performed (Figure 45).
Figure 44 - Graph to show difference in performance for time between all groups for CPLC1
Figure 45 - Graph to show difference in performance for time between all groups for CPLC5
10.3.5 Transfer effectiveness

Each group plateaued at different rates. There were significant differences in performance between the groups for CPLC 1, with the VR group performing CPLC 1 significantly quicker than the control group (median control 3375.6, VR 1781.0 seconds, p=0.007). Equivalence in performance was achieved by the control group on CPLC 4 and for the FLS group by CPLC 1 (median control 2353.6, VR 1781.0, FLS 2853.6; p= 0.502). This was deemed the nominal proficiency level.

The mean total operating time to reach the nominal proficiency level for the control group was 10861.35 seconds. The total operating time for the VR group was 1781.0 seconds, with a total training time on the VR simulator of 16400.00 seconds (273.33 minutes). This equates to a transfer effectiveness of 0.55 for the VR simulator ((10861.35 – 1781.0)/16400). Therefore, every second spent on the VR simulator is equivalent to 0.55 seconds in the OR.

The total operating time for the FLS group was 2853.6 seconds, with a total training time of 10435.29 seconds (173.92 minutes). This equates to a transfer effectiveness of 0.77 for the FLS box ((10861.35 – 1781.0)/10435.29). Therefore, every second spent training on the FLS box is equivalent to 0.77 seconds in the OR.

10.4 Cost analysis

10.4.1 Cost efficiency analysis of simulation and the number needed to train

The transfer effectiveness is defines how much time spent on the simulator is equivalent to time spent in the OR. Therefore, by practising technical skills in the skills laboratory beforehand, it would reduce the total time taken to complete the learning curve for a procedure in the OR. By analysing the cost per minute of OR function, this reduction in OR time would equate to a cost saving to a hospital purely from training in the skills laboratory.
10.4.2 OR cost

OR costs were analysed for Imperial College NHS Trust for the year 2009-2010. Total OR cost was analysed by evaluating the cost per hour of salaries for anaesthetic consultants, operating department practitioners, theatre nurses, health care assistants, recovery nurses and mean cost of equipment and sterilisation services. This was combined and a cost per minute of OR function was determined. Surgeons’ salaries were not included in the analysis. This equated to a total OR cost of £7.58/minute. This method has been previously used in the literature for assessing costs of operating room function (Bridges and Diamond, 1999).

10.4.3 Defining the learning curve for laparoscopic cholecystectomy (LC)

To assess the cost of training in the OR, it was necessary to define the length of the learning curve for laparoscopic cholecystectomy in the OR. A literature search of Pubmed (MEDLINE) was performed using the search terms “laparoscopic cholecystectomy” AND “learning curve”. Twenty five abstracts were analysed to determine studies that quoted a figure for the learning curve of laparoscopic cholecystectomy. Fourteen full papers that met these inclusion criteria were analysed and data was extracted that described the number of cases during the learning curve for laparoscopic cholecystectomy, and the average time to complete the procedure.

Fourteen papers analysed 32,523 operations. The mean number of cases documented to complete the learning curve was 61, with an average time to complete of 89 minutes. This gives a total OR time of 5429 minutes to complete the learning curve for laparoscopic cholecystectomy in the OR. The cost per minute of OR time is £7.58 per minute. Therefore, the total cost of the learning curve for laparoscopic cholecystectomy:
(Cost per minute in OR) x (Total time to complete learning curve) = 7.58 x 5429

= £41,151.82.
10.4.4 Cost of training in the VR laboratory

To train in the VR laboratory on the Lapmentor VR simulator requires substantial upfront costs. The simulator cost £100,000 with a £3,000 annual subscription for maintenance. Dedicated technicians are required to provide access for trainees and assistance for training, which equates to £24,000 per annum for one member of staff. Laboratory technician costs based on a 40 hour week equate to £0.19 per minute.

**Total cost to train one trainee to proficiency:**

\[ \text{Total cost} = \text{Cost of VR simulator} + \text{maintenance cost} + (\text{total VR training time} \times \text{technician cost per minute}) \]

\[ = £100,000 + £3,000 + (273.33 \times 0.19) \]

\[ = £103,052.57 \]

**Training time for the VR simulator is 273.33 minutes, therefore total cost of VR training per trainee per minute:**

\[ \text{Cost per minute} = \frac{\text{Total VR training costs}}{\text{Total VR training minutes}} \]

\[ = \frac{103,052.57}{273.33} \]

\[ = £377.02 \text{ per trainee per minute} \]
Simulator costs per trainee reduce with increasing numbers of trainees. Technician cost per minute is fixed regardless of how many students train, however as each trainee requires the same amount time to train at different times, total technician costs will increase with increased numbers of trainees. Therefore to train 100 trainees to proficiency on the VR simulator the cost per trainee equates to:

<table>
<thead>
<tr>
<th>Total Cost of training 100 trainees:</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Cost of VR simulator + maintenance cost + (VR training time x number of trainees x technician cost per minute)</td>
</tr>
<tr>
<td>= £100,000 + £3,000 + (273.33 x 100 x 0.19)</td>
</tr>
<tr>
<td>= £108,193.27</td>
</tr>
</tbody>
</table>

Total cost of VR training per trainee:

= (Total cost / number of trainees)

= £108,193.27/100

= £1081.93

Total cost per trainee per minute:

= Total cost per trainee / number of minutes trained for one trainee

= (1081.93/273.33)

= £3.96 per trainee per minute
10.4.5 Number needed to train on the Lapmentor VR simulator

This study demonstrates that VR simulation using the Lapmentor simulator has a transfer effectiveness of 0.55. Therefore, every minute spent on the VR simulator is the equivalent of 0.55 minutes in the OR.

Therefore, VR training to proficiency is equivalent to OR time:

\[
\text{Transfer effectiveness equivalent operating room time:}
\]

\[
= VR \text{ training time} \times \text{TER}
\]

\[
= 273.33 \times 0.55
\]

\[
= 150.33 \text{ minutes}
\]

- Total time to complete the learning in the OR for laparoscopic cholecystectomy in the OR is 5429 minutes. Therefore, by training to proficiency on the VR simulator before entering the OR, it will reduce the total OR time for the learning curve by the equivalent OR time calculated:

\[
\text{With prior VR training, total OR time:}
\]

\[
= \text{Learning curve in the OR} - (\text{VR training time} \times \text{TER})
\]

\[
= 5429 - (273.33 \times 0.55)
\]

\[
= 5278.67 \text{ minutes}
\]
Innovation in surgical training and its impact on healthcare
PhD thesis

- **Cost for one trainee:**
  - Cost of OR time = £7.58 per minute; cost of VR time for one trainee = £377.02 per minute. Therefore, total cost to complete the learning curve for one trainee in the OR if VR training is performed beforehand:

  \[
  \text{Total cost of the learning curve for laparoscopic cholecystectomy with prior VR training for one trainee:}
  \]
  \[
  = (\text{VR training time} \times \text{cost of VR per minute}) + [(\text{Total length of learning curve} - (\text{VR training time} \times \text{TER})) \times \text{OR cost per minute}]
  \]
  \[
  = (273.33 \times 377.02) + [(5429 - (273.33 \times 0.55)) \times 7.58]
  \]
  \[
  = £143,063.18
  \]

- **Cost for 100 trainees:**
  - Cost of OR time = £7.58 per minute; cost of VR time for 100 trainees = £3.96 per minute. Therefore, total cost to complete the learning curve for one hundred trainees in the OR if VR training is performed beforehand:

  \[
  \text{Total cost of the learning curve for laparoscopic cholecystectomy for one trainee with prior VR training for one hundred trainees:}
  \]
  \[
  = (\text{VR training time} \times \text{cost of VR per minute}) + [(\text{Total length of learning curve} - (\text{VR training time} \times \text{TER})) \times \text{OR costs per minute}]
  \]
  \[
  = (273.33 \times 3.96) + [(5429 - (273.33 \times 0.55)) \times 7.58]
  \]
  \[
  = £41,094.69
  \]
To determine the number needed to train on the VR simulator to make it cost efficient for a hospital, the cost allowance for each trainee must be determined. This is calculated by using the total cost of training only in the OR as the maximum total cost permitted for training if VR training is used beforehand.

<table>
<thead>
<tr>
<th>Without training in VR, total costs of training in the OR:</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Length of learning curve in OR x cost per minute of OR function</td>
</tr>
<tr>
<td>= 5429 x 7.58</td>
</tr>
<tr>
<td>= £41,151.82</td>
</tr>
<tr>
<td>Therefore, if VR is cost efficient, total training costs of VR training and OR training must be less than £41,151.82.</td>
</tr>
<tr>
<td>i.e. VR training cost + subsequent OR training cost &lt; £41,151.82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost allowance for VR training:</th>
</tr>
</thead>
<tbody>
<tr>
<td>= (Total cost of learning curve in OR) – (OR time if VR training performed x OR cost per minute)</td>
</tr>
<tr>
<td>= 41,151.82 – (5278.67 x 7.58)</td>
</tr>
<tr>
<td>= £1139.51</td>
</tr>
</tbody>
</table>

Therefore, the maximum cost allowance per trainee permitted to train to proficiency on VR is £1139.51. As previously discussed, the cost of the VR simulator reduces with increasing numbers of trainees. Technician cost per minute is fixed regardless of the number of trainees. However, 100 trainees require 100 times the total training time, therefore total technician costs will increase with increased numbers of trainees.
To determine the number needed to train:

**Training allowance per trainee per minute:**

Training allowance = VR cost per minute for N trainees x VR training time for one trainee

*Therefore:*

VR cost per minute for N trainees = Training allowance / VR Training time

= £1139.51 / 273.33 minutes

= £4.17 per trainee per minute

**If total cost per trainee per minute for 100 trainees (Page26):**

= [(Simulator cost + maintenance cost + (100 x VR training time x technician cost per minute))/100] / 273.33

Then total cost per trainee per minute for N trainees equals:

= [(Simulator cost + maintenance cost + (N x VR training time x technician cost per minute))/N] / 273.33

= [(100000 + 3000 + (N x 273.33 x 0.19))/N] / 273.33

= [(103000/N) + (273.33 x 0.19)] / 273.33

= £4.17

**Therefore N (Number needed to train):**

N = 103000 / [(4.17 x 273.33) – (273.33 x 0.19)]

= 94.71

Number needed to train = **94.71**

- Therefore, the Number needed to train (NNT) on the Lapmentor VR simulator to make it cost efficient to an institution is **94.71 trainees** (Figure 46 and 48)
Figure 46 - Graph demonstrating the reduction in costs when increased numbers of trainees use VR simulator

Total cost of learning curve in OR with VR training

Cost of training only in OR and associated number needed to train

Cost
### Figure 47 – Transfer effectiveness and cost of operating room function

<table>
<thead>
<tr>
<th>Training group</th>
<th>Training time</th>
<th>OR time to proficiency (seconds)</th>
<th>Transfer effectiveness</th>
<th>Number of trainees</th>
<th>Total training time (minutes)</th>
<th>Training room Cost per minute</th>
<th>Equivalent operating room time (minutes)</th>
<th>Operating room time (minutes)</th>
<th>Operating room cost per minute</th>
<th>Total cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-</td>
<td>195.68</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5429</td>
<td>7.58</td>
<td>£41,151.82</td>
</tr>
<tr>
<td>VR</td>
<td>273.33</td>
<td>29.68</td>
<td>0.55</td>
<td>1</td>
<td>273.33</td>
<td>377.02</td>
<td>150.33</td>
<td>5278.6685</td>
<td>7.58</td>
<td>£143,063.18</td>
</tr>
<tr>
<td>VR</td>
<td>273.33</td>
<td>29.68</td>
<td>0.55</td>
<td>100</td>
<td>273.33</td>
<td>3.96</td>
<td>150.33</td>
<td>5278.6685</td>
<td>7.58</td>
<td>£41,094.69</td>
</tr>
<tr>
<td>FLS</td>
<td>173.92</td>
<td>47.56</td>
<td>0.77</td>
<td>1</td>
<td>173.92</td>
<td>10.07</td>
<td>133.91</td>
<td>5295.0816</td>
<td>7.58</td>
<td>£41,888.09</td>
</tr>
<tr>
<td>FLS</td>
<td>173.92</td>
<td>47.56</td>
<td>0.77</td>
<td>100</td>
<td>173.92</td>
<td>2.31</td>
<td>133.91</td>
<td>5295.0816</td>
<td>7.58</td>
<td>£40,538.47</td>
</tr>
</tbody>
</table>
**Figure 48 – Number needed to train for different simulation modalities**

<table>
<thead>
<tr>
<th>Group</th>
<th>Total cost to complete learning curve in OR without simulation training (OR cost x total OR time)</th>
<th>Total time to complete learning curve in OR WITH simulation training (Total OR time – (Training time x TER))</th>
<th>OR cost per minute</th>
<th>Training allowance for simulation (Total OR cost – (Equivalent OR time x OR cost per minute))</th>
<th>Fixed training costs (costs per trainee)</th>
<th>Variable simulator costs per N trainees</th>
<th>Number needed to train (Variable simulator costs)/(training allowance – fixed training costs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR</td>
<td>£41,151.82</td>
<td>5278.67</td>
<td>7.58</td>
<td>£1139.51</td>
<td>£52.57</td>
<td>£103,000</td>
<td>94.71</td>
</tr>
<tr>
<td>FLS</td>
<td>£41,151.82</td>
<td>5295.08</td>
<td>7.58</td>
<td>£1015.10</td>
<td>£355.82</td>
<td>£1,361.27</td>
<td>2.18</td>
</tr>
</tbody>
</table>
### 10.4.6 Cost of training in the skills laboratory using FLS

To train in the skills laboratory using FLS requires upfront costs. The FLS box costs £1361.91 with £92.85 required for access to the online content per trainee. To complete the FLS training program requires considerable non-reusable equipment, with a mean of 72 sutures and endoloops required, costing £185.60 per trainee. Additional FLS equipment (penrose drains and gauze) is required for trainees to complete all tasks which cost £77.37 per trainee. A dedicated technician is required to provide access for trainee and assistance for training, which equates to £24,000 per annum for one member of staff. Technician costs based on a 40 hour week equate to £0.19 per minute. Therefore, total cost to train one trainee to proficiency on the FLS box:

**Total cost to train one trainee to proficiency on FLS:**

\[
\text{Total cost to train one trainee to proficiency on FLS:} = \left[ \text{Cost of FLS box} + \text{online access} + \text{consumables} + \text{extra FLS equipment} + (\text{total training minutes} \times \text{faculty training cost per minute}) \right]
\]

\[
= [1361.91 + 92.85 + 185.60 + 77.37 + (173.92 \times 0.19)]
\]

\[
= £1750.83
\]

**Total cost of FLS training per trainee per minute:**

\[
= \frac{\text{Total FLS training costs}}{\text{Total FLS training minutes}}
\]

\[
= £1750.83 / 173.92
\]

\[
= £10.07 \text{ per trainee per minute}
\]
Faculty cost per minute, consumables and online access costs *per trainee*, are fixed regardless of how many students train as each student requires them to complete the FLS. Therefore, as more trainees use them, the *total cost* of FLS online access, consumables and extra equipment increases. However, the *total cost* of the FLS box is variable as all trainees will use the same box, with a reduction in cost with increased numbers of trainees. Therefore to train 100 trainees to proficiency on the FLS box the cost per trainee equates to:

\[
\text{Total cost of training 100 trainees:} \\
= \text{Cost of FLS box} + [\text{Number of trainees} \times (\text{online access + consumables + extra FLS equipment}) + (\text{total training minutes} \times \text{faculty training cost per minute})] \\
= 1361.97 + [100 \times ((92.85 + 185.6 + 77.37) + (173.92 \times 0.19))] \\
= £40,248.06 \\
\]

\[
\text{Total cost of FLS training per trainee:} \\
= £40,248.06 / 100 \\
= £402.48 \\
\]

Training time on the FLS box is 173.92 minutes, therefore, total cost per trainee per minute if 100 trainees are using the FLS box:

\[
= (\text{total cost of FLS per trainee}) / \text{number of minutes per trainee} \\
= 402.48 / 173.92 \\
= £2.31 \text{ per trainee per minute} \\
\]
10.4.7 Number needed to train on FLS

This study demonstrates that simulation using the FLS box has a transfer effectiveness of 0.77, therefore every minute spent on the FLS box is the equivalent of 0.77 minutes in the OR.

<table>
<thead>
<tr>
<th>Therefore, FLS training to proficiency is equivalent to OR time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>= FLS training time x TER</td>
</tr>
<tr>
<td>= 173.92 x 0.77</td>
</tr>
<tr>
<td>= 133.92 minutes</td>
</tr>
</tbody>
</table>

- Total time to complete the learning curve in the operating for laparoscopic cholecystectomy in the OR is 5429 minutes. Therefore, by training to proficiency on the FLS box beforehand, it will reduce the total OR time for the learning curve by the equivalent OR time calculated:

<table>
<thead>
<tr>
<th>Transfer effectiveness equivalent operating room time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Learning curve in OR without training = 5429 minutes</td>
</tr>
<tr>
<td>FLS training reduces total learning curve by TER x FLS training time</td>
</tr>
<tr>
<td>0.77 x 173.92  5429 – (0.77 x 173.92) = 5278.67 minutes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>With prior FLS training, total OR time:</th>
</tr>
</thead>
<tbody>
<tr>
<td>= Learning curve in the OR – (FLS training time x TER)</td>
</tr>
<tr>
<td>= 5429 – (173.92 x 0.77)</td>
</tr>
<tr>
<td>= 5295.08 minutes.</td>
</tr>
</tbody>
</table>
• Cost of OR time = £7.58 per minute; cost of FLS for one trainee = £10.07 per minute.

Therefore, total cost to complete the learning curve in the OR if FLS training is performed:

**Total cost of the learning curve for laparoscopic cholecystectomy with prior FLS training for one trainee:**

\[
= (\text{FLS training time} \times \text{cost of FLS}) + (\text{Total length of learning curve} - (\text{FLS training time} \times \text{TER}) \times \text{cost per minute in OR})
\]

\[
= (173.92 \times 10.07) + ((5429 - (173.92 \times 0.77)) \times 7.58)
\]

\[
= £41,888.09
\]

• To determine the number needed to train on the FLS box to make it cost efficient for a hospital, the maximum allowance for each trainee must be determined. This is calculated by using the total cost of training only in the OR as the maximum cost permitted for training costs if FLS training is used beforehand

**Without training in FLS, total costs of training in the OR:**

\[
= \text{Length of learning curve in OR} \times \text{cost per minute of OR function}
\]

\[
= 5429 \times 7.58
\]

\[
= £41,151.82
\]

Therefore, for FLS training to be cost efficient, the total training costs of FLS training + OR training must be less than £41,151.82

I.e. Cost of FLS training + subsequent OR training cost < £41,151.82

**Cost allowance for FLS:**

\[
= (\text{Total cost of learning curve in OR}) - (\text{OR time if FLS training performed} \times \text{OR cost per minute})
\]

\[
= 41,151.82 - (5295.08 \times 7.58)
\]

\[
= £1015.10
\]
Therefore, the maximum cost allowance per trainee permitted to train to proficiency on FLS is £1015.10. As previously discussed, the cost of the FLS box is reduced with increased numbers of trainees. However, the fixed training costs of FLS (online access, consumables and extra FLS equipment) are increased as each trainee requires these. In addition, the technician cost per minute for training is fixed regardless of the number of trainees. However, each trainee requires the same length of training at different times, so total technician costs increases with more trainees using the facility. Therefore, N number of trainees are required to reduce the training allowance to £1015.10, therefore making the simulator cost efficient.

Training allowance for N trainees:

\[ \text{Training allowance} = \text{FLS cost per minute for } N \text{ trainees} \times \text{FLS training time for one trainee} \]

Therefore for N trainees:

\[ \text{FLS cost per minute} = \frac{\text{Training allowance}}{\text{FLS training time}} \]

\[ = \frac{£1015.10}{173.92} \text{ mins} \]

\[ = £5.84 \text{ per trainee per minute} \]

If total cost per trainee per minute for 100 trainees (Page 34):

\[ = \frac{\text{Cost of box} + \left\{ 100 \times (\text{online} + \text{consumables} + \text{extra equipment}) + (\text{training time} \times \text{faculty cost per}) \right\}}{100} \]

\[ 173.92 \]

Then total cost per trainee per minute for N trainees:

\[ = \frac{\text{Cost of box} + \left\{ N \times (\text{online} + \text{consumables} + \text{extra equipment}) + (\text{training time} \times \text{faculty cost per}) \right\}}{N} \]

\[ 173.92 \]

\[ = £5.84 \]
Therefore:

\[
5.84 = \frac{1361.97 + \{N \times (92.85 + 185.60 + 77.37) + (173.92 \times 0.19)\}/N}{173.92}
\]

\[
= \frac{1361.97 + \{N \times (388.87)\}/N}{173.92}
\]

\[
= \frac{[(1361.97/N) + 388.87]/173.92}{173.92}
\]

\[
= £5.84
\]

Therefore N (Number needed to train):

\[
N = 1361.97 / [(5.84 \times 173.92) - 388.87]
\]

= 2.18

The number need to train = 2.18

- Therefore, the Number needed to train (NNT) on the FLS box to make it cost efficient to an institution is **2.18 trainees** (Figures 48 and 49).
Figure 49 - Graph demonstrating the reduction in costs when increased numbers of trainees use the FLS simulator
10.5 Discussion

This study demonstrates the effectiveness of simulation in improving simulated operating room performance and its implications for hospital finances. The VR group did not demonstrate significant improvements along their learning curve, however, they performed the first and fifth CPLC significantly better than the control group. Therefore, training on VR simulation can significantly improve simulated operating room performance. The FLS group demonstrated significant improvement in performance along the learning curve in the operating room, but did not demonstrate any significant difference in performance from the control group until the fifth CPLC. Therefore, training on the FLS box before entering the simulated operating room can improve performance at a quicker rate than no technical training. The FLS and Lapmentor group subjects performed all CPLCs along the learning curve at a similar level, suggesting that both forms of simulation are effective training modalities for improving operating room performance. However, training to proficiency on the VR simulator took longer than training to proficiency on the FLS box (VR group – 273.33 minutes; FLS group – 173.92 minutes), therefore time spent training on the FLS box could be deemed to be more efficient than training on a VR simulator. This is confirmed by analysing the transfer effectiveness ratios, which demonstrate a TER of 0.55 for the VR simulator and 0.77 for the FLS box, implying that every hour spent training on the VR simulator is equivalent to 0.55 hours in the operating room, with every hour on the FLS box being equivalent to 0.77 hours in the operating room. Therefore every hour spent on the FLS box is more efficient in terms of equivalent operating room time than an hour spent on the VR simulator.

Although this chapter demonstrates that simulation training improves your surgical performance in the simulated OR, it is not possible for a surgeon to develop proficiency to
perform operations on real patients by practising on simulators alone. However, it is possible to practice on a simulator, learning and developing basic technical skills such that the first part of the learning curve is reduced. The initial part of the learning curve is often the most dangerous part for the patient with the highest rate of error. The literature review for the learning curve of laparoscopic cholecystectomy in the operating room gives a total length of 5429 minutes. This means that it takes a surgical trainee 5429 minutes of operating room time to reach a plateau of performance in the OR for laparoscopic cholecystectomy, which is considered proficiency in the literature. The TER defines the equivalent time in the operating room for any given length of time training on a simulator. Therefore, training to proficiency on a simulator can reduce the learning curve in the operating room by the TER defined equivalent operating room time that is calculated by the time spent on the simulator. For example, 273.33 minutes on the VR simulator with a TER of 0.57 implies an equivalent operating room time of 150.33 minutes. Therefore, by training on the VR simulator, it reduces total operating room time along a surgeon’s learning curve by 150.33 minutes. This in itself will reduce operating room costs by reducing the total cost of operating room time. In addition to this, by removing the early part of the learning curve from the operating room, it is likely to reduce risk to patients and the cost of any potential morbidity or litigation that could occur from operative error. This cost has not been investigated in this thesis, but it could be substantial.

The number needed to treat is defined as the number of patients that are needed to be treated to prevent one additional bad outcome. This is an epidemiological measure that is usually associated with the use of a medication. This model has been used to design the concept of the “number needed to train”. However, this concept does not take into account patient outcome, instead purely investigating the number needed to train on a simulator to
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make it financially viable to an institution. Simulators and VR simulators in particular can be very expensive upfront purchases. Therefore, it would useful to a hospital or institution to know how many trainees that they would need to make the purchase of a simulator cost efficient, such that they can allocate their resources according to the number of surgical trainees employed. The lower the number needed to train, the more viable the purchase of a simulator becomes. Furthermore, if an institution has a high number of trainees, it may imply the cost benefit of purchasing more than one simulator. The results of this study define the number needed to train on the FLS box is 2.17 with the number needed to train on the Lapmentor VR simulator of 94.71. Therefore it is clear that despite the upfront costs, the purchase of a simulator can be financially viable if an institution has a certain number of trainees. Only three trainees are required to reduce operating room costs enough to make the purchase of an FLS box cost efficient. Most hospitals with surgical departments have in excess of 2 trainees; therefore it can be recommended that all hospitals with surgical departments should invest in at least one FLS box. However, VR simulation has a number needed to train of 94.71, which implies that a hospital would need to have 95 trainees employed before the operating room cost savings would be sufficient to allow the purchase of a VR simulator. Therefore, only large teaching hospitals or universities should consider the purchase of a VR simulation.

This chapter concludes that only large teaching hospitals with substantial numbers of trainees should purchase VR simulators. However, this could lead to a two tier training system, with some trainees not having access to training resources. A framework for regional simulation training could be created using concepts from the airline industry. The “hub and spoke” structure for the provision of air travel is a recognised method within the industry (Nero, 1999). It has been demonstrated that the hub and spoke concept with a large central
airport acting as the hub, with smaller spoke airports, can increase profits by exploiting productive efficiencies with economics of traffic density and staffing. This concept has been adopted by other industries such as the haulage and freight industries to improve cost savings and profit. Although the aim of surgical education is not to make a profit, the concept of the hub and spoke could be utilised for the provision of simulation to try to make cost savings whilst still providing adequate training. Large teaching hospitals, universities or Deaneries could act as a hub, providing access to VR simulators to all trainees from a region, with smaller hospitals acting as spokes, with local access to FLS boxes for all trainees. This would require collaboration of resources between central hubs, but could provide cost savings for hospitals as operating times reduce due to the use of simulators at both a local and regional level.

It is vital to provide the infrastructure for trainees to learn how to operate. However, this is only one part of successful training programs. If hub and spoke structures for simulator provision are put in place, it still requires cooperation between universities or deaneries that may purchase the simulators with the hospitals that enjoy the resulting cost savings. It may be appropriate for this concept to be used by the Academic Health Science Centres (AHSC), where collaboration between hospital and university is already in place. There are currently five AHSCs in the UK which could provide the appropriate infrastructure staffing and finance to provide a hub centre, with cost savings seen by the ASHC itself through improved operating room efficiency (Dzau et al., 2010). University associated outlying hospitals could act as spoke hospitals, and also see cost savings.

This chapter provides important results that demonstrate both the effectiveness of simulation for teaching and training, but also the economic benefit that simulation could provide for the healthcare system. However, this study also has some limitations that should
be discussed prior to making any conclusions. It is important to mention that the TER is based on the airline industry where time in the cockpit is used for the calculation. This can be translated to surgical simulation where time in the cockpit is equivalent to time in the operating room. This study uses a simulated operating room time to calculate the TER. However, the simulated operating room used real tissue, operating room equipment and a realistic operating environment. This method is similar to previous studies in the literature that analyse the TER for surgical simulation (Aggarwal et al., 2007d).

Another important limitation for this chapter is the withdrawal rate of recruits. Thirty doctors were recruited and randomised into three groups. However, there were three recruits that withdrew from the FLS group, with one recruit from both the control group and VR training group that withdrew. All withdrawals were due to the recruits not being able to dedicate the time to the study. This has important implications for both the study results and for the future of surgical training. The FLS group had a 30% withdrawal rate. Therefore if the number need to train on the FLS box is 2.17, if a hospital has a similar withdrawal rate of 30% (roughly one in three) for training on the box, they would require an extra trainee to make the purchase cost efficient. In addition, the VR group had a 10% withdrawal rate, implying that a hospital would require 105 trainees to overcome the withdrawal rate and make a cost efficient purchase.

This also has important implications for surgical training. The necessity for training infrastructure and trainer enthusiasm to be in place has been discussed. However, another vital part of the successful implementation of a simulation into a training program is the willingness and enthusiasm of the trainees. If training opportunities in the operating theatre are reduced, it is vital that the trainees are willing to explore other avenues to gain expertise. They must be willing to embrace simulation, and use it properly rather than sporadically.
before losing interest. This study had 17% withdrawal rate for doctors that were being offered “free” training. The provision of surgical training is not a right, the trainee must be willing to give up their own time and embrace different training opportunities when they arise, which includes spending their own time in the simulation suite to learn and develop technical skills before entering the operating room.

A further limitation of this study is that the VR training group only trained using one VR simulator. Therefore it can only make recommendations for one VR simulator rather than VR simulation as a whole. Further work should focus on the assessment of the number needed to train on the many other VR simulators that are commercially available.

In addition, there are limitations in the analysis of the cost of the learning curve in the operating room. This was performed by analysing the literature for the length of the learning curve and the average time of operating over that learning curve. It does not take into account the proportion of the full operation performed by the trainees. It is likely that at the start of the learning curve, the supervising surgeon would perform part of the operation as the trainee learns the procedure in stages. However, by using simulation prior to entering the operating room, it is likely that the trainee would not spend as much time learning the steps of the procedure or the basic technical skills, as these should have already been learnt in the skills laboratory. Furthermore, the cost of the learning curve purely looks at operating room time. It does not take into account the litigation costs that occur due to surgical error. A surgeon at the start of the learning curve makes more errors than at the end of the learning curve (Moore and Bennett, 1995). Therefore, it is likely that the rate of litigation is higher for surgeons at the start of the learning curve (Carroll et al., 1998). If simulation training shortens the learning curve, thus reducing errors, it is likely to provide additional savings to a hospital
through a reduction in litigation costs. This has not been taking into account when analysing the number needed to train on the simulators.

The explanations for not purchasing a simulator for a hospital have often been justified by the large initial costs. Despite the demonstration that simulation is an effective method for training surgical trainees outside of the operating room, improving their technical skills, operative knowledge and operating room performance. This study provides evidence that although expensive, the initial costs can be recuperated by a hospital by improving operating room efficiency. Using the hub and spoke structure, it can further increase the efficiency, with smaller institutions providing the cheaper FLS box facility, with the hub hospital giving all trainees access to the more expensive VR simulators. This would improve operating room efficiency for all hospitals involved. With large numbers of trainees using the simulators regularly, it could even start to provide profit with substantial reduction in operating room costs.

Further work in this area should focus on the actual costs savings for specific hospitals depending on the amount of trainees they have. It would provide evidence for a geographical assessment of where hub and spoke hospitals should be placed. This would allow national recommendations to be made for the development of hub simulation centres, with associate spoke hospitals, and allow the formal incorporation of simulation into national training programs.
11. Discussion

11.1 Aims of thesis

Changes in healthcare and working hour legislation have had a detrimental effect on surgical training with a decrease in training opportunities that are available to the surgeon in training. It has been suggested that current surgeons will work for 6,000 hours between senior house officer and consultant posts compared to the 30,000 hours for previous generations of surgeons. It is vital to overcome this shortfall in “training hours” to ensure that future generations of surgeons have sufficient training opportunities to become competent consultant surgeons. However, in this age of austerity and cost savings, it is vital that surgical training is delivered such that surgical trainees are provided with effective training that is organised in a cost efficient manner.

The aims of this thesis were:

1. To investigate the current state of surgical training and the impact of the reduction in working hours for doctors
2. To evaluate the impact of virtual reality simulation on surgical training
3. To assess the impact that innovations in surgery have had on training
4. To establish the importance of proficiency based curricula for technical skills training
5. To assess the current cost of surgical training
6. To establish the most efficient way of training surgical technical skills
11.2 Development of a cost efficient and effective training program

Surgical training must evolve to allow the formal introduction of laboratory based training to augment its effectiveness. It is clear from the evidence provided in the literature that simulation training works, by improving technical skills of surgical trainees at the start of their careers. However, this has often been demonstrated through the provision of expensive simulators that are not available to all trainees. It has not been clear whether simulation training can be provided in a cost efficient manner to the hospital, whilst still providing the benefits of technical skill enhancement that is required by the surgical trainee.

Simulation has been heralded as an appropriate method for teaching technical skills for surgical training. Initial research aimed at the feasibility of simulation before progressing to establishing the appropriateness of the use of simulation technologies. There has since been extensive evidence published in the literature that validates the use of simulation for surgical training, by demonstrating face, content, construct and concurrent validity of various simulation modalities. Once established as a valid training tool, simulation research progressed to define expert derived proficiency levels with the development of proficiency-based training curricula that allow trainees to learn in a step wise manner. It is clear from this that simulation is a feasible and valid training modality; but more importantly, simulation works.

This thesis has advanced the evidence base for the use of simulation by analysing how simulation is currently used for surgical training, and what changes have occurred through innovations in operative surgery and innovations in simulator technology. It has then progressed to analysing the cost efficiency of simulation based training such that simulation can be fully integrated into training programs, to enhance the quality of surgical training whilst providing cost savings to hospitals and institutions that purchase the simulators.
The question now is where does simulation research go from here? To date the majority of simulation based research has been performed in the skills laboratory, with both training and the assessment taking place on simulation platforms such as bench top, VR, cadaveric or live porcine models. Despite this, there is limited evidence looking at the transfer of technical skills to operating room performance. There is a need for large randomised controlled trials looking at the transfer of skills onto real patients to assess the true impact of simulation training. This next step is vital to increase the adoption of simulation based training at a national level.

However, it is just the start, as VR to OR studies only give the immediate impact of simulation training when the trainee enters the operating room. Longitudinal studies are required to look at the long term impact of simulation training. The concept of predicative validity of a simulator requires prior training on a simulator with assessment in the operating room after a significant period of time. This would allow simulators to predict the level of surgical competence at an early stage. This type of simulation research would have important implications for training boards for both the selection of trainees and the development of personalised training programs. With accurate predicative validity, surgical training programs could conceivably select individual candidates that have the technical aptitude to excel in surgery, ensuring that resources are not wasted with only the best candidates selected for higher surgical training. In addition, once trainees are placed into training programs, predictive validity would allow the development of personalised training programs, identifying trainees that may require on-going simulation training prior to entering the operating room. This could ensure that all trainees are able to develop key competencies by the end of their training program.
This thesis provides evidence supporting the cost efficiency of simulation training, with cost savings due to operating room efficiency demonstrated following simulation training. However, a criticism of the thesis is that it does not assess the cost effectiveness of simulation, with no assessment of the impact on patient outcome. In the UK, the National Institute for Health and Clinical Excellence (NICE) produces guidelines for trusts and clinicians regarding various drugs, procedures and operations that should be available to patients. The cost effectiveness is assessed by demonstrating the impact that a drug or procedure has on patient outcome by assessing the Quality Adjusted Life Years (QALY) following its use. Large scale VR to OR studies would allow an assessment of patient outcome following simulation training and the establishment of the cost effectiveness of simulation training. This could lead to the development of guidelines by NICE, recommending the full incorporation of simulation training at a National Level.

Further questions arise from this thesis, specifically regarding the cohort selection for simulation based research studies. There are many studies in the literature that use medical students as study participants, as they are a unique cohort that are naïve in terms of surgical exposure, but are medically trained and have few scheduling issues. As a result it appears that they would be ideal candidates to take part in simulation research projects which require large time commitments. The work in this thesis has used both medical students and doctors as study participants. Although recruiting medical students is easier in terms of organising a research project, the data collected can be limited. It provides useful information regarding the effect of simulation training on novice surgeons. However, the aim of simulation research is for it to be used by surgical trainees, the majority of whom have some surgical experience. In addition, although training medical students on simulation should be encouraged, the majority will not enter the operating room for years after training, by which time the previous
training they received is likely to be redundant. Future work in this area should aim to use qualified doctors and surgical trainees as the participants in research projects. In this thesis, fully qualified doctors at the start of their surgical training have been recruited for research. This resulted in many difficulties in terms of scheduling and last minute cancellations due to clinical commitments, which in turn extends the length of the research study. However, the information obtained is more relevant to clinical practice and provides stronger evidence towards the effectiveness of simulation. The use of qualified doctors as recruits would also allow transfer to OR studies to take place, as surgical trainees can be assessed in the operating room immediately after simulation training takes place.

Surgical trainees have a finite amount of time in which they must develop key competencies to become a consultant surgeon. Efficiency in training is key to ensure that trainees do not waste time and maximise training opportunities when they arise. This thesis has advanced the literature in terms of using simulation both for basic surgical training and for advanced surgical training. Therefore, to ensure that training time is efficient, it is vital that the selection of simulation modality is based on the experience and training requirements of the individual trainee. As the complexity of tasks and procedures that are taught increases, so must the fidelity of the simulator that is used. This would allow the development of a training model for all surgical trainees that match the fidelity of the simulator to each stage of their career. For example, trainees could be divided into novice, lower, intermediate and higher surgical trainees, each based on their clinical level, each with differing training requirements (figure 50 and 51):
Figure 50 – Structured simulation training with fidelity of simulator matched to training requirement

Novice surgical trainees (NST)
Foundation year 1 and 2
• Should use bench top simulation, developing basic surgical skills on low fidelity, inexpensive models and laparoscopic box trainers.
• This should be completed prior to entering the operating room allowing the trainee to develop basic skills
• This would allow them assist safely and competently in the operating room

Lower surgical trainees (LST)
• Core surgical trainee year 1 and 2
• Should advance to laparoscopic technical skills training using validated technical skills curricula such as the Fundamentals of Laparoscopic Surgery (FLS) and task based VR simulators.
• This should occur prior to the trainee performing operations as the primary surgeon.
• The trainee would have developed basic laparoscopic skills, such that in the operating room they can concentrate on the operation itself.

Intermediate surgical trainees (IST)
• Specialist trainees 3 and 4
• Should use procedure based virtual reality simulation, staring with basic operations such as laparoscopic cholecystectomy and advancing to more complex procedures such as laparoscopic ventral hernia repair.
• Assessments could take place using validated cadaveric tissue models.
• This would allow the trainee to learn the specific techniques required to complete the operations, as well as developing other skills such as operative planning and decision making.
• It would be optimal for the trainee to learn and perfect a procedure in VR prior to attempting it on a patient.

Higher surgical trainees (HST)
• Specialist trainees 5-8
• Should use high fidelity, high complexity simulators such as procedure based VR simulator or live porcine simulators.
• This would allow trainees to develop the skills required to perform complex procedures such as laparoscopic bariatric and colorectal procedures.
• Ensuring that trainees learn and perfect operations on simulators prior to attempting on real patients would highlight the difficulties and potential pitfalls of the procedure.
Figure 51– Development of a cost efficient and effective training program
However, despite the evidence in the literature and provided by this thesis, more work needs to be done to fully integrate simulation training into formal training programs. As previously discussed, a hub and spoke model for simulation training would allow access to both low and high fidelity simulation to all trainees within a region. To enable this, it is vital to have support and administrative infrastructure of training board and program directors. In 2008, the London Deanery and NHS London launched the Simulation and Technology-enhanced Learning Initiative (STeLI) to promote the use of powerful educational technologies including simulation to enhance healthcare delivery and improve the quality of service. The STeLI group has provided simulation based technologies to all 32 London acute hospital trusts as well as developing a specialist simulation training facility at the London Deanery. This is the first step into mainstream incorporation of simulation to all levels of surgical trainees. However, more needs to be done. Structured simulation training is vital and to enhance its effectiveness, it needs to be used correctly with fidelity matched to surgical level. An organisation such as STeLI has the finance and infrastructure available to incorporate the proposed training structure (Figures 50 and 51) into formal training programs. Nationwide policy initiatives need to be put in place to ensure that simulation is adopted at all levels of training.

Another method for increasing the adoption of simulation at a national level focuses on the use of incentives to both training programs and individual trainees. This thesis has already discussed that simulation training can be provided in a cost efficient manner, where the upfront costs of purchasing the simulators can be recouped by the consequent reduction in operating room costs following simulation training. This provides an incentive to a trust or institution to invest in simulation. This can also been demonstrated at an individual level. In the United States, it is already mandatory for surgical residents to complete the FLS training
curriculum, as such it ensures that all new attending surgeons will have completed FLS. However, this is not the case for current practicing surgeons. To address this, Harvard University have used a novel approach by collaborating with CRICO/RMF, the insurance provider for medical practitioners. They developed an initiative whereby surgeons receive a $500 incentive from their insurance provider if they complete the FLS program. This policy is based on the concept that the insurance company will recoup the allocated incentives with a reduction in claims against their insured surgeons. Although a financial incentive such as this is unlikely to occur in the UK within a National Health Service, it does suggest an interesting area of future work. It is clear that simulation works. It improves technical skills, reduces error, decreases operating room time and could potentially reduce litigation costs though an improvement in patient safety. Therefore, by providing incentives to trainees to complete simulation training curricula, it could provide significant cost savings to the NHS.
11.3 Concluding remarks

Surgical training can be augmented with simulation outside of the operating room. Innovations in surgery have led to innovations in surgical simulation. This thesis has discussed the impact of innovation on surgical training and has proceeded to discuss the selection of different forms of simulation modality in terms of their effectiveness at improving technical skills in a cost efficient manner.

Simulation works. This is clear from the literature and from evidence provided by this thesis. Although simulation alone is not sufficient to train surgeons to operating room proficiency, it can provide an adjunct to surgical training, allowing trainees to train in the safety of skills laboratory, and shorten the learning curve in the operating room. If appropriate simulators are selected and used correctly, it can provide benefits to the healthcare system by reducing costs through an improvement in operating room efficiency.

The future of simulation based research for surgical training should aim to incorporate simulation into formal training programs at a national level. This can be done through large scale OR studies analysing predictive validity and cost effectiveness through its impact on patient outcome. By demonstrating the benefits of simulation training in terms of finance, patient outcome and the development of efficient personalised training portfolios; it can be envisaged that policy initiatives could be produced to fully integrate simulation training into national training programs for all surgical trainees.
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13. **Appendix:**

**Figure - Novice group SILS vs. LAP peg transfer time**

**Figure - Novice group SILS vs. LAP peg transfer path length**
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Figure - Novice group SILS vs. LAP peg transfer hand movements

![Box plot showing hand movements comparison between SILS and LAP](image)

Figure - Novice group SILS vs. LAP endoloop time

![Box plot showing endoloop time comparison between SILS and LAP](image)
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Figure - Novice group SILS vs. LAP endoloop path length

![Graph showing comparison between SILS and LAP endoloop path length]

Figure - Novice group SILS vs. LAP endoloop hand movements

![Graph showing comparison between SILS and LAP endoloop hand movements]
Figure - Novice SILS vs. LAP intra-corporeal suture time

Figure - Novice SILS vs. LAP intra-corporeal suture path length
Figure - All groups SILS peg transfer time

Figure - All groups SILS peg transfer path length
Figure - All groups SILS peg transfer hand movements

Figure - All groups SILS endoloop time
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Figure - All groups SILS endoloop path length

![Graph showing path length for different groups.]

Figure - All groups SILS endoloop hand movements

![Graph showing hand movements for different groups.]

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Figure - All groups SILS Intra-corporeal suture time

Figure - All groups SILS Intra-corporeal suture path length
Figure - All groups SILS Intra-corporeal suture hand movements