

**THE IMPACT OF COGNITIVE TASK ANALYSIS IN ORTHOPAEDIC TRAUMA
AND KNEE SURGERY SIMULATION TRAINING**

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Declaration of Originality

I hereby declare that this thesis is entirely my own work and any additional material has been appropriately cited.

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Abstract

Background: Virtual reality and cadaveric simulation are expensive and not readily accessible. Innovative and accessible training adjuncts are required to help meet training needs. Cognitive Task Analysis (CTA) has been used extensively to train pilots and in other surgical specialties. However, the use of CTA's within orthopaedics is in its infancy.

Aim: The aim of this thesis was to evaluate the effectiveness of CTA to train novices in femoral intramedullary nailing and diagnostic knee arthroscopy.

Methods: Design - A modified Delphi technique was used from three expert orthopaedic surgeons to design a Generic Cognitive Task Analysis (GCTA) Wizard tool. This tool was used to generate a femoral intramedullary nailing CTA tool. A similar technique was employed to design a CTA tool on diagnostic knee arthroscopy. The format of these CTA tools allowed the use of written and audio-visual modalities simultaneously to learn each phase of the surgical procedure.

Validation – A Randomized Controlled Trial (RCT) was undertaken with novice undergraduate medical students. They were randomized into two equal groups using either the CTA learning tool or a standard operative technique manual. Assessment was undertaken using the validated Touch SurgeryTM assessment tool on femoral intramedullary nailing.

A separate RCT was undertaken with junior orthopaedic trainees who were novices in diagnostic knee arthroscopy. They were assessed on a high fidelity phantom limb simulator using the validated ASSET global rating scale.

Results: The post test results analysis showed that the intervention group using the femoral nailing CTA tool significantly outperformed the control group. Similarly, the group using the knee arthroscopy CTA tool had significantly higher ASSET scores compared to the control group.

Conclusions: This research designed the first CTA learning tools in orthopaedic training. They demonstrated significant objective benefits to train novices in femoral intramedullary nailing and diagnostic knee arthroscopy.

Research Output

List of publications: -

- **Bhattacharyya R**, Davidson D, Sugand K, Bartlett M, Bhattacharya R, Gupte CM. Knee arthroscopy simulation: a randomized controlled trial evaluating the effectiveness of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) tool. **J Bone Joint Surg Am** 2017 Oct 4;99(19): e103.
- **Bhattacharyya R**, Sugand K, Al-Obaidi B, Sinha I, Bhattacharya R, Gupte CM. Trauma simulation training: a randomized controlled trial evaluating the effectiveness of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool. **Acta Orthopaedica** 2018 Oct 17, 17:1-7.
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- Knee arthroscopy simulation: a randomized controlled trial evaluating the effectiveness of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) tool. BOA, Liverpool, UK. Simulation free papers award session, 21/09/2017 – podium.
- Knee arthroscopy simulation: a randomized controlled trial evaluating the effectiveness of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) tool. American Association of Orthopaedic Surgeons, New Orleans, USA. 08/03/2018 – poster.
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- Knee arthroscopy simulation: a randomized controlled trial evaluating the effectiveness of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) tool. British Orthopaedic Research Society (BORS), London, UK. 05/09/2017 – poster.
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- Trauma simulation training: a RCT evaluating the effectiveness of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool. BOA, Liverpool, UK. Innovation in simulation award session, 21/09/2017 – podium.

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<http://wwwf.imperial.ac.uk/blog/surgeryandcancer/2017/07/27/cutting-edge-research-on-the-future-training-of-orthopaedic-surgeons/>
- New tool improves surgical training. Orthopaedics this week, 17.10.2017.
<https://ryortho.com/2017/10/the-genetic-origins-of-spinal-stenosis-robust-steroid-study-for-knee-oa-new-tool-improves-surgical-training/>

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Glossary of Abbreviations

ACGME	Accreditation Council for Graduate Medical Education
ACL	Anterior Cruciate Ligament
ASSET	Arthroscopic Surgical Skill Evaluation Tool
CTA	Cognitive Task Analysis
DP	Decision Points
EWTD	European Working Time Directive
FINCTA	Femoral Intramedullary Nailing Cognitive Task Analysis
GCTA	Generic Cognitive Task Analysis
IFINCTA	Imperial Femoral Intramedullary Nailing Cognitive Task Analysis
IKACTA	Imperial Knee Arthroscopy Cognitive Task Analysis
OSATS	Objective Structured Assessment of Technical Skill
PCL	Posterior Cruciate Ligament
RCT	Randomized Controlled Trial
SAC	Specialty Advisory Committee
TCS	Task Completion Score
TS	Technical Steps
VR	Virtual Reality

Chapter 1: Introduction

1.1 Background

Recent drawbacks of surgical training

Surgical training requirements have undergone significant changes over the years. In 1889, Sir William Halsted introduced a German residency style teaching in North America (1). Over a century later, this model still forms the basis of surgical training in North America and the United Kingdom. In this system technical skills, clinical experience and cognitive decision making is developed over years of cumulative experience (2). The craft is taught through proctorship where a trainee ‘sees one, does one, teaches one’. Albeit traditional and universal, this model may no longer be the most cost-effective method, especially in the current financially austere environment.

Restriction of working hours

With the introduction of the European Working Time Directive (EWTD) (3) across Europe and the 80-hour per week restriction by the Accreditation Council for Graduate Medical Education (ACGME) in the United States of America (4) there are significant strains on surgical training. A study (5) investigated the effect of EWTD on neurosurgical training. They retrospectively reviewed 50 emergency and 50 elective case notes, before and after implementation of the EWTD. There were significant negative effects on training following the implementation of the EWTD. Trainees had far less opportunity to be involved in

outpatient clinics (72% v 60%) and operating theatre sessions (79% v 63%) with their supervising consultant. There was also a significant reduction in the continuity of emergency patient care following the implementation of the EWTD. This study highlighted the negative impact of EWTD on both training opportunities and patient care.

West et al. (6) reported similar negative effect on cardiothoracic training following implementation of the EWTD. A postal and email survey conducted by the Specialty Advisory Committee (SAC) reported 100% of the respondents stating that EWTD had a negative impact on their training. Only 30% were satisfied with the training that they had received. There was a discrepancy in the training amongst different units, with trainees in larger units demonstrating higher satisfaction and greater operating time. However, this survey also showed improvement in the quality of life following EWTD implementation. A limitation of this study was that there was no comparison with similar data from a pre-EWTD cohort. Nonetheless, it still highlighted the poor satisfaction rates amongst cardiothoracic trainees post EWTD implementation in the UK.

The Welsh deanery reported a survey (7) in which 150 Senior House Officer (SHO's) in all surgical specialties, 50 registrars (SPR's) in general surgery and 84 consultants (CONs) in the deanery were recruited. The response rates were 81%, 78%, and 71% for SHOs, SpRs, and CONs, respectively. The majority of respondents were unhappy with the introduction of the EWTD to surgical practice. They reported a negative impact on clinical experience, surgical training and patient care. The majority supported exemption of surgical training from the EWTD regulations. Alarming, 29% SHOs, 41% SpRs, 33% CONs considered leaving the National Health Service if they were forced to work in the EWTD regulations.

Although this study was focused on the welsh deanery, it may well reflect the feeling across the surgical fraternity in the UK.

Training programs are now more structured with required number of procedures and assessments to be undertaken by the trainee before successful completion of training can be achieved. The Specialty Advisory Committee in the UK has specific guidelines and targets that trainees are required to achieve before they are granted a Certificate of Completion of Training (CCT) (8). For example, within trauma and orthopaedic surgery, a minimum of 1800 cases must be recorded over 6 years of training with indicative numbers of certain core procedures in both trauma and elective orthopaedics. Within this timeframe, competence in each of these procedures must be demonstrated as evidenced by Procedure Based Assessments (PBA's). There are similar targets for clinical competence in core clinical cases as evidenced by Case Based Discussions (CBD's) and mini Clinical Exercise Assessments (mini-CEX). Trainees are required to achieve a minimum number of each of these assessments as well as show progression to achieve competency. Additionally, teaching, research and management progression has to be demonstrated in this time period together with successful completion of the exit examinations in the specialty. (8) It is estimated that training hours for surgical trainees have reduced from 30,000 to 6,000 hours (9). Therefore, there is one-fifth the amount of time available now to train a competent surgeon compared to the pre-EWTD training days. With much less training time and more targets to meet, there is tremendous pressure on trainees to achieve the required level of skill and competency.

Senior involvement in service provision

Alterations in hospital management policies have also significantly impacted surgical training. There are quality assurance targets for most hospitals and specialties which have increased pressure on consultants to focus more on service, which is detrimental for training (10).

In 2013, the National Joint Registry (NJR) and the British Orthopaedic Association (BOA) released a joint statement (11) whereby, the outcomes of orthopaedic consultants performing hip and knee replacements are published. Although, this is potentially a good step for quality assurance and patient information, it has the risk of consultants being more protective of their practice. This may negatively impact on training.

With this move towards greater senior involvement in service provision and a trend towards reduced operating out of normal working hours has meant that trainees have lesser opportunity to operate independently (12),(13),(14). Independent operating is important to build trainee confidence at all levels but especially for senior trainees to help them prepare for the transition to being a consultant. Reduced independent operating may therefore have an impact on the confidence and performance of a junior consultant.

A study (15) has shown that trainees on average take double the time to complete procedures compared to consultants. Therefore, with service led initiatives and demands, trainees have fewer opportunities to operate. Trainers find less time for teaching and less opportunities for supervised training in the operating theatre.

Surgical technology and increased complexity of surgical procedures

There are increasing number of surgical techniques with varying levels of complexity which trainees are required to master with limited opportunity. Minimally invasive surgery has grown significantly over the years and now form a key component of most surgical specialties. Laparoscopy and arthroscopy require a different skill set to open surgery and trainees often feel less prepared to perform these skills in the operating theatre. There is a significant learning curve to develop the basic skills required to perform these procedures on patients. Pellegrini et al. (16) recognized the influence of increasing surgical technology on training. Routine open procedures such as appendectomy is now increasingly performed laparoscopically which has increased the learning curve and resulted in more senior involvement in these procedures (17). The authors (16) have recognized the increasing role of simulation to help trainees learn more technically demanding skills in a safe manner.

A study by Wang et al (18) evaluated the learning curve required to develop skills in minimally invasive spinal surgery. The Full Endoscopic (FE) interlaminar approach to lumbar disc surgery is more minimally invasive as compared to the conventional microsurgical technique. 30 patients with lumbar disc herniation were recruited. They were divided into three groups of 10 patients each. The procedure time, complication rates and need for conversion to an open procedure significantly reduced when group A was compared to group B and further reduced when group B was compared to group C. This study showed that the use of increasing and more complex minimally invasive techniques is associated with a significant learning curve. This increases senior involvement as the lead surgeon and reduces trainee operative experience.

Therefore, restricted working hours, service demands and provision and increasing use of complex surgical technology has impacted negatively on surgical training. In this setting it is the need of the hour to develop alternative methods of training which will supplement the existing methods to ensure newly appointed consultant orthopaedic surgeons are well equipped to provide a high quality of care to their patients.

1.2 Simulation:

Definition

Simulation is defined as “any technology or process that recreates a contextual background in a way that allows a learner to experience mistakes and receive feedback in a safe environment (19) .” Simulation provides a safe and controlled environment for trainees to learn and develop basic surgical skills required for a procedure before operating on patients. It allows the opportunity for repeated sustained practice. This minimizes the risk of complications and prioritizes patient safety. It also reduces the learning curve associated with learning new clinical skills, which in turn may improve efficacy of training in the operating theatre.

1.3 Types of Simulation

Simulation can have an impact on different aspects of surgical training. It can help trainees learn cognitive, clinical and technical skills. It can also be used as an effective assessment

tool. The focus of simulation training thus far has been on developing technical skills. Different methods have been tried. These include - cadaveric simulation, synthetic bone simulation and virtual reality simulation.

1) Cadaveric simulation

This form of simulation has been used in surgical training for centuries. It has significant advantages and is therefore very popular amongst trainers and trainees. The main advantages are (20):-

- It allows appreciation of anatomy and anatomical variations
- Trainees can practice dissection and appreciate tissue planes
- It allows practice of surgical approaches
- It resembles reality very closely
- It is high fidelity
- It is shown to develop transferrable operative skills

Research has shown cadaveric simulation to reduce errors amongst surgical trainees (21). Bergeson et al (21) evaluated the benefit of cadaveric training in reducing error rates for thoracic spine pedicle screw placement. Three orthopaedic residents with limited prior experience in pedicle screw placement were recruited in this study. They performed the task

five times each on cadaveric thoracic spine specimens. There was significant decrease in the total screw violation by the third attempt and critical screw violation by the fourth attempt. This study emphasized the need for cadaveric simulation training prior to operating room exposure for orthopaedic trainees.

Spinal surgeons have strongly advocated cadaveric simulation for pedicle screw insertion prior to trainees performing this in the operating theatre (22). A study (22) compared different types of cadavers in terms of resemblance of soft tissue and bony properties to real surgery. 10 senior spinal fellows/consultants with a mean experience of 9.5 years in spinal surgery were recruited. They inserted 2 pedicle screws each in three types of cadavers. Type A was Thiel embalmed, B was formaldehyde embalmed and C was Crosado embalmed. The participants completed a 7 point Likert scoring feedback questionnaire to evaluate these cadavers on the parameters as described above. They were blinded to the type of cadaver they were using as all cadavers were draped in an identical fashion. They also evaluated the role of simulation in spinal surgery and specifically for pedicle screw insertion. The Thiel cadaver scored the highest for soft tissue feel. The Crosado was rated the highest for bony feel. The formaldehyde cadaver scored the lowest for both bony and soft tissue feel. The study also strongly supported cadaveric simulation for spinal surgery and pedicle screw insertion. This study was a questionnaire analysis and therefore has its limitations. There was no objective evaluation of trainee performance on the different cadavers. Furthermore, they recommend cadaveric simulation to form part of the training program. This is entirely based on the feeling of the 10 spinal surgeons recruited in this study. However, it still

compares different cadaver types and indicates the ones that maybe better for bony or soft tissue simulation.

The British Association of Urological Surgeons developed a cadaveric simulation program (23). A study by Ahmed et al (23) evaluated this program with a prospective observational comparative study. 81 urology residents were recruited, who performed various procedures on fresh frozen cadaveric specimens under the supervision of senior urology consultants. After completion of the structured modules, all participants were required to complete an educational survey. The analysis showed face and content validity for this training module in urology. The majority of participants felt that this module improved their skills, gave transferrable skills and was feasible to be incorporated into training programs. This study once again demonstrated subjective satisfaction amongst trainees towards cadaveric simulation. However, there were no objective measurements undertaken to support this form of training. Furthermore, there were no comparative groups used in this study.

Camp et al (24) compared cadaveric and Virtual Reality (VR) simulation for diagnostic knee arthroscopy. They randomized 45 residents into 3 groups (cadaveric training, VR simulation training and control – no training). All participants were assessed objectively on a cadaveric specimen with the validated ASSET score. The cadaveric training group significantly outperformed the VR group both in terms of the objective ASSET scores as well as the time taken to complete the procedure. The VR group did show an improvement compared to the pre-test scores, however in this study this was not statistically significant. The control group showed no difference between the pre-test and the post-test scores. Interestingly, although

this study showed the best objective results for cadaveric simulation, it still suggested that in the long-term VR simulation might be more cost effective than cadaveric simulation.

Despite all the advantages and evidence to support cadaveric simulation training, there are significant disadvantages. It is expensive; difficulty with access to specimens and specialist storage demands; it is time consuming to prepare cadaveric specimens for training; there is reliance on tissue donation to maintain a storage bank; there is a potential risk of disease transmission and there is also a lack of uniformity amongst all specimens (20).

2) Synthetic Bone Simulation

This technique has been a mainstay in orthopaedic simulation training. The main advantages of this form of simulation training are: it is relatively inexpensive to have access to synthetic bones; replica bones are easy to produce because of the consistency of skeletal anatomy; synthetic bones are widely available; excellent for practice of basic fracture fixation techniques without posing any risk to patients; there are minimal storage costs; ethical approval is not required for their use (20).

A study by Leong et al (25) compared a cadaveric model for application of a dynamic compression plate to two synthetic bone models for a unreamed tibial intramedullary nailing procedure and application of a forearm external fixator. 21 subjects (six experts, seven intermediates, and eight novices) were recruited. They were assessed objectively using the validated OSATS score. Although there was a significant difference in the performance between the three grades of surgeons in the cadaveric dynamic compression plate model,

the two synthetic bone models showed no significant difference. This study has highlighted that synthetic bone models are less sensitive for assessment of surgical skills in trauma.

Addition of haptic feedback to synthetic bone models may improve its training and assessment ability. A surgical simulator with haptic force feedback was developed in maxillofacial surgery (26). The authors could demonstrate construct, face and transfer validity of this simulator.

The main disadvantages of synthetic bone simulation are: lack of understanding of the influence and importance of soft tissues; cannot simulate surgical approaches; lack of true haptic feedback; lacks the unique internal architecture and viscoelastic properties of real bone (27).

3) VR Simulation

VR simulation is commonly used as a training tool within all surgical specialties. With the ever-increasing use of minimally invasive procedures, this mode of simulation allows trainees to develop the basic skills in a safe and controlled environment. This reduces their learning curve in the operating theatre and enhances patient safety.

The advantages of VR simulation are: it can record progress and assess motion analysis; it can simulate a wide range of procedures; it allows for scenario simulation; it is very useful to develop basic arthroscopic/endoscopic skills in a controlled environment (20).

In general surgery, Aggarwal et al (28) developed a training curriculum, to assist trainees in

acquiring the psychomotor skills needed for laparoscopy and also be assessed on laparoscopic simulators. They included 12 tasks at 3 levels of difficulty (easy, medium and complex) to be performed on the laparoscopic simulator. 20 medical students were randomized into 2 equal groups. They completed 2 sessions of all tasks at the easy level, 10 sessions at the medium level, and finally 5 sessions of the 2 most complex tasks at the hard level. At the medium level, subjects were randomized into 2 equal groups performing either all 12 tasks (group A) or the 2 most complex tasks (group B). Performance was measured by time taken, path length, and errors for each hand. The results were compared between groups, and to those of 10 experienced laparoscopic surgeons. It showed that at the medium level, learning curves reached plateau at the second and sixth repetitions. Performance at the hard level was similar between the 2 groups, and all achieved the pre-set expert criteria. This study developed a graduated curriculum in simulation laparoscopy, which enabled trainees to progress from easy to complex level of laparoscopic skills. This curriculum was incorporated in established surgical training programs.

A randomized controlled trial investigated the efficacy of VR simulation in knee and shoulder arthroscopy (29). 14 orthopaedic residents were randomized to either a VR simulation group (n=8) or didactic lectures (n=6). They were assessed objectively on cadaveric models with the injury grading index. There were significant benefits in shoulder arthroscopy and a trend towards improvement in knee arthroscopy in the VR simulation group. This study highlighted the benefits of this method of training in arthroscopic surgery.

A study by Howells et al (30) demonstrated transfer validity of arthroscopic skills learnt on a bench top knee simulator to the operating theatre. They randomized 20 junior orthopaedic

trainees to receive training on a bench top knee simulator or no additional training. They were assessed by a blinded consultant in the operating theatre performing a diagnostic knee arthroscopy with a global rating scale. The simulator trained group performed significantly better than the control group. This study showed that the psychomotor skills learnt on a bench top simulator can be applied to an actual procedure in the operating theatre.

Limitations of VR simulation training

Despite all the benefits of VR simulation, it has significant disadvantages. The initial set up costs are very high and there is also a high maintenance costs. This makes access to this type of simulation difficult (20).

In the USA it is estimated that 25% of training programs do not have a dedicated simulation facility and 87% of training program directors reported a lack of sufficient funds as the main barrier (31). The situation is similar in the UK and worldwide. This has resulted in lack of availability of this method of simulation across all training programs making it difficult to incorporate this into the teaching curriculum.

In this setting, newer, innovative and easily accessible training adjuncts to the traditional apprenticeship model are necessary to help meet training needs.

1.4 Cognitive Task Analysis (CTA)

Traditionally, surgical training has focused primarily on cultivating motor skills and practical aspects of the surgical process such as time to complete a procedure, accuracy, and a reduction in errors. CTA is a newer approach to training that focuses on cognitive decision

making behind technical steps and identifies potential errors and solutions (32). This technique allows experts to impart complex knowledge to trainees in a more simplified and efficient manner.

Definition:

A systematic review by Wingfield et al (32) defined CTA as: A process by which expert knowledge is imparted to trainees by experienced surgeons in a simplified and logical manner. It involves the inclusion of step-by-step intraoperative protocols, intra-operative checklists and mental rehearsal only when accompanied with defined steps. A CTA is focused on the mental learning of steps and does not include only manual and/or technical aspects of surgical training.

CTA has been used to train pilots, musicians, military personnel and sportsmen(33),(34). It is well established that cognitive learning of motor skills is key to undertaking a successful practical procedure (32),(35),(36),(37),(38). Spencer et al. described surgical training to be 75% cognitive and 25% mechanical (35).

Flin et al (37) studied the decision making process during a surgical procedure. They highlighted four decision-making strategies that may be used by surgeons are: intuitive (recognition-primed), rule based, option comparison and creative. By understanding these processes better, this can form part of cognitive teaching of surgical decision making.

In sports psychology, CTA has shown to improve performance in Olympic athletes (39). A literature review by Suinn et al (39) found that mental practice significantly enhances performance of elite athletes. Cognitive understanding of skills was also found to be effective for novices and experts who were learning diverse new skills. They highlighted that cognitive processes have an equally important role to play in improved performance for athletes.

There have been studies reporting the benefit of CTA's in surgical training. Wingfield et al (32) performed a literature review to evaluate the effectiveness of CTA in the technical and non-technical performance of surgeons as well as surgical outcomes. They only included studies that utilized cognitive skills training in surgical procedure or other practical procedures such as central venous lines. They defined studies as using a CTA when cognitive steps or mental checklists accompanied technical steps. These were always derived from experts. A CTA research ranking scale was used by the authors to determine the suitability of inclusion of studies in this review. According to this scale the studies were scored based on their journal impact factor, the number of participants and the study type. The journal impact factor was graded from 1.5-4.5. The higher the impact the greater was the score. The study type was graded from meta-analysis of RCT's to literature review and the number of participants from ≤ 9 to ≥ 500 . Using this scale, they included 13 studies. Studies that were primarily literature review or commentary and those which focused on technical aspects of training only were excluded. 6 out of 13 studies focused on general surgery, 2 focused on central venous catheterization placement, 2 studies focused surgical procedures related to head and neck (cricothyroidotomy and percutaneous tracheostomy placement), 2 studies highlighted vascular procedures (endovascular aortic aneurysm repair

and carotid artery stenting), and 1 detailed endovascular repair. They reported that 92.3% of studies showed that CTA improves surgical outcome parameters, including time, precision, accuracy, and error reduction in both simulated and real-world environments (32). This review has demonstrated the benefits of CTA in various surgical procedures and specialties.

Arora et al (40) undertook a RCT to evaluate the benefit of CTA in Laparoscopic Cholecystectomy(LC). They randomized 18 participants into two equal groups. One group performed Mental Practice (MP) 30 minutes before undertaking the LC whilst the other group was given an online lecture. Both groups performed 5 LC each. They were assessed using the Objective Structured Assessment of Technical Skills-based global ratings scale. A previously validated Mental Imagery Questionnaire was used assess the cognitive component of the task. The MP group significantly outperformed the control group in both objective and cognitive assessment. This study demonstrated that mental practice of a surgical procedure results in improved technical and cognitive performance.

Further studies have also shown benefit of mental training in laparoscopic cholecystectomy. A RCT (41) randomized 98 surgical trainees to 3 groups (mental training, practical training and control). This study did not use a strict CTA model, however designed an operation primer for the mental training group. This included specific nodal points. The nodal points were the necessary structural motor components that follow a sequence. These are accompanied by potential hazards that can occur during the operation and color illustration for better cognitive imagery and understanding. This study also focused on ideomotoric training. Here the subjects visualized their understanding of the procedure based on the operation primer. They performed this first under the guidance of their mental trainer and

then independently. All participants were assessed on a pelvic trainer simulator objectively using the Objective Structured Assessment of Technical Skills (OSATS) tool. The mental training group outperformed both the practical training group and the control group. This study has shown the benefit of a specific type of mental training in laparoscopic cholecystectomy.

A novel mental skills curriculum was recently published for laparoscopic simulator training (42). They randomized 46 pre-medical students into two groups. All participants had the Fundamentals of Laparoscopic Surgery (FLS) training. The intervention group (n=24) had additional training with the mental skills curriculum (MSC). The MSC group demonstrated significant benefits in mental skills use, less stress in the operating room and improvement in laparoscopic skills during the retention test. This study shows that a dedicated cognitive learning tool can improve the cognitive understanding as well as technical competence in novice surgeons.

The utility of CTA based training has been evaluated for other surgical procedures. A study (43) analyzed the efficacy of a CTA based curriculum for open cricothyrotomy. They randomized 26 participants into two groups. Participants were both undergraduate medical students as well as post graduate year 2 and 3 residents. The CTA group (n=12) were given a procedural checklist based CTA curriculum developed from 6 expert surgeons. The control group (n=14) learned the procedure using the standard technique in the surgical skills simulation centre. Both groups were assessed objectively on a 19-point checklist score and a self-efficacy score based on a 140-point self-appraisal inventory. The CTA group

significantly outperformed the control group on both the parameters. This study once again demonstrated the benefits of CTA based training over traditional methods to teach a surgical procedure. A potential limitation of this study was that the participants were a mixture of third year medical students and post graduate residents. Although the authors have performed a pre-test to ensure that the groups are comparable, there is a potential of selection bias. Furthermore, the distribution of these participants between the two groups is not clearly defined in this study. Nonetheless, it still adds to the evidence supporting CTA based training in surgery.

A study by Sullivan et al (44) showed that experts omitted important technical steps and decision points during teaching a colonoscopy procedure in the operating theatre. Three expert colorectal surgeons participated in the study. They were videotaped teaching the steps of a colonoscopy procedure to year two postgraduate level residents. The residents were just observing. The experts were instructed to vocalize each step of the procedure. Following, the procedure the experts participated in a series of interviews to generate a CTA including technical steps and key decision points. The final CTA included 26 technical steps and 14 decision points. Expert A only identified 50% of the technical steps and 43% of the decision points; expert B identified 30% of the technical steps and 25% of the decision points and expert C included 26% of the technical steps and 38% of the decision points. This study demonstrated the importance of a CTA tool to capture details of a procedure which are often missed during traditional teaching methods.

A CTA was designed for laparoscopic appendectomy by three experts (45). A series of structured interviews were carried out to generate a list of technical steps and decision

points. A consensus was reached using the modified Delphi technique to generate the master CTA which included 24 technical steps and 27 decision points. Only 75% of the technical steps and 5% of the decision points were identified by all three experts. Furthermore, this study found that experts were more likely to teach operative steps to junior trainees and decision points to senior trainees. This reflects the inconsistencies in the traditional methods of teaching a surgical procedure in the operating theatre. The study also supports previous research (44) that a CTA captures valuable information missed during teaching in the operating theatre.

In the field of orthopaedic training, the use of CTA is in its infancy. There is one study in the literature that has reported a RCT evaluating the effectiveness of cognitive skills learning in total knee arthroplasty (46). They randomized 21 residents to two groups. One taught only technical skill whilst the other was focused more on teaching the cognitive decision making behind technical skills. Objective assessment was obtained with the Objective Structured Assessment of Technical Skill (OSATS) both before and after the course, as well as a pre- and post course error-detection exam and a post course multiple choice cognitive skills test. They found that both groups had no difference in performance in the technical skills test and the knowledge test but the cognitive skills group performed better in the error detection test ($p = 0.02$). Their findings proved that cognitive skills training in surgery can reduce errors and allow surgeons to perform technical skills better and more accurately.

The use of CTA in orthopaedic training is in its infancy. With the evidence presented above that strongly support the use of this form of cognitive simulation, there is a need to evaluate the benefits of CTA in orthopaedic trauma and elective surgical training.

1.5 Aims and Objectives

Aim:

The overall aim of our study was to evaluate the effectiveness of CTA learning tools to train orthopaedic trauma and knee surgeons.

Objectives:

Specific objectives were: -

- to design a generic Cognitive Task Analysis (CTA) wizard for orthopaedic trauma
- to design and validate a Femoral Intramedullary Nailing (FIN) CTA tool
- to design and validate a CTA tool for diagnostic knee arthroscopy

Chapter 2: The Delphi method

2.1 History of the Delphi method

The Delphi method originated in the 1950s in studies conducted by the RAND corporation (47), (48). The name “Delphi” was intentionally coined by Kaplan, an associate professor working for the RAND corporation, in a research project designed to improve expert predictions in policy making (49). Kaplan et al (49) traced the history of “Delphi” as far as ancient Greek history. The origin of the temple at Delphi and its oracle was traced back by archaeologists and historians. The proposed theory is that people used to come to the prophetess at the temple of Delphi, known as Pythia. The idea was to disseminate knowledge to make the world a better place (47).

A large Delphi survey in the civil sector was first published in 1964 (50). The Japanese, then took interest in the Delphi technique. They have conducted multiple studies over the years mainly within science and technology (47). In the 1990’s, this technique started being used in Europe. Initially the Dutch and the German agencies used it, followed by the French and United Kingdom(47).

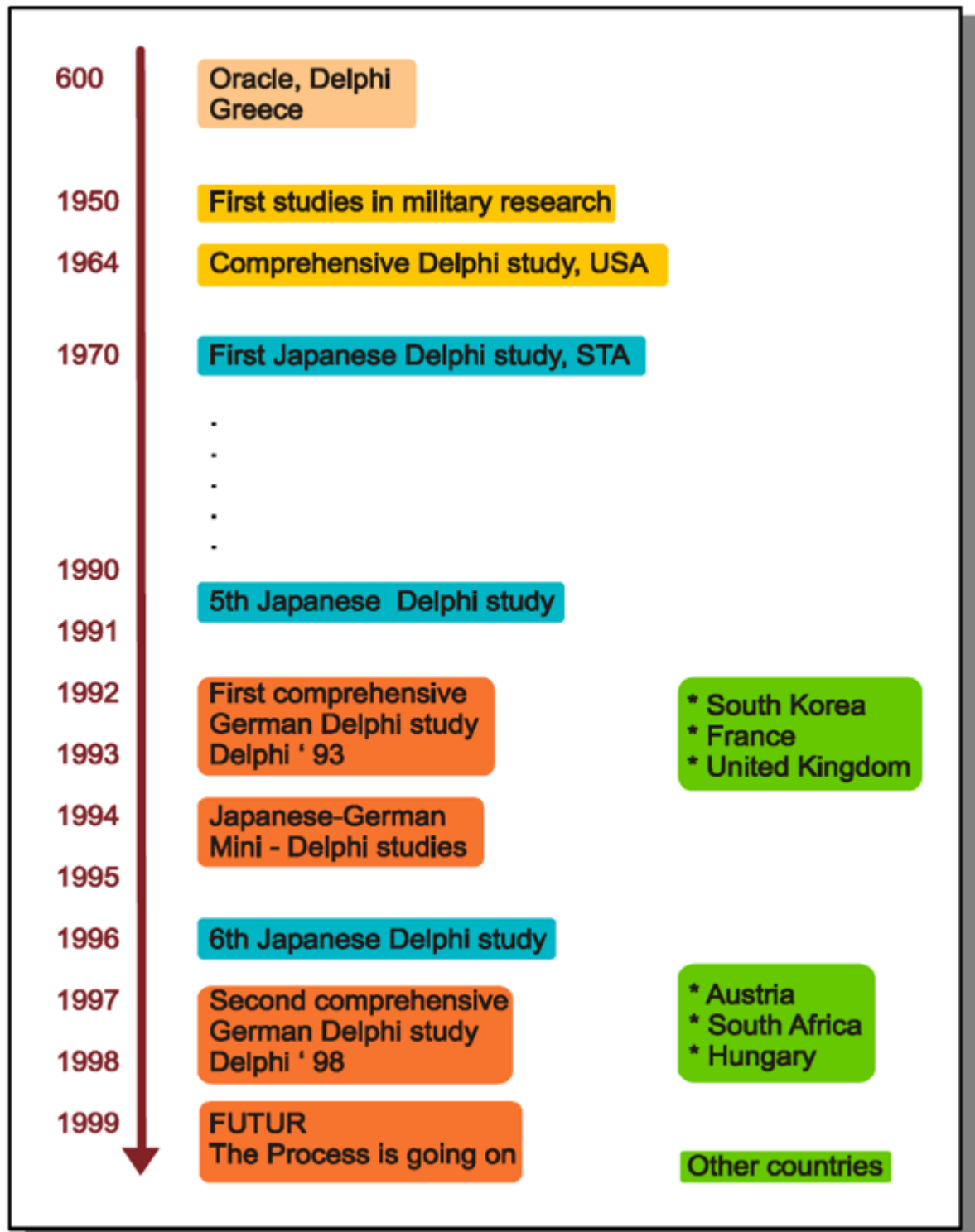


Figure 2.1: Genealogical tree of Delphi (47) – (image used with permission from author Kerstin Cuhls – see appendix 3)

2.2 Definition

Linstone and Turoff (51) defined the Delphi technique as “Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem”.

They suggest that to accomplish this ‘structured communication’, some feedback of individual contributions of information and knowledge is required with assessment of the group judgment or view and opportunity for individuals to revise views. A degree of anonymity is also needed for the individual responses (51).

The technique is used when expert judgement and opinion on a problem or research question is indispensable. It utilizes a series of questionnaires or interviews with the experts to obtain their views on a complex problem. This is obtained in a structured manner so that it can be organized in a manner which is easy to analyze. One of the main advantages of this technique is that it avoids direct disagreement and confrontation amongst experts (48).

Dalkey and Helmer (52) observed that : the Delphi process “appears to be more conducive to independent thought on the part of the experts and to aid them in the gradual formation of a considered opinion. Direct confrontation, on the other hand, all too often induces the hasty formulation of preconceived notions, an inclination to close one’ s mind to novel ideas, a tendency to defend a stand once taken, or, alternatively and sometimes alternately, a predisposition to be swayed by persuasively stated opinions of others”.

2.3 Applications of the Delphi technique

This technique can be used to solve problems and collect data on a wide range of issues.

Linstone and Turoff (51) identified some of the potential areas of application of the Delphi as:

- Collecting data which is current or historical, not accurately known or available
- Evaluating the importance of historical events
- Analyzing potential budget allocations
- Examining planning options (regional or urban)
- Developing a University curriculum
- Describing advantages and disadvantages of policy options
- Describing causal associations in complex economic or social problems
- Identifying differences between real and perceived human motivations
- Exposing personal values and social goals priorities
- Information systems research (48)
- Developing CTA's within medical and surgical research (44)

This study (51) also examined the circumstances that leads to the need for using the Delphi technique.

- The problem requires collective subjective judgments and is not conducive to precise analytical techniques.

- The individuals required to participate to solve a difficult problem may be from a diverse background and expertise and their collective opinion is required.
- The total number of individuals required are not able to interact effectively in a face to face set-up.
- Frequent group meetings are not possible due to time and cost effectiveness.
- A group communication process will be more effective than individual opinions to solve the problem.
- The group communication needs to be supervised and be anonymous because of constant disagreements amongst participants, to allow a consensus to be reached.
- Scenarios where a fair opinion from a heterogeneous group of participants need to be obtained. In this scenario, this technique avoids dominance by quantity or strength of personality.

2.4 Characteristics of the Delphi

The Delphi technique currently exists in two distinct forms (51). The conventional Delphi technique is the “paper and pencil” exercise. In this form, a questionnaire is designed and

sent to a group of experts. The questions are constructed in a manner which can extract relevant information to solve a complex problem. An independent reviewer analyses the responses to the first questionnaire. The common responses are written in a separate document. A repeat questionnaire is designed for the respondent group to evaluate the areas which are not agreed upon by all participants. They receive at least one opportunity to review the results from the first round of responses. The idea is to obtain agreement from a group of experts to solve a complex problem. There may be modifications to the process of obtaining responses. The participants may be interviewed by an independent reviewer and their responses analyzed. This however may not be possible if there are a large number of respondents (51).

Another variation to this technique, known as the “real-lucres” Delphi or the Delphi conference utilizes a computer software system which analyses the responses. In this process, the results are summarized by a pre-programmed software. The advantage of this process is that it is quicker. This is because it avoids the delays involved in the process of summarizing each response round. It is also useful where an opinion from a large number of respondents need to be analyzed. In this scenario, this process is more efficient and practical. However, a major disadvantage of this form of Delphi is that it does not allow the flexibility that is possible with the conventional technique. The design of the communication needs to be strictly defined prior to the process (51).

The Delphi process can be broadly divided into four phases. In the first phase, the subject under investigation needs to be defined and then explored. The second phase consists of

describing how the group view a problem. Any disagreements need to be highlighted and explored in third phase. The last phase is a final evaluation of the initial analysis that has been fed back to the respondents for a consensus to be reached (51).

Potential reasons of failure of the Delphi technique (51)

- A rigid structure of the data gathering process can lead to lack of flexibility and poor representation of the views of the respondents. A certain amount of freedom needs to be given to experts to draw the relevant information from them. The role of the independent reviewer is merely to analyze the responses and not impose their views on either the question structure or the Delphi design.
- It is incorrect to assume that the Delphi technique can be a substitute for all other human communication for a given situation. It must be applied to a situation where a complex problem is required to be solved with the help of the knowledge and expertise of specialists in their field. Various experts with their experience will be able to solve a complex issue better than information from one source.
- Poor presentation of the group response can minimize the accuracy and value of the technique.
- Disagreements are ignored instead of being explored can lead to a false consensus amongst experts.

- Respondents should be compensated for their time as this is a demanding and thorough process which is time consuming and therefore can lead to a poor response.

2.5 Participants in the Delphi methodology

The three key groups involved in the Delphi process are (53): -

- 1) Decision makers
- 2) Staff
- 3) Respondents

- 1) Decision makers

This is the group of people who work with the results of the Delphi process. As the Delphi process can be applied to a large range of activities, this group of people can be extremely varied. Ultimately, they will be responsible for the outcomes following the Delphi methodology.

- 2) Staff

This group conducts the actual Delphi process. They are responsible for the design of the questionnaire or conducting the interviews, depending on the process chosen. They coordinate the process. It is important that they have good knowledge of the area that is being studied. They, are required to analyze the results in collaboration with the decision makers and re-run the process with the respondents until a consensus is reached.

3) Respondents

This is the group of people whose judgements are required to answer a complex problem. They are the experts who answer specific questions with their knowledge and experience. The data from the Delphi process is obtained from this group. This group of people is very important for the success of the Delphi.

The number of participants in the Delphi methodology is variable and is adapted to meet the requirements of the study. Studies in the surgical literature that have used the modified Delphi technique to develop CTA's have usually included 3 experts (44),(45). A study by Sullivan et al (44) developed a CTA on Colonoscopy. Here 3 expert colorectal surgeons were videotaped teaching this procedure to postgraduate residents in the operating theatre. Following this, they were instructed to perform a "free recall" of the technical steps and decision points involved in this procedure. This study found that with the use of three experts they could demonstrate that a CTA on colonoscopy developed from their expertise using the modified Delphi method was significantly better and more comprehensive than the teaching they were able to provide in real time in the operating theatre.

Another study (45) also included 3 experts to develop a CTA for laparoscopic appendectomy. The experts were interviewed, to generate a list of technical steps and decision points independently. They then participated in a consensus meeting, to generate the final CTA. In this process, there is complete agreement amongst the three experts on all the technical steps and decision points that are included in the final CTA.

From the evidence presented above, three experts in the modified Delphi technique to generate surgical procedure CTA's have been a success. Too many experts, can make the process confusing, laborious and may be counter-productive. Fewer than three experts, can reduce the quality of the Delphi and make it more of an expert opinion rather than a consensus from a group of experts.

2.6 Examples of the Delphi technique in the medical literature

There are examples of studies within the surgical literature that have used the modified Delphi technique to reach consensus on management of clinical conditions. Eubank et al. (54) used this to gain clinical consensus on the diagnosis and treatment of rotator cuff pathology. They divided the Delphi methodology into three rounds. 14 experts representing physiotherapy, athletic therapy, sports medicine and orthopaedic surgery were included to participate in this methodology. In round 1, 123 best practice statements were distributed to the experts. They marked agree or disagree against each statement. 80% consensus (11/14 experts) was required to include the statement in the final guideline document. The statements which did not meet this target were revised based on the recommendations of the panel. These were recirculated to the panel in round 2 of the process. Again an 80% consensus was required to include a statement in the final guideline document. The statement that did not meet this requirement was listed for round 3. This was a face to face meeting amongst the panel experts mediated by the facilitator. Here agreement was

determined by a show of hands, so at this stage this was no longer anonymous. The statements at this stage were either retained, modified or eliminated. 80% consensus criteria were still maintained for round 3. The results showed that round 1 generated 44 statements, round 2 had 5 statements and round 3 provided 10 statements. The final guideline document therefore included 59 statements. This study adopted the Delphi technique over three rounds. Their approach was slightly different as they used a set number of statements to be sent to the experts in round 1. As a result, from the initial list of 123 statements only 59 (48%) were included in the final document. In other studies (44), (45) the first round has usually been a free recall process to generate the initial template from the experts. Then this has been refined over the next two rounds to achieve final consensus. In this technique, fewer statements or steps are eliminated. This demonstrates flexibility in the approach for using the modified Delphi technique. However, it does highlight the ability of this technique to generate standardized and high quality results from the knowledge and skills of experts in the field. This can be extremely useful both in the clinical and the training environment.

The 80% consensus used in the above described study was based on the work by Lynn (55). They reported that if 10 or more participants were involved in a content validation study, then a minimum of 80% consensus was required. However, if there were fewer than 10 participants then 100% consensus was required.

There are other examples of studies using the modified Delphi technique in the medical literature. A study (56) used this methodology to obtain a consensus statement for the management of Barrett's dysplasia and early oesophageal carcinoma. This group performed

an international systematic review of different management strategies for this condition. A software program was used to gain anonymous feedback on the statements selected. These were regulated by the feedback coordinator and the consensus chair. This study showed how the Delphi technique can be modified and innovative software programs can be used to obtain consensus on a large scale regarding a clinical question.

Global definitions of clinical conditions may be desirable for better understanding of the problem, global collaborative research and therefore improved management of these conditions. The modified Delphi technique has been used to gain a global consensus on the classification and definition of Gastro-oesophageal reflux disease (57). Here, four rounds of the Delphi process were used with repeated iterative voting. A series of statements was developed by five experts following a systematic review of the literature. 44 experts from 18 countries participated in the process online. Over a 2-year period and after 4 rounds of voting, a consensus was reached regarding the definition and classification of this disease. “GERD was defined as a condition that develops when the reflux of stomach contents causes troublesome symptoms and/or complications”(57). Oesophageal and extra oesophageal syndromes were added as sub-classifications to the condition. New information generated through this process included: a patient-centered approach that is independent of endoscopic findings, identifiable syndromes formed part of sub-classifications, and the identification of laryngitis, cough, asthma, and dental erosions as potential syndromes associated with gastro-oesophageal reflux disease. This study achieved an international consensus which will certainly help future research into this condition and extend its applications across other medical research.

A study (58) identified 23 Quality Indicators (QI) in Renal Cell Carcinoma (RCC) using the modified Delphi technique. 13 medical oncologists and urological surgeons participated in a 3-round modified Delphi technique. The QI's were initially identified following a systematic review and additional suggestions from the experts. The first two rounds were e-mail questionnaires, followed by a final in-person meeting. The final 23 QI's were spread across different aspects in the spectrum of the disease, ranging from screening, diagnosis, prognosis, surgery for localized and advanced disease, systemic therapy, follow-up and survival outcomes. This method was well applied in this study to use the knowledge and expertise of both oncologists and surgeons. This will allow evaluation in the quality of care provided to RCC patients and monitor outcomes.

There is further evidence to support the suitability and success of this technique in the healthcare setting (59), (60) to develop clinical guidelines as well as gather opinions of a diverse group of experts covering a range of issues related to diverse clinical conditions.

2.7 Summary

The Delphi methodology is a very useful technique to gain consensus on issues ranging from large scale information systems research to the healthcare field. In medicine, it is a proven method to obtain information from a range of experts from diverse backgrounds on a clinical problem or to develop clinical guidelines. In the educational field, it is very beneficial to use this technique to develop CTA's on various practical procedures and surgical techniques. It may form an integral part in modern surgical education and training.

Chapter 3: Generic Cognitive Task Analysis (GCTA) wizard: a tool to train future orthopaedic trauma surgeons

3.1 Introduction

As we have discussed previously, there are significant strains on surgical training with reduced working hours, greater senior involvement in service provision and increasing number of surgical techniques of growing complexity (6),(7),(12),(13),(14). Simulation provides a safe and controlled environment to develop surgical skills and allows repeated sustained practice (29). The most prevalent form of simulation in orthopaedic training is cadaveric simulation and VR simulation (23),(24). However, these are expensive and not readily accessible (20). In this setting, newer and more accessible training adjuncts are required to help meet training needs. We have discussed the effectiveness of CTA to train pilots, musicians, military personnel and in other surgical specialties(32),(61). There are no CTA's published in the field of orthopaedic trauma to train future orthopaedic surgeons. There is significant scope for research in this area to evaluate the effectiveness of CTA's in orthopaedic training.

Objective

To develop an online generic wizard tool that can be used by experts to design procedure-specific CTAs to benefit orthopaedic trauma training.

3.2 Methods

(1) Modified Delphi technique

A modified Delphi technique was used to gain consensus on the technical steps and decision points that are applicable to any orthopaedic trauma procedure. The Delphi methodology is a flexible technique that can be used to gain expert consensus on a wide range of issues. The number of participants required for this depends on the research question. In previous studies in the surgical literature, 3 experts have successfully been used to design CTA's on procedures such as colonoscopy and laparoscopic appendectomy (44),(45). This guided us to use three experts in our modified Delphi technique to design a generic trauma CTA. Our experts were defined as fellowship trained orthopaedic trauma surgeons who undertake trauma surgery as part of their routine orthopaedic practice. The Delphi was conducted over 3 rounds.

Round 1

The 3 experts were interviewed independently to generate a list of technical steps, decision points and errors (and solutions) that are applicable to any orthopaedic trauma procedure. Each expert was instructed to participate in a "free recall" procedure. The instruction was:

-

"Please list all technical steps and cognitive decision making underpinning these technical steps that can be applicable to any orthopaedic trauma procedure ranging from pre-operative planning to post-operative care and rehabilitation".

They dictated these steps away from the operating theatre. These were transcribed by

independent and blinded secretary to produce a document for each expert. In this round, the experts generated the information independently and blinded to each other's content.

These were analyzed by an independent reviewer. All the technical steps and decision points that were common to the 3 experts were identified in round 1. Since we used fewer than 10 experts in the Delphi process, only those steps were included in the final CTA which had 100% consensus from all 3 experts (55).

Round 2

In round 2, the steps that were common to 2 experts or exclusively generated from one expert were listed separately. These steps were reviewed by the panel of experts. As in round 1, the experts reviewed these steps independent of each other. They were simply asked to tick agree or disagree next to the steps listed. If they disagreed with a step, they were instructed to either modify the step or eliminate it completely. The steps agreed upon by all experts in rounds 1 and 2 were listed at the end of round 2.

Round 3

In round 3, the experts had a face to face meeting. They reviewed all the steps that were agreed upon in rounds 1 and 2. This round also offered an opportunity for the experts to review any steps that were modified in round 2. Only those steps which had 100% agreement from all 3 experts at the end of the three rounds were included in the final CTA.

The experts divided a generic orthopaedic trauma procedure into seven phases: 1) pre-

operative planning; 2) theatre and patient set-up; 3) preparation and draping; 4) approach; 5) reduction and fixation; 6) closure; 7) post-operative care and follow-up.

(2) Design of the Generic orthopaedic trauma CTA (GCTA) wizard tool

The information generated from the above Delphi technique was uploaded onto a software in liaison with a software engineer. The criteria for the tool design were: it should be user friendly, quick, visually attractive, reproducible and translatable.

It was written by a software engineer in a Meteor/React framework and the data was stored using the MongoDB data store.

React is a JavaScript library for building reactive user interfaces. It is one of the three rendering libraries supported by Meteor; the alternatives are Blaze and Angular (62). React has a vibrant and growing ecosystem and is used widely in production in a variety of combinations with different frameworks. It is user friendly, reliable and reproducible (62).

The MongoDB (63) database was used to store our data. The advantages of this system are: -

- Leverage data and technology to maximize competitive advantage
- Reduce risk for mission-critical deployments
- Accelerate time-to-value
- Dramatically lower total cost of ownership

Picture and video content for the tool is managed through a media content management service. The information generated from the modified Delphi technique was input in the software described above to create the GCTA orthopaedic trauma wizard tool (Figure 1).

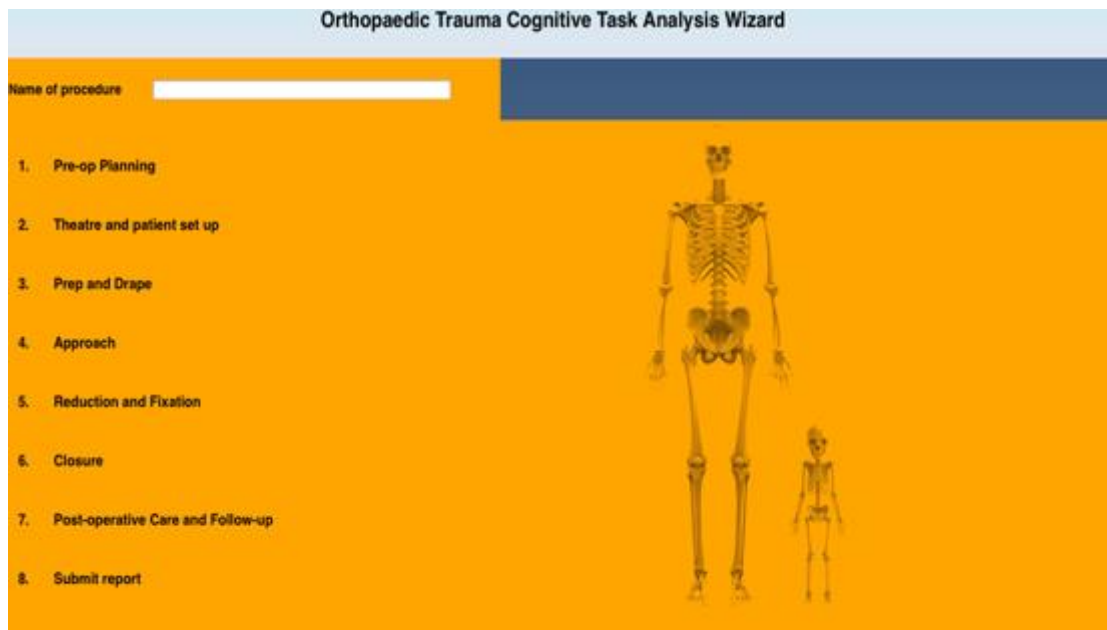


Figure 3.1 Snapshot of the GCTA wizard

This tool was divided into 2 components: 1) the creation tool and 2) the learning tool. The creation tool includes the steps generated from the modified Delphi technique. These form a guide for any expert worldwide to input information on any orthopaedic trauma procedure into the creation tool.

The learning tool is generated once an expert has input information into the creation tool to generate a procedure-specific CTA.

(3) Proof of technical design

A CTA for femoral intramedullary nailing generated by using the modified Delphi technique from three trauma experts (the details of this CTA will be described in chapter 4 of this thesis) was used to test our GCTA wizard tool. The aim was to test the ability of the GCTA creation tool to generate a procedure specific CTA with multimedia modalities.

3.3 Results

Modified Delphi technique for TS (figure 3.2)

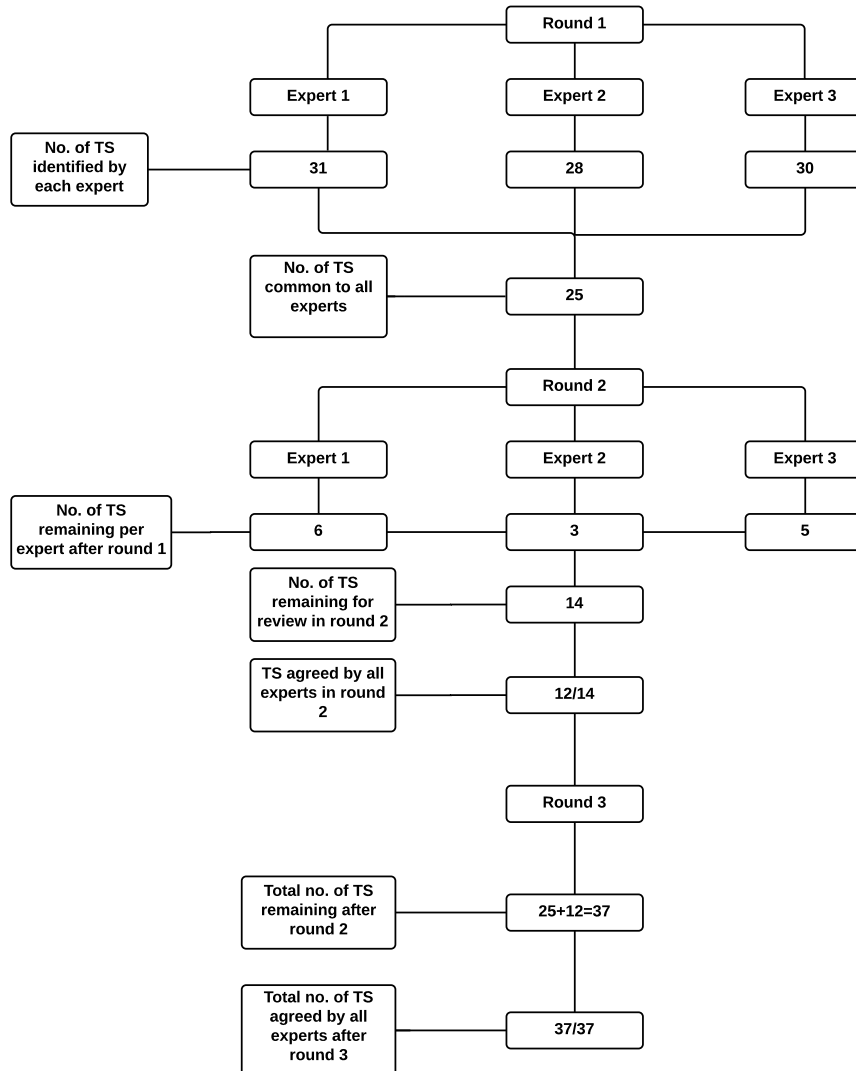


Figure 3.2: Flowchart showing Delphi for TS

Round 1

In round 1, 31 TS were identified by expert 1, 28 by expert 2 and 30 by expert 3. 25 TS were common to all 3 experts. They divided the procedure into 7 phases.

- 1) Pre-op planning
- 2) Theatre and patient set-up
- 3) Prep and drape
- 4) Approach
- 5) Reduction and fixation
- 6) Closure
- 7) Post-operative care and follow-up

TS common to all 3 experts

Phase 1 - Pre-op Planning

Diagnosis

Fracture pattern

Choice of operation – indications, contra-indications

Equipment

Phase 2 - Theatre and patient set up

Operating table, attachments and set up

Patient positioning

Position of the image intensifier

Tourniquet

Phase 3 - Prep and Drape

Choice of prep

Phase 4 – Approach

Incision: -

Identify appropriate landmarks

Length of incision

Exposure

Phase 5 - Reduction and Fixation

AO principle to fix the fracture- absolute stability (interfragmentary screw, dynamic compression plate), relative stability (intramedullary fixation, bridging plate)

Fracture reduction technique (closed, open, direct, indirect)

Fixation technique – describe according to procedure

Appropriate use of image intensifier

Phase 6 – Closure

Describe the layers to be closed and preferred technique

Phase 7 - Post-operative Care and Follow-up

Patient destination immediately post-surgery - ward/ITU/HDU

Blood review

Thromboprophylaxis

Antibiotic prophylaxis

Weight bearing status

Monitor neurovascular status

Wound review- time frame for this

Physiotherapy

Round 2

In round 2, the remaining 6 TS from expert 1, 3 from expert 2 and 5 from expert 3 were reviewed by the panel.

Remaining TS from expert 1

1. Mechanism of Injury
2. Template pre-operative radiographs
3. High or low energy trauma – covered in the decision points
4. Position of the theatre lights
5. Holding the reduction - clamps, wires, cables
6. Referral to appropriate specialties

Remaining TS from expert 2

1. Determine need for image intensifier
2. Position of the scrub team, anaesthetic team, assistant
3. Area to be covered with prep and draping technique

Remaining TS from expert 3

1. Any physiological variables that need to be followed up on that have been identified intra-op by the anesthetic team
2. Dressing change as and when required
3. Long term follow-up plan
4. Rehabilitation program

5. Cementing technique – too specific, not applicable to all trauma procedures

12/14 TS were agreed upon at the end of round 2. The 2 steps that were rejected by all experts were: -

1. High or low energy trauma: reason provided by experts - covered in the decision points.
2. Cementing technique: reason provided by experts - too specific, not applicable to all trauma procedures.

At the completion of round 2, 37 TS were identified by all 3 experts.

Round 3

In round 3, the 25 TS from round 1 and 12 TS from round 2 were reviewed by the panel. They agreed on all these steps to include 37 TS in the final CTA.

TS included at the completion of round 3 (final CTA)

Phase 1 - Pre-op Planning

Mechanism of Injury

Diagnosis

Fracture pattern

Choice of operation – indications, contra-indications

Template pre-operative radiographs

Equipment

Determine need for image intensifier

Phase 2 - Theatre and patient set up:

Operating table, attachments and set up

Patient positioning

Position of the scrub team, anaesthetic team, assistant

Position of the image intensifier

Position of the theatre lights

Tourniquet

Phase 3 - Prep and Drape

Choice of prep

Area to be covered with prep and draping technique

Phase 4 – Approach

Incision: -

Identify appropriate landmarks

Length of incision

Exposure

Phase 5 - Reduction and Fixation

AO principle to fix the fracture- absolute stability (interfragmentary screw, dynamic compression plate), relative stability (intramedullary fixation, bridging plate)

Fracture reduction technique (closed, open, direct, indirect)

Holding the reduction - clamps, wires, cables

Fixation technique – describe according to procedure

Appropriate use of image intensifier

Phase 6 – Closure

Describe the layers to be closed and preferred technique

Phase 7 - Post-operative Care and Follow-up

Patient destination immediately post surgery - ward/ITU/HDU

Any particular physiological variables that need to be followed up on that have been identified intra-op by the anesthetic team

Referral to appropriate specialties

Blood review

Thromboprophylaxis

Antibiotic prophylaxis

Weight bearing status

Monitor neurovascular status

Wound review- time frame for this

Dressing change as and when required

Physiotherapy

Long term follow-up plan

Rehabilitation program

(2) Modified Delphi technique for DP (figure 3.3)

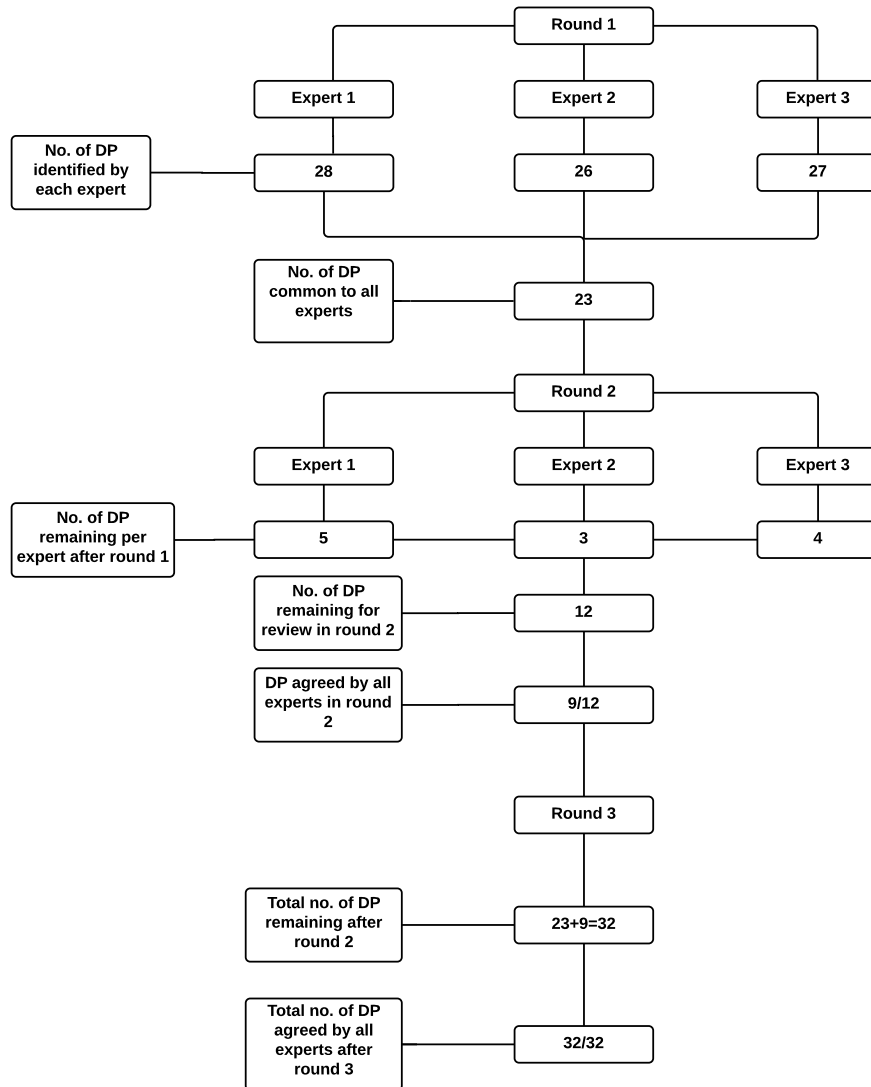


Figure 3.3: Flowchart showing Delphi for DP

Round 1

In round 1, 28 DP were identified by expert 1, 26 by expert 2 and 27 by expert 3. 23 DP were common to all 3 experts.

DP common to all experts in round 1

DECISION POINTS

Phase 1 - Pre-op Planning

Is the diagnosis correct?

Is the fracture accurately classified?

Any associated injuries that need treatment?

Has the indications and contra-indications been reviewed prior to the operation?

Is this definitive fixation or temporary stabilization?

Has the right implant been chosen for the operation?

Are there backup implant options available in the shelf?

Phase 2 - Theatre and patient set up:

Are the correct operating table/attachments available?

Is a tourniquet required – any alternatives?

Is the WHO checklist appropriately completed?

Phase 3 - Prep and Drape

Has a proper sterile field been achieved?

Phase 4 – Approach

Has the landmarks been identified correctly?

Is the incision in the correct place?

Has adequate exposure been obtained to undertake the procedure comfortably?

Avoid neurovascular structures

Phase 5 - Reduction and Fixation

Is the fracture pattern appropriate for the AO principle chosen?

Is the fracture adequately reduced according to principle of fixation being used?

Is a logical sequence of steps being followed for the fracture fixation technique?

Is the image intensifier being used effectively?

Phase 6 – Closure

Missed layers

Phase 7 - Post-operative care and follow-up

Has the immediate post-operative instructions been followed

Has the weight bearing status been documented accurately?

Round 2

In round 2, the remaining 5 DP from expert 1, 3 from expert 2 and 4 from expert 3 were reviewed by the panel.

Remaining DP's from expert 1

- 1) Is it high or low velocity - important for soft tissue assessment?
- 2) Any additional injuries documented?
- 3) Is the theatre set up providing effective utilization of space and resources?
- 4) Is any further surgery required in future - plan incision accordingly
- 5) Is the final result of the operation appropriate?

Remaining DP's from expert 2

- 1) Is any further imaging required for pre-op planning?
- 2) Is the choice of operation correct keeping the patient factors and fracture pattern in mind?
- 3) Ensure anesthetic team and scrub team positioned appropriately?

Remaining DP's from expert 3

- 1) Is there any additional equipment required to undertake the operation?
- 2) Has the incision been marked prior to the start of surgery?
- 3) Is there a long-term rehabilitation program been documented and explained to the patient and medical team?
- 4) Community care provider informed about patient's operation and post-operative plan.

9/12 of the remaining DP were included by the panel at the completion of round 2. The 3 DP's that were rejected in round 2 were: -

- 1) Any additional injuries documented: reason provided by experts - Already covered by another DP.
- 2) Ensure anesthetic team and scrub team positioned appropriately: reason provided by experts - Already covered by another DP.
- 3) Has the incision been marked prior to the start of surgery: reason provided by experts – this is optional and depends on the operating surgeon.

Round 3

In round 3, the 23 DP from round 1 and 9 DP from round 2 were reviewed by the panel.

They agreed on all these steps to include 32 DP in the final CTA.

DP's included at the end of round 3 (final CTA)

DECISION POINTS

Phase 1 - Pre-op Planning

Is it high or low velocity - important for soft tissue assessment

Is the diagnosis correct?

Is the fracture accurately classified?

Any associated injuries that need treatment?

Is any further imaging required for pre-op planning?

Is the choice of operation correct keeping the patient factors and fracture pattern in mind?

Has the indications and contra-indications been reviewed prior to the operation?

Is this definitive fixation or temporary stabilization?

Has the right implant been chosen for the operation?

Are there backup implant options available in the shelf?

Is there any additional equipment required to undertake the operation?

Phase 2 - Theatre and patient set up:

Is the correct operating table/attachments available?

Is the theatre set up providing effective utilization of space and resources?

Is a tourniquet required – any alternatives?

Is the WHO checklist appropriately completed?

Phase 3 - Prep and Drape

Has a proper sterile field been achieved?

Phase 4 – Approach

Has the landmarks been identified correctly?

Is any further surgery required in future - plan incision accordingly

Is the incision in the correct place?

Has adequate exposure been obtained to undertake the procedure comfortably?

Avoid neurovascular structures

Phase 5 - Reduction and Fixation

Is the fracture pattern appropriate for the AO principle chosen?

Is the fracture adequately reduced according to principle of fixation being used?

Is a logical sequence of steps being followed for the fracture fixation technique?

Is the image intensifier being used effectively?

Is the final result of the operation appropriate?

Phase 6 – Closure

Missed layers

Incorrect technique

Phase 7 - Post-operative Care and Follow-up

Has the immediate post-operative instructions been followed?

Has the weight bearing status been documented accurately?

Is there a long-term rehabilitation program been documented and explained to the patient and medical team?

Community care provider informed about patient's operation and post-operative plan

(2) GCTA creation tool (figure 3.4)

The creation tool permits any trauma expert to create a CTA on any orthopaedic trauma procedure. For each of the seven phases described above, the expert can input the relevant technical steps, cognitive decision points and common errors (and solutions). There are also tabs for any additional information that the author may wish to add that is not part of the generic CTA information generated by our experts. Additionally, the tool allows the user to add any images/video clips for each phase of the procedure. For each phase, there are written information on the technical steps, the cognitive decision making behind each step, potential errors and solutions. Furthermore, there are accompanying images, video clips and audio recordings that explain each step. This tool includes written, audio and visual stimuli to teach each phase of a complex trauma procedure.

Orthopaedic Trauma Cognitive Task Analysis Wizard

Name of procedure

Reduction and Fixation Back

Technical Steps	Decision Points	Errors and Solutions	Video and Images
AO principle to fix the fracture- absolute stability (interfragmentary screw, dynamic compression plate) , relative stability (intramedullary fixation, bridging plate) Fracture reduction technique (closed, open, direct, indirect) Holding the reductions - clamps, wires, cables	Is the fracture pattern appropriate for the AO principle chosen? Is the fracture adequately reduced according to the principle of fixation being used? Is a logical sequence of steps being followed for the fracture fixation technique?	+	Add Media

Figure 3.4: Snapshot of the GCTA wizard creation tool

(3) GCTA learning tool (figure 3.5)

The learning tool is generated when an expert submits all written information and video/images in the creation tool. In this tool, each phase of the procedure will appear as a separate tab. Clicking on each phase will open a split screen. On the left-hand side, all the written information will appear including technical steps, cognitive decision points and errors for that phase. On the right, there will be any accompanying images/video clips and audio voice recordings explaining that phase of the procedure. This multi-sensory stimulatory instruction is repeated for all the other phases of the procedure.



Figure 3.5: Snapshot of the GCTA learning tool

(4) Proof of technical design (figure 3.6)

The written information and the multimedia modalities (images/video clips and audio recordings) generated from a separate Delphi process for femoral intramedullary nailing was input in our GCTA creation tool which successfully generated a CTA learning tool. This tool included all written information for the procedure on the left-hand side of a split screen and all multimedia modalities corresponding to the written information on the right-hand side for each phase of an antegrade femoral intramedullary nailing procedure (figure 5). This demonstrated the feasibility of our creation tool to accurately generate a learning tool in the desired structure and format.

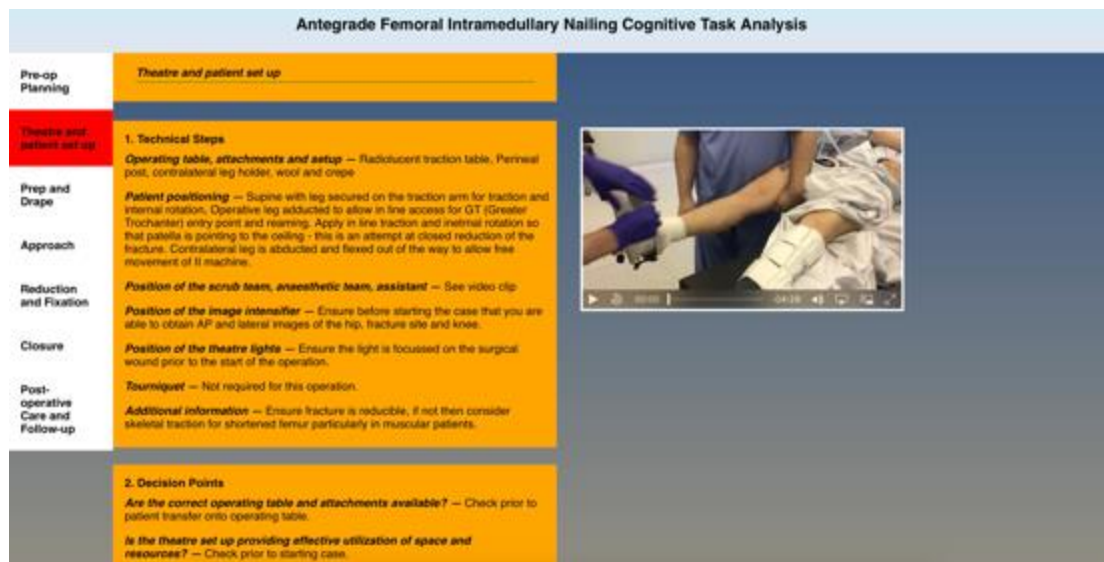


Figure 3.6: Snapshot of an Antegrade Femoral Intramedullary Nailing CTA

3.4 Discussion

This is the first study in the orthopaedic literature describing a trauma CTA creation and learning wizard tool. We have utilized a modified Delphi technique to validate the information obtained from three trauma experts. An online wizard was created to incorporate written information and multimedia (videos/images and audio recordings) modalities to design an innovative tool that will allow trainers to create any trauma CTA. The learning tool has a split screen layout that allows users to use multiple stimuli (written, audio, visual) simultaneously whilst learning each phase of the procedure.

The use of CTAs has been reported in other surgical specialties to teach trainees(44),(64),(65),(61) Sullivan *et al.* (44) described a CTA for colonoscopy. This was

a written CTA with a list of technical steps and decision points for a colonoscopy procedure. The study found that experts were leaving out key information whilst teaching in the operating theatre, which was captured during their CTA. Specifically, Surgeon A described 50% of the technical steps and 43% of decision points. Surgeon B described 30% of the technical steps and 25% of decision points. Surgeon C described 26% of the technical steps and 38% of the decision points. These results, show that a significant proportion of important procedural steps and cognitive decision making behind these steps can be omitted during teaching in the operating theatre by experts. However, when they participate in a “free recall” process, they are likely to include all these steps when describing an operation. Furthermore, using the Delphi technique from three experts fine tunes this process and makes the information more scientific and robust. This study however, only had written checklists as part of their CTA. Whilst, this still has excellent educational value, it may not cater to the learning methods used by a range of learners. Our tool incorporates multimedia audiovisual modalities in addition to written information. This will attract a variety of learners. Traditionally, teaching has been delivered with the use of words. Although, this has proven to be successful over a period of time, there is evidence that learners who listen or read information solely in the form of words, struggle to remember key ideas (66). Studies have shown that multimedia learning results in superior retention of information and problem solving when compared to learning from words alone (67),(68),(69). Our CTA followed this principle to design a multimedia tool where the structured information from the experts and accompanying video clips and audio recordings appear on the same screen. This allows learners the flexibility to use these multiple modalities simultaneously or

independently depending on their preference. Furthermore, this makes the tool more visually attractive and stimulating.

Other studies (64),(65) have attempted the use of video clips and other multimedia methods. Luker et al. (64) described a multimedia CTA for Flexor tendon repair. 10 plastic surgery residents were evaluated on three separate occasions performing a flexor tendon repair. The learning they acquired between the first and second attempts was used as control data in this study. Between the second and third attempts a CTA was provided to the residents. The aim was to analyze if this improved their decision-making skills. The CTA was designed with the use of the modified Delphi technique. Three experts in flexor tendon repair were recruited. They participated in a series of interviews. This was conducted by two independent researchers. The experts identified important technical steps, decision-making points and maneuvers to avoid potential pitfalls. These were reviewed and analyzed until a consensus was reached. They also produced animations and video-clips to aid understanding of their written information. This provided learners with a pictorial representation of the written information. There was a significant improvement in the decision-making skills of the residents when performing a flexor tendon repair following the use of this CTA.

A study by Yeung et al. (70) developed a CTA based educational videos for basic skills in plastic surgery. 78 junior residents participated in a need based assessment survey and identified five key skills. They were: subcuticular suturing, horizontal and vertical mattress suturing, hand splinting, digital nerve block, and excisional biopsy. Three plastic surgery experts were video recorded performing these skills and describing each step whilst

performing these skills. They were interviewed to obtain further information. This was divided into action, decision or assessment steps. This formed the basis of a Cognitive Demands Table (CDT) for each of these five skills. The final CDT was reviewed by all three surgeons to ensure consensus. The results analysis showed that 27% to 40% of the steps were missed by the experts in their original transcript compared to the final CDT. This study generated instruction videos for basic surgical skills using a CTA model. It further added to evidence that individual experts are likely to omit key steps when teaching a surgical procedure. The modified Delphi process with three experts worked successfully to generate a comprehensive CTA for the surgical skills identified by the original survey.

The multimedia CTA's described above used the audio-visual and written modalities independently from each other. In our CTA, we used a web-based tool which allowed simultaneous use of written and audio-visual information with a split screen function. Additionally, we have divided a trauma procedure in different phases and for each phase there is written and audio-visual information. So, for every step, we have three different modalities explaining that step. Furthermore, the studies mentioned above have focused on one surgical procedure whereas, our generic creation tool will allow experts and surgical educators to create CTAs for any trauma procedure. This has a wider application and has the potential to develop into a trauma CTA library.

Currently, in trauma education the traditional apprenticeship model is most widely used to teach trainees. Additionally, trainees use standard operative technique manuals available from implant companies. These 'op-techs' often can be confusing and difficult to visualize

the dynamics of each operative step. We believe that there should be multimedia-based scientific learning tools widely and freely available to trauma trainees as an adjunct to the traditional apprenticeship model. Our tool is not meant to substitute the traditional learning methods but to enhance the quality of training and act as a useful adjunct to learning in the operating theatre. Our GCTA multimedia wizard tool may be that stepping-stone for future CTA-based multimedia training in trauma surgery with the potential of translating into any surgical specialty.

A potential limitation of this study may be the use of three experts. We decided to use three trauma experts because majority of the CTA-based studies reported in the surgical literature used three experts successfully to design the CTA (44),(45),(64),(70). However, there have been no studies performed thus far that have investigated the effect of the number of experts required in the modified Delphi protocol to create a model CTA. This may be an area for future research. Since our generic trauma CTA wizard tool will be freely and widely available, we could apply the modified Delphi technique for specific trauma procedures with any number of experts submitting their CTAs to create a larger consensus in the future.

3.5 Conclusion

This is the first study in orthopaedic trauma that has reported the design of a novel, technologically innovative, multimedia-based generic CTA wizard. Our training tool relies on the simultaneous use of numerous stimuli to teach each phase of trauma procedures. This has the potential to develop into a digital CTA library, created by a multitude of global experts, that will develop and evolve non-technical skills and surgical decision-making

within trauma education. Additionally, it may find application within other sub-specialties of orthopaedics and other surgical specialties.

Chapter 4: Design of the Imperial Femoral Intramedullary Nailing CTA (IFINCTA) tool (*an adaptation of this chapter has been published in the Acta Orthopaedica on the 18th October, 2018 (71)*)

4.1 Introduction

The burden of orthopaedic trauma is greater than ever before with major trauma now affecting the elderly population in addition to the high energy injuries in the younger age group (72). In this setting, newer, innovative and easily accessible training adjuncts to the traditional apprenticeship model are necessary to help train competent orthopaedic trauma surgeons.

It is well established that cognitive learning of motor skills is key to undertaking a successful practical procedure (32), (73). Cognitive Task Analysis (CTA) allows experts to provide complex information to trainees in a logical and efficient manner, which makes it easier to comprehend, visualize and digest procedural steps (32). It has been extensively used to train pilots, musicians, military personnel (32) and it has shown to improve performance in Olympic athletes (39). Wingfield *et al.* reported that CTA improves surgical outcome parameters, including time, precision, accuracy, and error reduction in both simulated and real-world environments (32). CTAs have been used successfully in other surgical specialties to train residents(40),(45),(44),(64). However, it is new to orthopaedic training. There are no studies in the existing literature that has investigated the efficacy of CTA to train residents in orthopaedic trauma.

Aim: to evaluate the effectiveness of a novel CTA tool to improve understanding of the

procedural steps in antegrade femoral intramedullary nailing.

4.2 Methods

In this study, we first designed the IFINCTA tool and then evaluated the effectiveness of this tool to teach the procedural steps using a randomized controlled trial.

(1) Design of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool

(a) Procedural steps and Delphi technique

3 expert, fellowship trained orthopaedic trauma surgeons who perform trauma as part of their routine clinical practice participated in this study. The modified Delphi technique was used to generate the final written information of the IFINCTA tool from the 3 experts over 3 rounds.

Round 1

The experts were interviewed independently to generate a list of technical steps, cognitive decision points and potential errors and solutions that are applicable to an antegrade femoral intramedullary nailing procedure. These were analyzed by an independent reviewer. All the technical steps and decision points that were common to the 3 experts were identified in round 1.

Round 2

In round 2, the steps that were common to 2 experts or exclusively generated from one

expert were listed separately. These steps were reviewed by the panel of experts to reach an agreement. The steps agreed upon by all experts in rounds 1 and 2 were listed at the end of round 2.

Round 3

In round 3, the experts reviewed all the steps that were agreed upon in rounds 1 and 2. Only those steps which had 100% agreement from all 3 experts at the end of the three rounds were included in the final CTA.

The experts divided this procedure into seven phases: 1) pre-operative planning; 2) theatre and patient set-up; 3) preparation and draping; 4) approach; 5) reduction and fixation; 6) closure; 7) post-operative care and follow-up.

(b) Audiovisual stimuli

One of the experts in our study recorded a video of an antegrade femoral intramedullary nailing procedure for a diaphyseal femoral shaft fracture. This video was divided into separate clips reflecting each of the 7 phases. A voice over was recorded later as a “free recall” procedure with the same expert. This was superimposed on the video clips. The other two experts

reviewed this video and a consensus was reached regarding the final content of the video so that it accurately reflected the written CTA master template.

(c) Creation of the IFINCTA tool

The written information generated from the modified Delphi technique and the video clips and audio recordings were input into a wizard tool developed in our unit. This is an online (web-based) tool which is used by experts to create CTA's. This led to the design of the IFINCTA tool (figures 4.1-4.7). This tool has a split screen format. The left side has all the written information on the technical steps, cognitive decision points and potential errors and solutions. The right side has the multimedia modalities including video clips, audio voice recordings and images. This is the first multimedia orthopaedic trauma CTA tool described in literature. This is different from the existing AO surgery reference as the AO surgery reference is not a CTA tool. It does not contain defined decision points and separate sections on errors and solutions for each phase of a trauma procedure as is present in our CTA tool. Furthermore, the videos in the AO surgery reference are not integrated with each phase of their procedure which makes the design and the format of our tool different.

4.3 Results

List of technical steps included in the final CTA following the Delphi methodology: -

TECHNICAL STEPS

Phase 1 - Pre-op Planning (Figure 4.1)

- Diagnosis - Femoral shaft fracture, sub trochanteric fracture, reverse oblique hip fractures
- Fracture pattern - spiral, oblique, transverse

- Choice of operation – Femoral locked intramedullary nailing
- Review pre-operative radiographs - template nail size and length
- Equipment - Fracture traction table, Femoral Nailing instrument kit, image intensifier

Phase 2 - Theatre and patient set up: (Figure 4.2, refer video clip in IFINCTA tool-link in Appendix 2)

- Operating table, attachments and set up - Radiolucent traction table, Perineal post, contralateral leg holder, wool and crepe
- Patient positioning - Supine with leg secured on the traction arm for traction and internal rotation
- Operative leg adducted to allow in line access for GT (Greater Trochanter) entry point and reaming
- Apply in line traction and appropriate rotation to reduce fracture
- Contralateral leg is abducted and flexed out of the way to allow free movement of the fluoroscopy machine
- Position of the scrub team, anaesthetic team, assistant
- Pre-op Image Intensifier position - Ensure before starting the case that you can obtain AP and lateral images of the hip, fracture site and knee
- Ensure fracture is reducible, if not then consider skeletal traction for shortened femur particularly in muscular patient

Phase 3 - Prep and Drape (Figure 4.3, refer video clip in IFINCTA tool- link in Appendix 2)

- Choice of prep - 4% Chlorhexidine or betadine
- Area to be covered with prep - From iliac crest to tibial tuberosity on the anterolateral Side
- Draping technique - Sterile transparent drape adherent to the lateral aspect of thigh and knee

Phase 4 - Approach and Entry point (Figure 4.4, refer video clip in IFINCTA tool- link in Appendix 2)

- Incision - Incise the skin 3-5 cm proximal and curve it just posterior to the greater trochanter, extending 4 cm proximally
- Exposure: -
 - Incise the fat layer
 - Bluntly dissect through gluteus medius down to the greater trochanter
 - Insert a self-retaining retractor, such as Norfolk and Norwich - to allow adequate access to tip of the GT
- Entry point - Trochanteric entry point - just medial to the tip of GT on the AP plane and in line with the intramedullary canal on the lateral

- Insert an awl or guide pin at the desired entry point up to the level of the lesser trochanter –check with AP and lateral radiographs of the hip
- Open the proximal part of the femur using reamers, as appropriate for the chosen nail

Phase 5 - Reduction and Fixation (Figure 4.5, refer video clip in IFINCTA tool- link in Appendix 2)

- AO principle to fix the fracture-relative stability (intramedullary fixation)
- Fracture reduction technique - depending on the location, type and pattern. Most fractures can be reduced closed on the traction table with manipulation of the fracture site
- Holding the reduction -Once reduction achieved pass the ball tip guidewire past the fracture – this holds the reduction
- Pass the guidewire down to the physal scar of the distal femur. Check guidewire is central on AP and lateral view and certainly away from anterior cortex. Use blocking/poller screws/Steinman pin if required to position guidewire satisfactorily
- Measure the length of the guidewire - this determines the length of the nail
- Reaming - Ensure the skin protector is used at all times during reaming
- Start with forward cutting reamer - 9mm in diameter. Go up in 0.5 mm increments until "cortical chatter" is heard. The nail diameter is usually 1.5 mm smaller than the last reamer used
- Assemble the nail on the jig
- Insert the nail over the guidewire

- Occasionally gentle tapping on the assembled slap hammer may be required to insert nail
- Remove the ball tip guidewire

Proximal Locking: -

- Insert drill sleeve through the jig
- Stab incision is made over the entry point as guided by the drill sleeve
- Drill through both cortices as guided by the nail jig assembly
- Measure and insert appropriate length of screw
- Insert 2 proximal locking screws

Distal Locking: -

- Take a true lateral radiograph of the distal femur - this will ensure that the femoral nail holes are perfectly round. Also ensure they are in the centre of the II image.
- Take a scalpel and place it so that it is at the centre of the hole (II image). Make a stab incision and then perform blunt dissection down to bone with artery forceps
- Take the drill and check with II that the tip of the drill bit is at the centre of the chosen hole in all directions (Superior, inferior, medial, lateral)
- Drill in line with the II direction
- Drill through the near and far cortex. Remove drill driver but leave the drill bit in place and confirm with II that it is through the hole
- Measure with depth gauge and insert appropriate length screw

- Repeat process for the second hole
- Finally take lateral and AP radiographs of distal femur
- Remove nail jig assembly
- Insert an end cap at the proximal end of the nail
- Ensure saved fluoroscopy images of AP and lateral of hip, fracture site and distal femur
- Do distal locking first as it will allow fracture to be back-slapped and any distraction to be corrected

Phase 6 – Closure (Figure 4.6, refer video clip in IFINCTA tool- link in Appendix 2)

- Thorough washout of wound
- Proximal wound - Close fascia and subcutaneous layer with absorbable suture, clips (or interrupted non-absorbable suture) to skin
- Locking screw wounds - clips (or interrupted non-absorbable suture) to skin

Phase 7 - Post-operative Care and Follow-up (Figure 4.7)

Immediate post-operative instructions: -

- Check neurovascular status post-surgery and monitor thigh for compartment syndrome
- Blood tests - day 1 post-surgery - Full Blood Count, renal function

- Thromboprophylaxis - chemical and mechanical thromboprophylaxis as per local protocol
- Mobilize full weight bearing
- Physiotherapy - static quadriceps exercises and passive knee ROM followed by active hip
- and knee ROM
- Monitor wound in the post-operative phase for signs of infection and hematoma
- Clips/sutures should be removed in 12-14 days

Long term follow-up: -

- In outpatient clinic in 2 weeks' post-surgery for wound check and removal of sutures
- Patient needs to be followed up in outpatient clinic until clinical and radiological union of fracture

List of decision points included in the final CTA

DECISION POINTS

Phase 1 - Pre-op Planning

- Check if patient had any preoperative hip pain
- Is the diagnosis correct

- Is there any intra-articular distal fracture extension that would influence operation choice
- Any associated injuries that need treatment? - Associated neck of femur fractures, distal femur fractures, other ipsilateral limb injury or any other injury
- Is any further imaging required for pre-op planning? - Full length femur views including hip and knee AP and lateral, need for CT/MRI if fracture pattern not clear from plain radiographs or if there is suspicion of pathological lesion
- Is the choice of operation correct keeping the fracture pattern in mind? - Is this fracture amenable for antegrade femoral nailing or does it require retrograde nailing/plating
- Has the indications and contra-indications been reviewed prior to the operation?
- Has the right implant been chosen for the operation? - Recon nail/ cephalomedullary nail.
- Implant available in the diameter required
- Are there backup implant options available in the shelf? - other nail types if correct diameter nail not available/ plating kit
- Is there any additional equipment required to undertake the operation? - cables/wires, plates

Phase 2 - Theatre and patient set up

- Are the correct operating table/attachments available? - Check prior to patient transfer onto operating table

- Is the theatre set up providing effective utilization of space and resources?
- Is the WHO checklist appropriately completed?

Phase 3 - Prep and Drape

- Has a proper sterile field been achieved?

Phase 4 - Approach and Entry point

- Ensure adequate access to the tip of the Greater Trochanter
- Ensure entry point is in the correct place for the type of nail chosen. Most commercially available nails have a trochanteric entry point. Ensure that the nail being used is not a piriformis entry nail
- Check with II that the desired entry point has been achieved - this is critical for the rest of the procedure to be performed properly
- Alternative method to cannulated awl for entry point - 3.2 mm K wire. Note an opening reamer must be used if this technique is used to make the entry point before the ball tip guide wire is passed

Phase 5 - Reduction and Fixation

- Fracture needs to be adequately reduced for the guide wire to be passed across it, occasionally needs open reduction

- If open reduction is performed - fracture can be held with a reduction clamp or cables
- Check the position of the wire with an AP and lateral radiograph of the hip, fracture site and knee before proceeding further
- Ensure the size is read on the correct side of the scale (800 m /1000m scale) according to the nail available
- Ensure the nail is not too long or short
- Some femoral nails have a wider proximal diameter - ensure that proximal reaming is performed before nail insertion
- Ensure that the drill guides and wire guides are going through the jig and nail before it is inserted
- Ensure AP and lateral radiographs of the hip, fracture site and distal femur is taken to
- Ensure desirable nail position and fracture reduction
- Correct nail position - Not protruding proximally, until the physeal scar distally on the AP view and in the centre of the femoral canal on the lateral view

Proximal Locking: -

- Ensure fracture rotation is correct before the nail is locked proximally and distally
- Check with II - screw positions are correct before moving onto the next step

Distal Locking: -

- Ensure that you can see a perfect circle for the distal locking holes. An oblique hole can compromise this step and result in the screw not passing through the nail.
- Ensure that you drill in line of the II and then check the position of the drill bit before

placing the screw to ensure this has passed through the hole

- Take a lateral radiograph first of the distal femur to ensure that the screws are through the nail
- Take an AP radiograph of the distal femur to ensure that the correct size of distal locking screws have been inserted

Phase 6 – Closure

- Ensure all layers and wounds are closed appropriately

Phase 7 - Post-Operative Care and Follow-up

- Immediate post-operative instructions followed
- Has the weight bearing status been documented accurately in the operation note
- Community care provider informed about patient's operation and post-operative plan

List of errors & solutions included in the final CTA

ERRORS and SOLUTIONS

Phase 1 - Pre-op Planning

E: missed distal intra-articular fracture extension S: Review radiographs thoroughly and ensure adequate views and image quality available to make this judgement

E: Missed ipsilateral femoral neck fracture S: Consciously review the femoral neck region to ensure any fractures are not missed

E: Other missed injuries S: Thorough clinical assessment and review of all imaging to ensure other injuries not missed

Phase 2 - Theatre and patient set up:

E: Wedge attachment of the traction table is not removed prior to the operation which prevents proper intra-op images of the hip. S: Remove the wedge prior to the operation.

Phase 3 - Prep and Drape

E: Area prepped, dried straightaway and drape applied. S: Allow prep time to dry on its own before drape is applied - this achieves better sterility.

Phase 4 – Approach

E: Straight incision. S: Ensure slight posterior curve to allow smooth access of the nail jig onto the GT.

E: Entry point too lateral on the AP projection - can cause eccentric reaming and varus malreduction especially of proximal shaft fractures. S: Ensure entry point is just medial to the tip of the GT

E: Entry too posterior on the lateral - can cause nail to perforate the anterior femoral cortex distally. S: Ensure on lateral view - the entry point is in line with the intramedullary canal of the femur

Phase 5 - Reduction and Fixation

E: Continue to attempt closed reduction even when it is difficult to achieve. S: Have a low threshold for open reduction in displaced sub trochanteric fractures

E: Guidewire not checked properly on all radiographs before reaming is performed

E: Incorrect nail size chosen - if too long can penetrate the knee joint. If too short may not provide adequate stability of fixation. Proximally the nail should not be protruding out of bone. This can cause soft tissue irritation and pain.

E: Nail inserted without proximal reaming can cause proximal femoral fractures

E: Nail inserted without checking that drill guides can pass through it. This results in the nail required to be removed which can cause iatrogenic fractures and loss of fracture reduction.

Proximal Locking: -

E: Drill sleeve is not completely down to bone - can lead to incorrect measurements and therefore, incorrect size of screw.

Distal Locking: -

E: Drilling through an improper circle can lead to the drill missing the hole and the screw placed incorrectly and not through the distal locking hole. S: If this happens then correct

the position of the II first to ensure perfect circles of the nail locking hole and then carefully redrill to ensure drill has passed through the hole of the nail.

E: Distal locking screws too short - does not effectively lock the nail distally

E: Distal locking screws too long - can cause irritation of soft tissues.

Phase 6 – Closure

E: Stab incision wound missed during closure.

Phase 7 - Post-Operative Care and Follow-up

E: poor/inaccurate documentation of post-operative instructions leading to sub-optimal post-operative management

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis		
Pre-op Planning	Pre-op Planning	
Theatre and patient set up	1. Technical Steps	
Prep and Drape	Mechanism of injury – High velocity - example - RTA Low velocity - falls in the elderly Diagnosis – Femoral shaft fracture, Subtrochanteric fracture, reverse oblique hip fractures Fracture pattern – Spiral, oblique, transverse	
Approach	Choice of operation - indications, contra-indications – Antegrade femoral locked intramedullary nailing for fractures as described in the diagnosis. Template pre-operative radiographs – template nail size and length	
Reduction and Fixation	Equipment – Fracture traction table, femoral nailing instrument set, correct nail type in different diameters and length and image intensifier.	
Closure		
Post-operative Care and Follow-up	2. Decision Points	
	Is it high or low velocity - important for soft tissue assessment – Assess if the fracture is open or closed. Assess for soft tissue swelling, risk of compartment syndrome. Assess neuromuscular status of the affected limb. Is the diagnosis correct? – Ensure the diagnosis has been reviewed accurately and the correct operation has been chosen. Is the fracture accurately classified? – Ensure the fracture pattern is accurately evaluated pre-op. This will help in planning any additional manoeuvres that may be required during the procedure. Any associated injuries that need treatment? – Associated neck of femur fractures, distal femur fractures, other ipsilateral limb injury or any other injury	

Figure 4.1: Snapshot of the pre-operative planning phase of the IFINCTA tool – this shows the split screen format with the written information of the technical steps and decision points on the left and radiographic image of the fracture on the right

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis

Pre-op Planning	Theatre and patient set up	
Theatre and patient set up	1. Technical Steps Operating table, attachments and setup — Radiolucent traction table, Perineal post, contralateral leg holder, wool and crepe Patient positioning — Supine with leg secured on the traction arm for traction and internal rotation. Operative leg adducted to allow in line access for GT (Greater Trochanter) entry point and reaming. Apply in line traction and internal rotation so that patella is pointing to the ceiling - this is an attempt at closed reduction of the fracture. Contralateral leg is abducted and flexed out of the way to allow free movement of II machine.	
Prep and Drape	Position of the scrub team, anaesthetic team, assistant — See video clip Position of the image intensifier — Ensure before starting the case that you are able to obtain AP and lateral images of the hip, fracture site and knee.	
Approach	Position of the theatre lights — Ensure the light is focussed on the surgical wound prior to the start of the operation.	
Reduction and Fixation	Tourniquet — Not required for this operation. Additional information — Ensure fracture is reducible, if not then consider skeletal traction for shortened femur particularly in muscular patients.	
Closure		
Post-operative Care and Follow-up		
	2. Decision Points Are the correct operating table and attachments available? — Check prior to patient transfer onto operating table. Is the theatre set up providing effective utilization of space and resources? — Check prior to starting case.	

Figure 4.2: Snapshot demonstrating the theatre and patient set-up phase of the procedure with the technical steps, decision points, errors and solutions on the left and a video clip together with an audio voice-over on the right explaining this phase of the procedure

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis	
Pre-op Planning	Prep and Drape
Theatre and patient set up	1. Technical Steps <i>Choice of prep</i> — 4% Chlorhexidine or betadine
Prep and Drape	<i>Area to be covered with prep</i> — From iliac crest to tibial tuberosity on the anterolateral aspect of the leg to be operated on. <i>Draping technique</i> — Sterile transparent drape adherent to the lateral aspect of the thigh and knee.
Approach	
Reduction and Fixation	2. Decision Points <i>Has a proper sterile field been achieved?</i> — Has a proper sterile field been achieved?
Closure	<i>Additional information</i> — alternative draping with u drapes - good alternative if reduction aids anteriorly are required - eg pelvic ball-spike pusher.
Post-operative Care and Follow-up	3. Errors and Solutions <i>Error 1</i> — Area prepped, dried straightaway and drape applied <i>Solution</i> — Allow prep time to dry on its own before drape is applied - this achieves better sterility

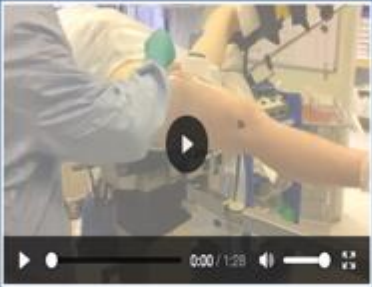


Figure 4.3: Snapshot showing the preparation and draping phase of the procedure with the technical steps, decision points, errors and solutions on the left and a video clip together with an audio voice-over on the right explaining this phase of the procedure

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis		
Pre-op Planning	Approach	
Theatre and patient set up	1. Technical Steps Incision: - identify appropriate landmarks — Incise the skin 3-5 cm proximal and curve it just posterior to the Greater Trochanter(GT), extending 4 cm proximally.	
Prep and Drape	Incision: - length of incision — Curved incision approximately 4 cm in length	
Approach	Additional information — Approach - Incise the fat layer, incise the fascia lata. Bluntly dissect through gluteus medius down to the greater trochanter. Insert a self retaining retractor - to allow adequate access to tip of the GT. Entry Point: Trochanteric entry point - just medial to the tip of the GT on the AP plane and in line with the intramedullary canal on the lateral. Opening the proximal femur: Insert a cannulated awl or guidepin at the desired entry point upto the level of the lesser trochanter - check with AP and lateral radiographs of the hip. Open up the proximal part of the femur using reamers, as appropriate for the chosen nail. Insert a 3mm ball tip guide wire through the cannulated awl or the opening created as described above upto the fracture site.	
Reduction and Fixation		
Closure		
Post-operative Care and Follow-up	2. Decision Points Have the landmarks been identified correctly? — Ensure adequate access to the tip of the GT by placing the incision in the correct place Is any further surgery required in future - plan incision accordingly — Not applicable to this operation.	

Figure 4.4: Snapshot showing the approach phase of the procedure with the technical steps, decision points, errors and solutions on the left and a video clip together with an audio voice-over on the right explaining this phase of the procedure

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis		
Pre-op Planning	Reduction and Fixation	
Theatre and patient set up	1. Technical Steps AO principle to fix the fracture- absolute stability (interfragmentary screw, dynamic compression plate) , relative stability (intramedullary fixation, bridging plate) — relative stability (intramedullary fixation)	
Prep and Drape	Fracture reduction technique (closed, open, direct, indirect) — depending on the location, type and pattern. Most fractures can be reduced closed on the traction table with manipulation of the fracture site.	
Approach	Holding the reductions - clamps, wires, cables — Once reduction achieved pass the ball tip guidewire past the fracture - this holds the reduction.	
Reduction and Fixation	Fixation technique - describe according to procedure — Pass the guidewire down to the physal scar of the distal femur. Check guide wire is central on AP and lateral view and away from anterior cortex. Use blocking/poiler screws/steinman pin if required to position guidewire satisfactorily. Measure the length of the guidewire - this determines the length of the nail. Reaming - Ensure the skin protector is used at all times during reaming. Start with forward cutting reamer - 9mm in diameter. Go up in 0.5 mm increments until "cortical chatter" is heard. The nail diameter is usually 1.5 mm smaller than the last reamer used. Assemble the nail on the jig. Insert the nail over the guidewire. Occasionally gentle tapping on the assembled mallet may be required to insert nail. Remove the ball tip guidewire. Proximal Locking:- Insert drill sleeve through the jig. Stab incision is made over the entry point as guided by the drill sleeve. Drill through both cortices as guided by the nail jig assembly. Measure and insert appropriate length of screw. Insert 2 proximal locking screws. Distal Locking:- Take a true lateral radiograph of the distal femur - this will ensure that the femoral nail holes are perfectly round. Also ensure they are in the centre of the II image. Take a scalpel and place it so that it is at the centre of the hole (II image). Make a stab incision and then perform blunt dissection down to bone with artery forceps. Take the drill and check with II that the tip of the drill bit is at the centre of the chosen hole in all directions (Superior, inferior, medial, lateral). Drill in line with the II direction. Drill through the near and far cortex. Remove drill driver but leave the	
Closure		
Post-operative Care and Follow-up		

Figure 4.5: Snapshot showing the reduction and fixation phase of the procedure with the technical steps, decision points, errors and solutions on the left and a video clip together with an audio voice-over on the right explaining this phase of the procedure

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis

Pre-op Planning	Closure	
Theatre and patient set up	1. Technical Steps <i>Describe the layers to be closed and preferred technique</i> — Washout of wound Proximal wound - Close fascia and subcutaneous layer with absorbable suture, clips (or interrupted non-absorbable suture) to skin. Locking screw wounds - clips (or interrupted non-absorbable suture) to skin.	
Prep and Drape	2. Decision Points <i>Missed layers</i> — Ensure all layers and wounds are closed. <i>Incorrect technique</i> — Ensure water tight closure of the fascial layer.	
Approach	3. Errors and Solutions <i>Error 1</i> — Stab incision wound missed during closure. <i>Solution</i> — Ensure all stab wounds are closed.	
Reduction and Fixation		
Closure		
Post-operative Care and Follow-up		

Figure 4.6: Snapshot showing the closure phase of the procedure with the technical steps, decision points, errors and solutions on the left and a video clip together with an audio voice-over on the right explaining this phase of the procedure

Antegrade Femoral Intramedullary Nailing Cognitive Task Analysis

Pre-op Planning	Post-operative Care and Follow-up	
Theatre and patient set up	1. Technical Steps <i>Immediate post-operative instructions</i> — Monitor vital signs to ensure patient is physiologically stable in the post-operative phase. Check neurovascular status post surgery and also monitor thigh for compartment syndrome.	
Prep and Drape	<i>Patient destination immediately post surgery - ward / ITU / HDU</i> — Decision in liaison with the anaesthetic team - depending on the physiological status of the patient.	
Approach	<i>Any particular physiological variables that need to be followed up on that have been identified intra-op by the anaesthetic team</i> — Identify with the anaesthetic team and document clearly in the post-op instructions.	
Reduction and Fixation	<i>Referral to appropriate specialities</i> — Usually not required following this operation.	
Closure	<i>Blood review</i> — Full Blood count and renal function tests usually the day after the operation. Perform on the same day if any concerns with blood loss intra-operatively.	
Post-operative Care and Follow-up	<i>Thromboprophylaxis</i> — Follow local protocol for mechanical and chemical thromboprophylaxis. <i>Antibiotic prophylaxis</i> — Follow local protocol. Usually 2 post op doses of antibiotics unless otherwise contra-indicated. <i>Weight-bearing status</i> — Usually full weight bearing following this procedure. <i>Monitor neurovascular status</i> — Check sensation distally and also movement in the foot and toes. Monitor distal pulses and assess perfusion status distally. Document this clearly in post-operative review.	

Figure 4.7: Snapshot showing the post-operative care and follow-up phase of the procedure with the technical steps, decision points, errors and solutions on the left and video clip together with an audio voice-over on the right explaining this phase of the procedure

4.4. Discussion

This is the first CTA learning tool that has been described in orthopaedic trauma. It utilizes written and audio-visual stimuli simultaneously which makes it unique in its design. CTA learning tools described in other surgical specialties have mainly focussed on written information generated from a modified Delphi technique (44),(45). Although, these tools have shown significant benefits in teaching these procedures, they do not cater to varying learning styles. Our tool has described the technical steps involved in each phase of an antegrade femoral intramedullary nailing procedure and the cognitive decision making behind each of these steps. Additionally, potential errors and methods of dealing with these have been described. We have supplemented this written information with multimedia video clips and audio voice recordings. Therefore, a learner can simultaneously read the written information, watch video clips (recorded in the operating theatre by one of our experts) and listen to audio recordings describing each of these steps. This is generated using our GCTA wizard tool as described in chapter 3 of this thesis. The learning tool is an online web based tool, which is easily accessible to trainees and allows repeated sustained practise. It has a user-friendly format with the written information on the left side of a split screen and the multimedia content on the right. This is repeated for each phase of the procedure (figures 4.1-4.7). Other studies have attempted to use multimedia applications to design CTA's (64). However, the modalities have been used independent of each other which makes our tool both educationally innovative and technologically novel.

We have used a sound modified Delphi technique to generate the information for our CTA. 100% consensus from three trauma experts ensured quality of content used in our CTA to

teach this procedure. Majority of CTA's described in other surgical specialties to describe procedures such as colonoscopy, laparoscopic appendectomy and flexor tendon repair (44),(45),(67) have used three experts in their Delphi methodology successfully. We were guided by this in our choice of three experts. There are no studies in the educational or surgical literature that have investigated the optimum number of experts required in the Delphi methodology to describe CTA's. Our generic wizard tool as described in chapter 3 of this thesis allows any number of experts to create CTA's using our creation tool. This may allow investigation into the advantages and disadvantages of using a certain number of experts in the Delphi methodology and may form an area of future work.

4.5. Conclusion

We have designed a novel and innovative CTA learning tool for antegrade femoral intramedullary nailing from three trauma experts using the modified Delphi technique. In the next chapter, we will investigate the effectiveness of this tool to teach this procedure to novice undergraduate medical students.

Chapter 5: Trauma simulation training: a randomized controlled trial evaluating the effectiveness of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool *(an adaptation of this chapter has been published in the Acta Orthopaedica on the 18th October, 2018 (71))*

1.1 Introduction

Previous research has highlighted the benefits of virtual reality (VR) and cadaveric simulation in orthopaedic training(22),(24),(74),(75). Recently, in orthopaedic trauma VR simulators have been used to train novices in procedures such as Dynamic Hip Screw fixation (76). However, these are expensive and are not readily accessible to trainees worldwide. In the USA, it is estimated that 25% of training programs do not have a dedicated simulation facility and 87% of training program directors reported a lack of sufficient funds as the main barrier (31).

The burden of orthopaedic trauma is greater than ever before with major trauma now affecting the elderly population in addition to the high energy injuries in the younger age group (72). Reduced training time, and ever increasing trauma workload and restricted access to cadaveric and VR simulation facilities have made it necessary for newer, innovative and easily accessible training adjuncts to the traditional apprenticeship model to help train competent orthopaedic trauma surgeons.

We have established the importance of CTA as a learning tool in surgical training in the previous sections of this thesis. There are no studies in the existing literature that has investigated the benefits of CTA to train novices in orthopaedic trauma.

Aim: to evaluate the effectiveness of a novel CTA tool to improve understanding of the

procedural steps in antegrade femoral intramedullary nailing.

5.2 Methods

(1) Experimental Design to evaluate the effectiveness of the IFINCTA tool to teach the procedural steps to novice medical students

This was a double blinded, randomized controlled trial.

(2) Recruitment

Approval from our institutional Medical Education Ethics Committee (MEEC) was obtained for this study (reference number: 1617-08). 30 undergraduate medical students initially registered their interest in participating in the study. They completed a questionnaire assessing their experience in femoral intramedullary nailing. The inclusion criteria were: if they have observed ≤ 5 antegrade femoral intramedullary nailing procedures. 8/30 students could not attend due to other commitments coinciding with the timing of the study. The remaining 22 students all matched the inclusion criteria and completed the study. All participants gave written consent to participate in the study.

(3) Randomization

The participants were randomized into two equal groups (n=11) using the random number generator function on Microsoft Excel (Microsoft Corporation). This generated two sets (each set n=11) of random numbers from 1 to 22. These were divided into two groups – the intervention and the control group.

We followed the CONSORT protocol for the recruitment and randomization – figure 5.1.

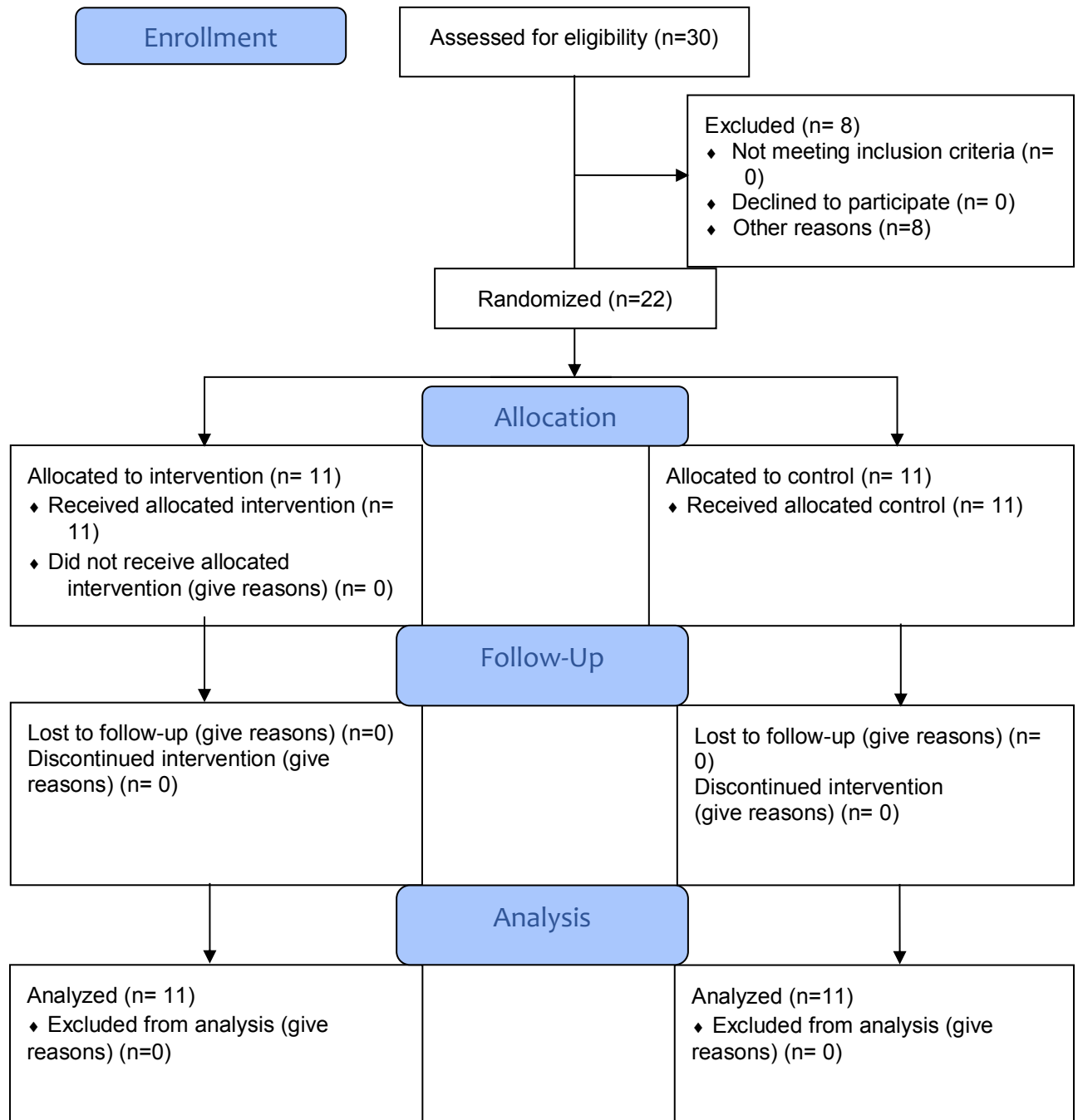
Intervention group

The intervention group was given the IFINCTA learning tool. There were no restrictions or time limit given to them regarding the use of this tool. They were instructed to record the number of minutes they used this tool prior to returning for the post test. They were blinded to whether they belonged to the intervention or the control group as they were not aware if their learning tool was the intervention or the control tool.

Control group

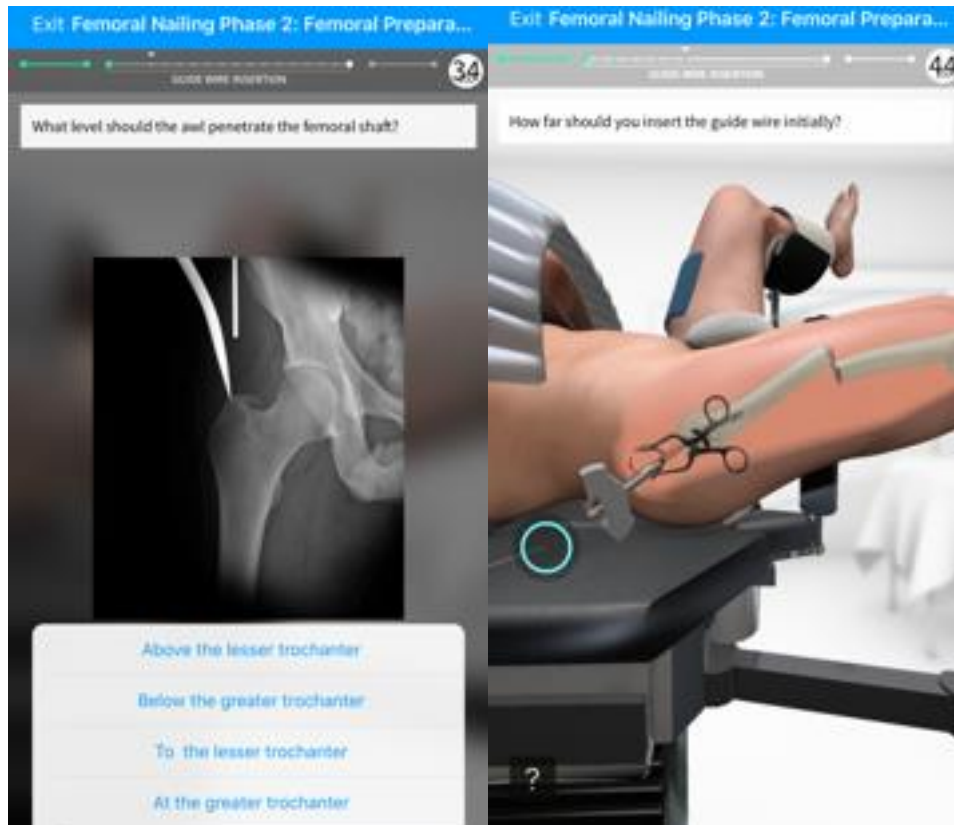
The control group was given a standard commercially available operative technique manual for femoral intramedullary nailing. This was used as the control tool as it was representative of one of the most common methods used by trainees to learn this procedure prior to attending the operating theatre.

Figure 5.1: CONSORT diagram showing recruitment and follow-up of participants



(a) “Touch surgery” application assessment tool

We used the validated “touch surgery” application (Kinosis Limited, London, UK) assessment tool for femoral intramedullary nailing (77). This is a cognitive, interactive VR application which utilizes computer animation to explain operative steps of a surgical procedure. It is available on mobile and smart phone devices. It has separate learning and assessment tools. In our study, we used only the validated assessment tool (figure 5.2) for four modules of this procedure (1=patient positioning and preparation, 2=femoral canal preparation, 3=proximal locking, 4=distal locking and closure). Points were scored for single best answer questions for each step of the procedure (figure 5.2a) and for virtually completing manual steps (incision, drilling etc.) using swipe interactions on the screen (figure 5.2b). The final score for each module is automatically calculated by the software and is scored as a percentage with no negative marking (77).



(a)

(b)

Figure 5.2: “Touch surgery” assessment tool for antegrade femoral intramedullary nailing(a) demonstrating single best answer questions for cognitive decision making, (b) showing the digital swipe interactions required to complete the procedure
 (Image courtesy of Mr Chinmay M Gupte, Dr Kapil Sugand and Digital Surgery Ltd from Touch Surgery App (iOS version) v.5 (2018))

(b) Data collection

The students were supervised during the assessments by an independent supervisor and were blinded to whether they belonged to the intervention or the control group. They were given basic instructions on how to complete the assessment. All participants completed a pre-test for analysis of baseline scores to ensure that the groups were homogenous. They were then provided with their respective learning tools for a week and instructed to use them as many times as they felt comfortable before returning for the post-test. At the end of the week the students completed the post-test using the same assessment tool.

The students in the intervention group (n=11) rated the IFINCTA tool on 5 parameters (table 1) using the Likert rating scale (1 = Strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, 5 = strongly agree). The three expert trauma surgeons who designed the IFINCTA tool agreed on these parameters.

No.	Parameter
1	The tool was easy to use.
2	The tool made the procedure easy to understand.
3	The written, visual and audio modalities being simultaneously present was useful.
4	It would be beneficial to use this tool prior to attending an operating theatre session on femoral intramedullary nailing.
5	You enjoyed using this tool.

Table 5.1: IFINCTA tool rating parameters

(5) Statistical Analysis

A priori power calculation was conducted using mean percentage scores from a previous pilot study whereby the intervention group scored 80.4% vs. the control group which scored 54.6% in module 2 of the assessment tool with an $\alpha=5\%$ and $\beta=20\%$ resulting in a power=80%. The sample size resulted in minimum $n=9$ per group. The difference of scores was also deemed significant according to the expert surgeons. The data obtained from the validation study was input in the SPSS software version 23. The analysis showed that it was non-parametric. The median scores for the 4 modules was calculated for both groups. The Mann-Whitney U test was used for independent data and the Wilcoxon signed rank test was used for paired data where p-value of <0.05 was statistically significant.

5.3 Results

(1) Participant demographics, baseline characteristics and flow through the study

All 22 medical students (17 male, 5 female) who matched the inclusion criteria completed the study. The median age was 22.5 years. The median year of undergraduate studies was 4 (1-5) in the intervention group compared to 5 (1-5) in the control group. The median number of antegrade femoral intramedullary nailing procedures observed in the operating theatre prior to the study in the intervention group was 1 (0-5) compared to 1.5 (0-5) in the control group. The mean time (minutes) the participants used their learning tool in the intervention group was 55 (45-65) compared to 57 (35-70) minutes in the control group. The flow of the participants through the study is described in figure 5.1.

(2) “Touch Surgery” assessment

(a) Pre-test scores

There was no significant difference in the median pre-test scores between the intervention and the control groups. All scores are summarized in table 5.2.

Module	Intervention (IFINCTA) median scores (interquartile range)	Control “op tech” median scores (interquartile range)	Mann-Whitney U test for median difference in scores
patient positioning and preparation	50(40-55)	45(25-55)	p = 0.37
femoral canal preparation	53(50-59)	56(38-62)	p = 1
proximal locking	57(50-60)	50(50-57)	p = 0.39
distal locking and closure	57(53-63)	58(51-63)	p = 0.69

Table 5.2: Comparison of pre-test “touch surgery” assessment scores between intervention and control groups

(b) Post-test scores

The post-test scores were significantly better in the intervention group compared to the control group for all four modules in the “touch surgery” assessment tool for antegrade femoral intramedullary nailing (figure 4). The scores are summarized in table 5.3.

Module	Intervention (IFINCTA) median scores (interquartile range)	Control “op tech” median scores (interquartile range)	Percentage (%) difference	Mann-Whitney U test for median difference in scores
patient positioning and preparation	80(75-82)	60(45-72)	20	p=0.0004
femoral canal preparation	79 (67-84)	58 (48-67)	21	p=0.001
proximal locking	77 (70-82)	67 (52-72)	10	p=0.005
distal locking and closure	82 (81-86)	63 (53-78)	19	p=0.004

Table 5.3: Comparison of post-test “touch surgery” assessment scores between intervention and control groups

(c) Comparison between the pre-test and post-test scores for both groups

The difference in scores between the pre-test and the post-test for the intervention and the control groups is summarized in table 5.4. Both groups showed improvement in the post-test compared to the pre-test but this was much higher in the intervention group compared to the control group.

Module	Difference between pre-test and post-test Intervention (IFINCTA) median scores	Wilcoxon signed rank test	Difference between pre-test and post-test) control (“op tech”) median scores	Wilcoxon signed rank test
patient positioning and preparation	30	p=0.003	15	p=0.003
femoral canal preparation	26	p=0.003	2	p=0.35
proximal locking	20	p=0.003	17	p=0.04
distal locking and closure	25	p=0.003	5	p=0.04

Table 5.4: Comparison between pre-test and post-test scores for the intervention and the control group

(3) IFINCTA tool rating analysis (table 5.5)

All participants (100%) agreed (>3 on the likert scale) on parameters 2-4 on the rating analysis. 10/11 (90.9%) agreed that the tool was easy to use and 9/11 (81.8%) enjoyed using the tool.

No.	Parameter	Agreed (>3 on Likert scale)	
1	The tool was easy to use.	10/11	90.9%
2	The tool made the procedure easy to understand.	11/11	100%
3	The written, visual and audio modalities being simultaneously present was useful.	11/11	100%
4	It would be beneficial to use this tool prior to attending an operating theatre session on femoral intramedullary nailing.	11/11	100%
5	You enjoyed using this tool.	9/11	81.8%

Table 5.5: IFINCTA rating analysis

5.4 Discussion

We have demonstrated that the IFINCTA tool is effective in teaching the procedural steps to novice undergraduate medical students with very little prior knowledge of this operation.

There was no significant difference between the “touch surgery” scores in the pre-test between the intervention and the control groups, thereby ensuring that the groups were comparable. However, the post-test demonstrated significantly better scores in the group using the IFINCTA tool compared to the control group. Although there were improvements in both groups between the pre-test and post-test, the difference was much higher in the IFINCTA group compared to the control group. Our analysis, has demonstrated that the IFINCTA is an effective tool to improve the cognitive understanding of an antegrade femoral intramedullary nailing procedure for novice students. It is also superior compared to a standard operative technique manual which is a commonly used resource by residents to learn the steps prior to attending the operating room.

Previous research has demonstrated benefits and a training effect of the “touch surgery” application to teach femoral intramedullary nailing to novices (76),(77). “Touch surgery” uses computerized animations and written information to teach the procedural steps. There are no defined cognitive decision points and description of specific errors and solutions in this application. Furthermore, our tool has video clips (with superimposed audio voice-overs) recorded in the operating room demonstrating the procedure. The IFINCTA allows the learners to understand the technical steps involved and the cognitive reasoning behind performing each technical step and makes them aware of potential errors and solutions using simultaneous written and audio-visual modalities. This makes our tool both educationally novel and technologically innovative.

Studies have highlighted the effectiveness of VR and cadaveric simulation to teach orthopaedic trauma procedures (25),(76). However, these are expensive and not readily accessible to trainees(31). Our CTA tool is easily accessible and available for trainees. It allows repeated sustained practice which is important in simulation training. The IFINCTA tool can serve as a very useful training adjunct to the traditional apprenticeship model. We believe that using this tool prior to attending the operating theatre will provide learners with a sound understanding of the technical steps and the decision making involved in this procedure. This will reduce their learning curve and allow more effective utilization of theatre training time. This is key in the current environment of reduced training hours (9) available to achieve competency.

The subjective assessment of the tool showed that the vast majority felt that the tool aided their understanding of the procedure. They agreed that the tool was easy to use and they enjoyed using it. The participants believed that this tool is a useful adjunct to learning in the operating room and they would like to use the tool prior to attending a teaching session in the operating room.

Strengths and Limitations

The strengths of this study include that it is a prospective, double-blind randomized controlled trial with a comparable intervention and control group. We used a sound modified Delphi technique to design the IFINCTA tool. This tool is educationally novel and technologically innovative and has demonstrated significant benefits to improve the cognitive understanding of the procedure for novice students.

Our goal is for learners to use this tool prior to attending the operating theatre to give them a robust foundation in the understanding of this procedure which will complement their learning in theatre. The limitation of this study currently is that we have not yet analyzed the impact of this tool to improve operating room performance which carries its own ethical implications. We were obliged to demonstrate the ability of our CTA in a simulation setting to improve cognitive understanding, prior to using it in the operating room.

Future work

An area of future work would involve evaluating the effectiveness of the IFINCTA tool to improve technical performance in the simulation and the operating theatre setting. Assessment of technical performance in the simulation setting in orthopaedic trauma is an area that is still under development. It is contrasting when compared to arthroscopic procedures where various simulation assessment techniques have been validated (78),(79). In our unit, we are developing real time simulation assessment techniques to evaluate the impact of our CTA tool on technical performance, which is an area of future research. Following this, we will evaluate transfer validity in the operating room.

Application

With an ever-increasing rise of orthopaedic trauma workload (72) and reduced training hours (9), simulation-training techniques have increasingly been encouraged (80). We have

designed a new user-friendly, accessible CTA learning tool that has demonstrated significant benefits in improving the knowledge of novice students in antegrade femoral intramedullary nailing. We believe that similar CTA learning tools can have a wide application and impact within trauma and orthopaedic training in the future.

5.5 Conclusion

This is the first study to demonstrate the effectiveness of a CTA learning tool in orthopaedic trauma training. The IFINCTA tool has shown significant benefits in the cognitive understanding of novices in antegrade femoral intramedullary nailing. We recommend using this tool to provide a sound foundation for novice trainees prior to starting their apprenticeship training in the operating room.

Chapter 6: Knee arthroscopy simulation: Design of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) tool *(an adaptation of this chapter has been published in the JBJS Am journal (81))*

6.1 Introduction

Knee arthroscopy is the commonest orthopaedic procedure performed in the USA (82). It requires a different skill set to open surgery and often trainees feel less prepared in the operating theatre. Complications of knee arthroscopy are rare but devastating. They include infection, haemarthrosis, articular cartilage damage from arthroscopic instruments and instrument breakage from use of excessive force. Previous research has highlighted the efficacy of virtual reality (VR) and cadaveric simulation in knee arthroscopy training (23),(29),(76),(83),(84),(85),(86).

Rebolledo et al (29) randomized fourteen junior orthopaedic residents into two groups. The intervention group were trained on a VR simulator (Insight Arthro VR, GMV) for both shoulder and knee arthroscopy. The control group were given didactic lectures with arthroscopy models. They were assessed on a cadaveric model using time to completion and the injury grading index (scale 1-10). There was significant improvement in performance in shoulder arthroscopy and a trend towards improved performance in knee arthroscopy.

A study by Cannon et al. (74) investigated transfer validity of skills learnt in a VR simulator to the operating theatre for diagnostic knee arthroscopy. 54 postgraduate year 3 residents from seven institutions were recruited in the study. They were randomized into two groups.

The intervention group received training on a high-fidelity VR simulator. The training level was determined by using the proficiency scores of five community level orthopaedic surgeons performing a diagnostic knee arthroscopy on a VR simulator. The control group continued with their normal training received from the residency program. 48/54 residents completed the study. They were assessed on a real patient in the operating theatre. A global rating scale and a procedural checklist including visualization and probing scores were used to assess the participants. There was a significant improvement in performance for the intervention group as compared to the control group. This study demonstrated transfer validity of skills learned on a VR simulator to the operating theatre for a diagnostic knee arthroscopy procedure.

Camp et al. (24) compared cadaveric with VR training for diagnostic knee arthroscopy. 45 residents were randomized into three groups. All residents completed a pre-test on a cadaveric model. The validated ASSET (78) score and time required to complete the procedure were used to assess the participants. The control group received no further training between the pre and the post test. The simulator group received four hours of training on a VR simulator and the cadaveric group also received four hours training on a cadaveric model. The same assessment method was used for the post test for all residents. The cadaveric group showed the most significant improvement when compared to the simulator and the control groups. The simulator group also showed improvement compared to the control group. The study concluded that cadaveric training is most beneficial but if the VR simulator is used for at least 300 hours per year then it may be more cost effective when compared to cadaveric training.

Despite the advantages highlighted above for cadaveric and VR simulation in knee arthroscopy, they are expensive and are not readily accessible to trainees worldwide. In the USA, it is estimated that 25% of training programs do not have a dedicated simulation facility and 87% of training program directors reported a lack of sufficient funds as the main barrier (31). In this setting, newer, innovative and easily accessible training adjuncts to the traditional apprenticeship model are necessary to help meet training needs in knee arthroscopy.

The benefits of CTA based training in other surgical specialties has already been discussed (45), (60), (61), (64). We felt that a CTA for diagnostic knee arthroscopy would be very beneficial to provide trainees with a basic understanding of the technical steps and cognitive decision making involved in this procedure. Furthermore, it would increase awareness amongst trainees regarding the potential pitfalls in this procedure and methods to avoid these pitfalls.

To our knowledge there are no studies in the existing literature that had investigated the efficacy of CTA to train novice trainees in diagnostic knee arthroscopy.

Objective: to design a novel CTA for diagnostic knee arthroscopy utilizing the modified Delphi technique

6.2 Methods

(1) Procedural steps and Delphi technique

3 expert (fellowship trained) orthopedic knee surgeons who perform knee arthroscopy as part of their routine clinical practice participated in this study. We used the modified Delphi technique to generate a list of technical steps, decision points, errors and solutions to describe each phase of a diagnostic knee arthroscopy procedure. The Delphi methodology was divided into three rounds.

Round 1

In round 1, the 3 experts were interviewed independently to generate a list of Technical Steps (TS), Decision Points (DP), Errors & Solutions (ES) that are applicable to a diagnostic knee arthroscopy procedure. Each expert was instructed to participate in a “free recall” process. The instruction was: -

“Please list all technical steps, cognitive decision points and errors and solutions that can be applicable to a diagnostic knee arthroscopy procedure ranging from pre-operative planning to post-operative care and rehabilitation”.

The diagnostic knee arthroscopy procedure was divided into 7 phases: (i) theatre and patient set-up; (ii) preparation and draping; (iii) anterolateral portal placement; (iv) examination of the patello-femoral joint and the lateral compartment; (v) examination of the medial compartment and antero-medial portal placement; (vi) examination of the intercondylar notch and the lateral compartment; (vii) post-operative care and rehabilitation.

They dictated these steps away from the operating theatre. These were transcribed by an independent and blinded secretary to produce a document for each expert. In this round, the experts generated the information independently and blinded to each other's content.

These were analyzed by an independent reviewer. All the technical steps, decision points, errors and solutions that were common to the 3 experts were identified in round 1. Since we used fewer than 10 experts in the Delphi process, only those steps were included in the final CTA which had 100% consensus from all 3 experts (55).

Round 2

In round 2, the steps that were common to two experts or exclusively generated from one expert were listed separately. These steps were reviewed by the panel of experts. As in round 1, the experts reviewed these steps independent of each other. They were simply asked to tick agree or disagree next to the steps listed. If they disagreed with a step, they were instructed to either modify the step or eliminate it completely. The steps agreed upon by all experts in rounds 1 and 2 were listed at the end of round 2.

Round 3

In round 3, the experts had a face to face meeting. They reviewed all the steps that were agreed upon in rounds 1 and 2. This round also offered an opportunity for the experts to review any steps that were modified in round 2. Only those steps which had 100% agreement from all 3 experts at the end of the three rounds were included in the final CTA.

(2) Audiovisual stimuli

The supervising consultant of the study recorded a video of a diagnostic knee arthroscopy. This video was divided into separate clips reflecting each of the 7 phases. A voice over describing each step was superimposed on the video. The other two experts reviewed this video and a consensus was reached regarding the final content of the video so that it accurately reflected the written CTA master template. The final CTA learning tool included an excel spreadsheet with the 7 phases describing the technical steps, cognitive decision points and potential errors with the video clips accompanying each phase of the procedure. This created a diagnostic knee arthroscopy learning tool that utilized written information, visual video clips and audio recording describing every step of the procedure from patient positioning to post-operative care and rehabilitation (Figure 6.8). Three simultaneous learning modalities and stimuli helped trainees to understand the technical skills required, the reason underpinning each skill and the potential errors that can occur during this procedure based on the knowledge and experience of experts in this field.

6.3 Results

(1) *Final list of TSs following the modified Delphi technique*

The modified Delphi technique was followed as described in the methods section of this chapter. All steps had 100% agreement amongst the three experts. The following TS were included in the final CTA.

TECHNICAL STEPS

Pre-op Planning

- Mechanism of injury - twisting, non-contact pivot injury, trauma
- Diagnosis/Indications - Meniscus tear, ACL/PCL/ multiligamentous injuries, loose bodies, articular cartilage injuries, osteochondral defects, synovectomy for removal of diseased synovial tissue, washout for septic knee, lateral release, assessment for suitability prior to performing unicompartmental knee replacement/ high tibial osteotomy
- Equipment - check availability prior to procedure

Phase 1 - Theatre and patient set up:

- Operating table, attachments and set up - Ensure that the arthroscopy stacks are placed on the opposite side of the knee that you are working on. Ensure the screen is adjusted to the correct height and level with the patient's chest from proximal to distal. The foot pedals for the shaver are placed on the side of the table you are working on.
- Patient position - Supine with high thigh tourniquet. Lateral support at the level of the tourniquet. The patients' feet should be at the end of the bed and the ipsilateral thigh and knee at the edge of the bed.
- Apply the skirt (blue plastic cut off drape) around the tourniquet
- Examination Under Anaesthesia - Check for effusion, range of motion, patellar mobility, Anterior/Posterior drawer test, Lachman test, Pivot shift and dials test

Phase 2 - Prep and Drape

- Choice of prep - alcoholic betadine: wait for this to dry
- Area to be covered with prep - From the tourniquet to the ankle. Foot does not need to be prepped. Prepping technique and inflation of tourniquet - see phase 2 of the video
- Draping technique - see video: need proximal and foot shut off and extremity drape
- The camera is white balanced with a white swab as shown in the video
- Ensure all pipes are adjusted as shown in the video: lengths so that the re just enough cable for the end to stretch 6cm beyond the foot

Phase 3 - Placement of Anterolateral portal

- Identify appropriate landmarks - The patella tendon, patella, lateral femoral condyle and lateral tibial plateau is marked
- Soft spot - The triangle is defined between the lateral border of the patella tendon, lateral femoral condyle and lateral tibial plateau and the soft spot is identified between these three structures
- Incision - Make a vertical stab incision (< 5mm in length) with a no 15 scalpel with the blade facing upwards in the centre of the soft spot aiming towards the intercondylar notch

Phase 4 - Diagnostic Arthroscopy – Patello Femoral Joint (PFJ) and lateral gutter

- Introduce the trochar in the same direction that the incision was made pointing towards the intercondylar notch with the knee in 80 degrees' flexion
- Slide the trochar underneath the patella gently while extending the knee to enter the suprapatellar pouch
- The scope is then introduced into the suprapatellar pouch
- Ensure that the fluid is turned on
- The focus is adjusted as required and any fat pad or blood that is obscuring the view is drained
- After a good view is obtained the PFJ (patello-femoral joint) is examined
- The light lead is kept at the 3 o'clock position and the camera is kept parallel to the tibia at all times - in this position the patellofemoral articulation is examined. Patella tracking can be examined in this position by flexing the knee to 30 degrees
- Patella - Then the patella is examined - checking the medial and lateral facet. Ensure the light lead is pointing down (6 o'clock position) to look up at the patella
- Examine the trochlea - medial and lateral side. Ensure light lead is pointing upwards (12 o'clock) to look down on the trochlea
- Gently guide the scope into the lateral gutter. Examine the gutter, popliteal hiatus and popliteal tendon

Phase 5 - Diagnostic Arthroscopy - medial compartment and anteromedial portal placement

- The scope is gently moved back to the suprapatellar pouch before guiding it over the medial femoral condyle into the medial gutter
- After examining the medial gutter the arthroscope is gently withdrawn into the anterior aspect of the medial joint and then introduced into the medial compartment with gradual flexion of the knee
- To make the anteromedial portal the scope is turned medially with the knee in 90 degrees' flexion
- A white needle is inserted at the centre of the red light from the scope over the medial soft spot aiming towards the intercondylar notch (see phase 5 of the video).
- The needle is held at right angles to the skin during insertion and then seen under direct vision to ensure the desired position of the portal is achieved
- Make a stab incision in a vertical fashion with a 15 scalpel with the blade pointing upwards in the same direction as the needle
- With the knee at 90 degrees the arthroscopy probe is first inserted into the medial compartment. The articular cartilage of the medial femoral condyle and tibial plateau is examined with the probe. The body of the medial meniscus can also be examined in this position.
- Ensure the medial femoral condyle is examined with the knee in flexion and extension
- The knee is then extended and a valgus and external rotation force is applied to examine the posterior horn of the medial meniscus

Phase 6 - Diagnostic Arthroscopy - intercondylar notch and lateral compartment

- With the knee in 90-degree flexion examine the notch
- Probe the femoral insertion of the ACL to ensure it is stable
- Visualize the tibial insertion of the ACL
- Visualize the PCL
- Keep the probe and the arthroscope in the hiatus formed by the lateral femoral condyle, lateral tibial plateau and the ACL
- Bend the knee into the figure of four position to open the lateral compartment and gently guide the arthroscope into the lateral compartment ensuring the camera is parallel to the tibia
- Visualize and probe the posterior horn, body and anterior horn of the lateral meniscus
- Visualize and probe the articular cartilage of the lateral femoral condyle and tibial plateau
- Closure: Close the portal sites with 3-0 non-absorbable mattress sutures and opsite dressing; Use wool and crepe bandage for compression dressing

Phase 7 - Post operative care and rehabilitation

- Check neurovascular status post-op in recovery
- Patient is assessed by the physiotherapist to ensure that they are safe for discharge the same day
- Keep wool and crepe bandage on for 48 hours
- GP to remove stitches in 12-14 days and check portal sites
- Rehabilitation and timing and duration of follow-up is tailored according to the therapeutic procedure that was performed

(2) Final list of DPs' following the modified Delphi technique

The modified Delphi technique was followed in an identical manner as for the TS. All steps had 100% agreement amongst the three experts. The following DP's were included in the final CTA.

DECISION POINTS

Pre-op Planning

- Review current clinical picture - are symptoms still present. Is the operation required?
- Review the imaging available including the MRI scans yourself. Don't depend solely on the MRI report.
- Ensure all equipment available on the shelf depending on what procedure is required to be performed

Phase 1 - Theatre and patient set up:

- Ensure enough valgus stress possible with the lateral support to work in the medial compartment
- Ensure the leg can go in the figure of four position to work in the lateral compartment

- The skirt is applied to ensure cleansing fluid does not collect under the drape and cause tourniquet burn
- Anterior Drawer/ Lachman - ACL, Posterior drawer - PCL, varus stress - LCL, valgus stress - MCL, Dials test - posterolateral corner

Phase 2 - Prep and Drape

- Ensure assistant on the opposite side does not decontaminate against the operating table whilst prepping – surgeon should ideally stand on the opposite side during prepping to reduce this risk

Phase 3 - Placement of Anterolateral portal

- The blade is faced upwards to ensure that there is no iatrogenic injury to the lateral meniscus
- Vertical incision allows possible extension in case an open procedure is required
- Ensure the blade is perpendicular to the skin in both the proximal-distal and medio-lateral plane and parallel to the tibial plateau

Phase 4 - Diagnostic Arthroscopy - PFJ and lateral gutter

- Take care not to cause iatrogenic injury to the articular cartilage of the patella, trochlea, lateral femoral condyle and the ACL during trochar and scope introduction
- Note any patella maltracking

- Record damage to the articular cartilage of the patella and trochlea according to ICRS/Outerbridge classification (see additional information provided)
- Examine the lateral gutter for synovitis and loose bodies

Phase 5 - Diagnostic Arthroscopy - medial compartment and anteromedial portal placement

- Assess the medial gutter for any loose bodies
- Check the position of the white needle under direct vision. Ensure that it is not too far medial and is above the level of the medial meniscus. Also check it is not too shallow or steep otherwise the medial femoral condyle will get in the way of the instruments during working on the posterior structures.
- Introduce scalpel under direct vision to avoid iatrogenic injury to the medial meniscus and medial femoral condyle
- The knee should be moved in a range of 0-90 degrees to view all weight bearing portions of the articular cartilage of the femoral condyle with the light lead moved through 180 degrees
- Record any articular cartilage injury to the medial femoral condyle/tibial plateau according to the ICRS/Outerbridge grading
- Look at the body, posterior and anterior horn of the medial meniscus and record any tears.
- The location and pattern of the tear should be noted to plan further procedure - repair/menisectomy

Phase 6 - Diagnostic Arthroscopy - intercondylar notch and lateral compartment

- Occasionally the ligamentum mucosum or the Hoffa's fat pad obscures the view of the ACL - these may need to be debrided to improve view
- Probing the ACL is critical to ensure it is still attached to the medial wall of the lateral femoral condyle
- The posterior horn of the lateral meniscus is best seen with the knee in flexion whilst the anterior horn is seen with the knee in slight extension
- The knee should be moved in arrange of 0-90 degrees to view all weight bearing portions of the articular cartilage of the femoral condyle with the light lead moved through 180 degrees.
- The cartilage should also be probed to check for pathological softening or any chondral flap tears
- The meniscus should be assessed for tears - characterize type and location to decide on further treatment

Phase 7 - Post operative care and rehabilitation

- Compression dressings used to minimize swelling following surgery and use of tourniquet

(3) Final list of Errors and Solutions following the modified Delphi technique

ERRORS and SOLUTIONS

Pre-op Planning

- Equipment availability not checked prior to the operation
- MRI incorrectly read/reported

Phase 1 - Theatre and patient set up:

- Poor theatre set up and patient positioning can make the procedure very difficult to perform

Phase 2 - Prep and Drape

- Do not prep the working area of the knee after the popliteal fossa has been prepped.

Phase 3 - Placement of Anterolateral portal

- Portal placed too laterally which makes it difficult to work in the medial compartment;
In this case re-identify landmarks and redo anterolateral portal placement
- Blade facing downwards which puts the lateral meniscus at risk of injury

Phase 4 - Diagnostic Arthroscopy - PFJ and lateral gutter

- Too much force applied to introduce the scope can cause iatrogenic injury to important structures
- Missing the lateral gutter at this stage can lead to missed loose bodies in the joint if the surgeon forgets to examine it at the end of the procedure

Phase 5 - Diagnostic Arthroscopy - medial compartment and anteromedial portal placement

- Introducing the scalpel blind can cause iatrogenic injury to the medial meniscus, patella tendon or the medial femoral condyle
- Incomplete visualization of all weight bearing portion of the femoral condyle and the tibial plateau
- Incomplete visualization of the posterior horn of medial meniscus in a tight knee. Use assistant to give extension and valgus force to ensure the posterior horn of medial meniscus is appropriately examined.

Phase 6 - Diagnostic Arthroscopy - intercondylar notch and lateral compartment

- Mistaking the ligamentum mucosum for the ACL
- Incomplete visualization of all the weight bearing portion of the femoral condyle
- Incomplete visualization of the anterior horn of the lateral meniscus

Phase 7 - Post operative care and rehabilitation

- No errors for this phase identified

Snapshots of video clips showing the 7 phases of the IKACTA tool (Figures 6.1-6.7, refer video clips 001,002,003,004,005,006 provided as supplementary material with this thesis)

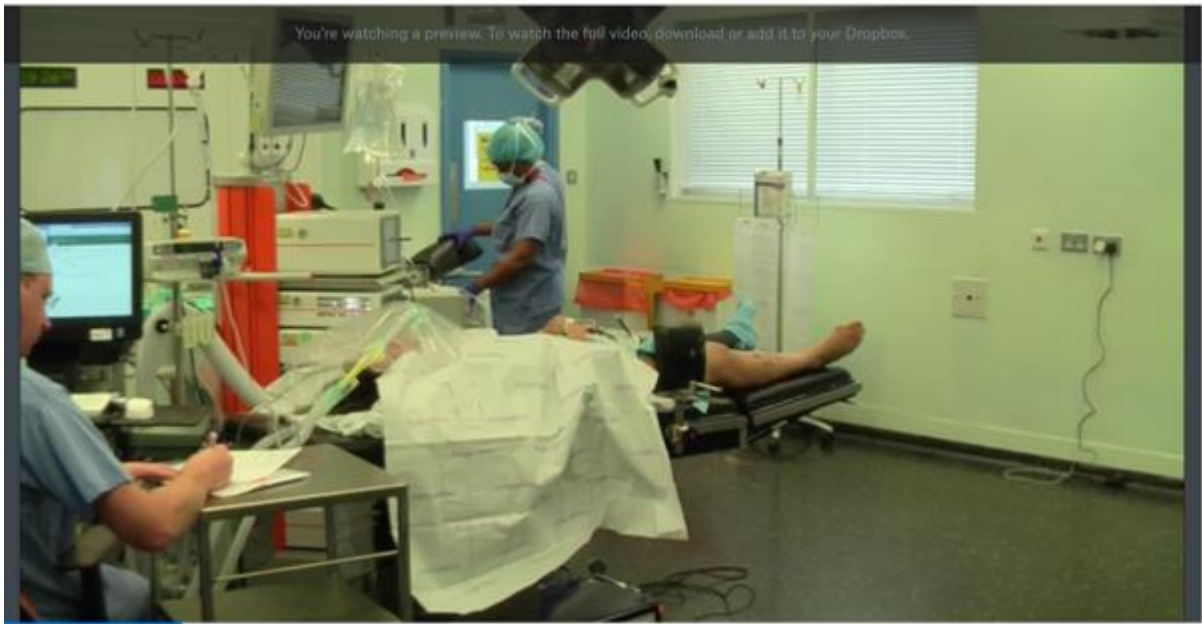


Figure 6.1: Snapshot of the video clip for phase 1: theatre and patient set-up for a diagnostic knee arthroscopy procedure – this shows the position of the patient on the operating table and the position of the arthroscopy stacks and anaesthetic machines in relation to the operating table



Figure 6.2: Snapshot of the video clip for phase 2: prep and drape for a diagnostic knee arthroscopy procedure – this snapshot shows the area to be prepped and the video clip shows the technique used to maintain sterility throughout whilst prepping and draping for this procedure

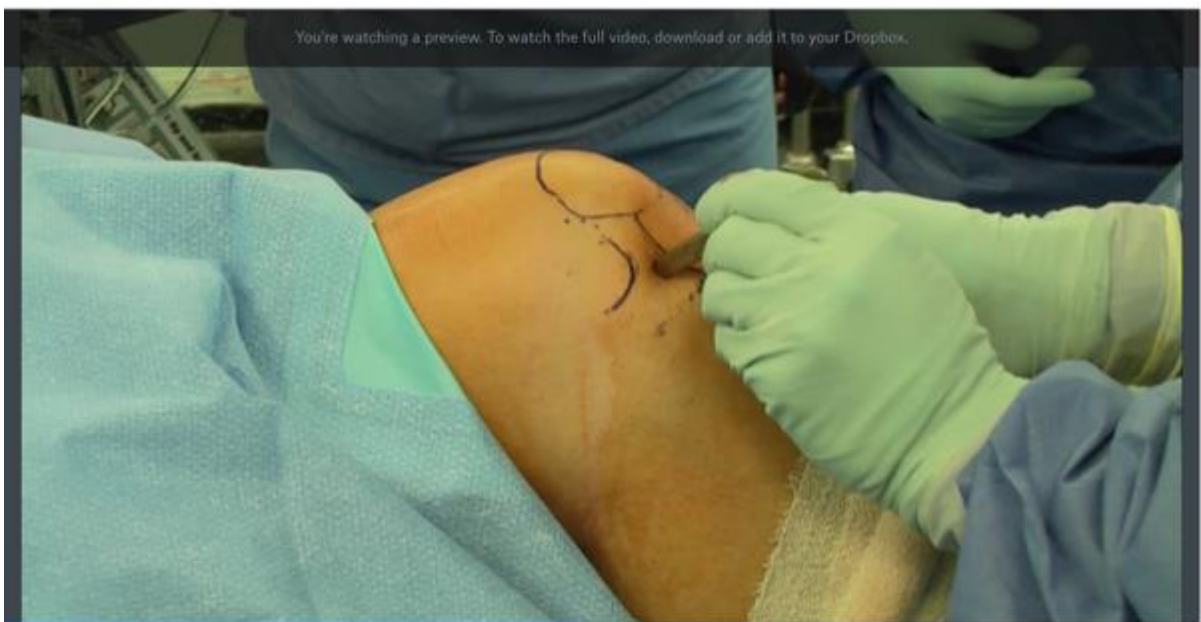


Figure 6.3: Snapshot of the video clip for phase 3: placement of the anterolateral portal – this snapshot shows the optimum position for the anterolateral portal

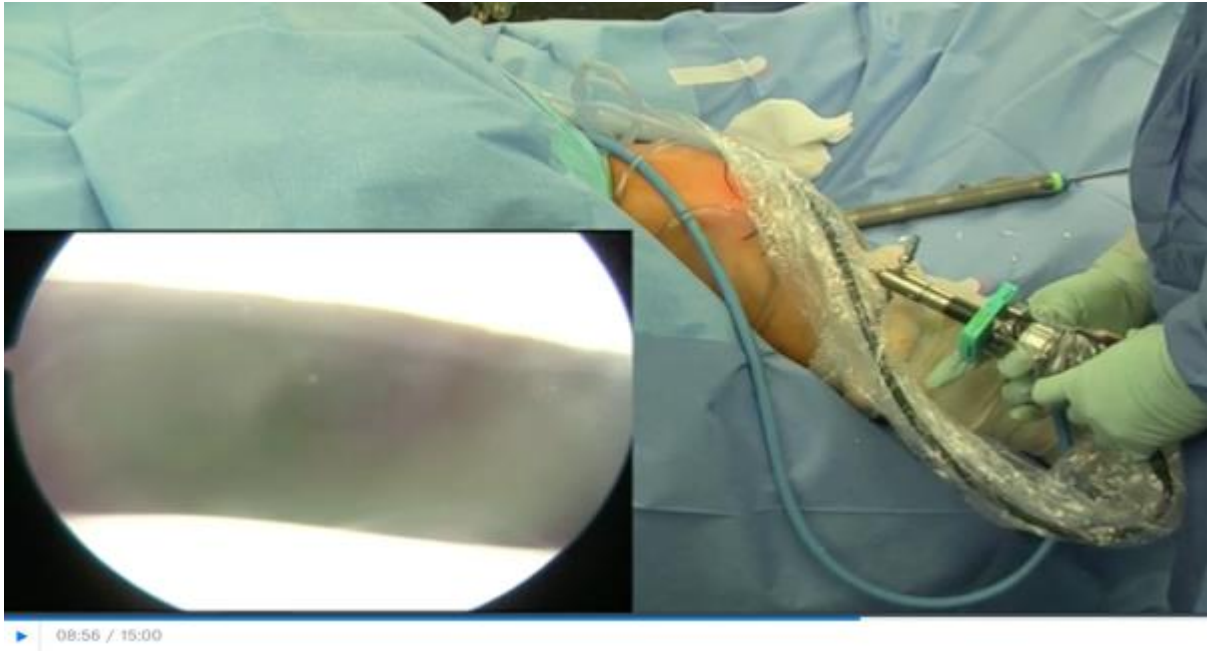


Figure 6.4: Snapshot of the video clip for phase 4: Diagnostic Arthroscopy - PFJ and lateral gutter – this shows the position of the leg in extension whilst examining the Patello-Femoral Joint (PFJ)



Figure 6.5: Snapshot of the video clip for phase 5: Diagnostic Arthroscopy - medial compartment and anteromedial portal placement – snapshot shows the position of the leg and the technique to identify the optimal position whilst making the anteromedial portal

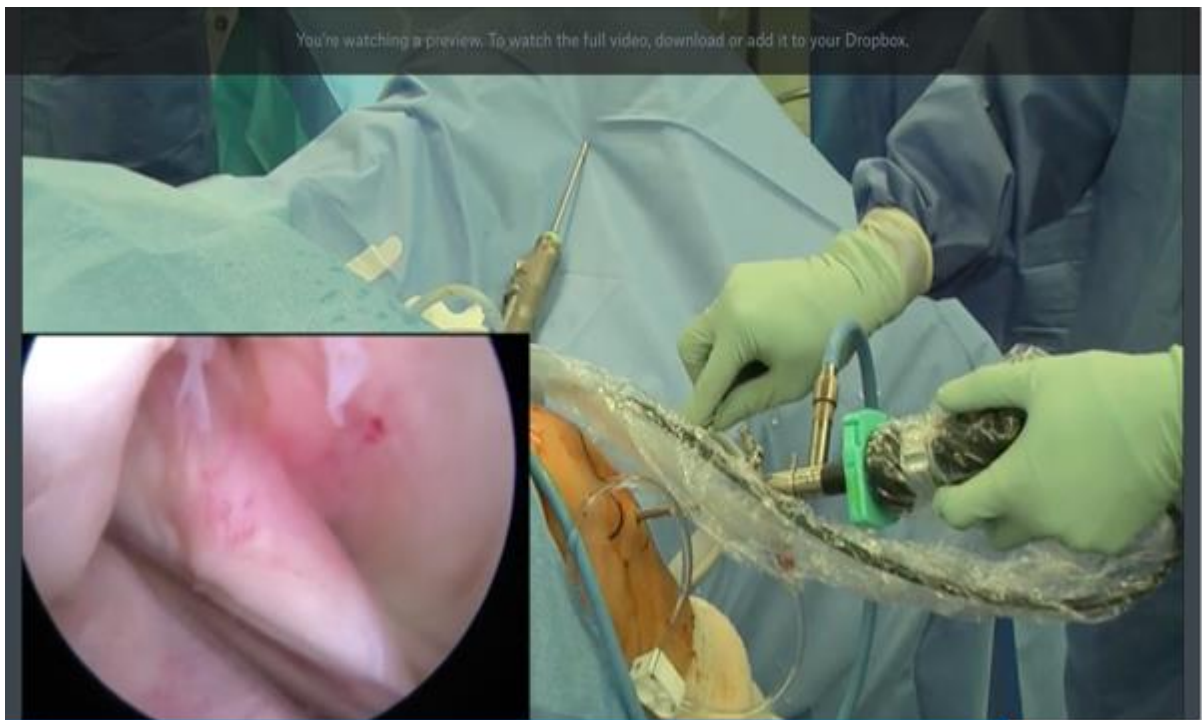


Figure 6.6: Snapshot of the video clip for phase 6: Diagnostic Arthroscopy - intercondylar notch and lateral compartment – this shows examination of the intercondylar notch and probing the femoral insertion of the ACL



Figure 6.7: Snapshot of a video clip showing the “figure of 4” position of the leg for entry into the lateral compartment and probing of the posterior horn of the lateral meniscus

DIAGNOSTIC KNEE ARTHROSCOPY CTA			
TECHNICAL STEPS	DECISION POINTS	ERRORS and SOLUTIONS	VIDEO/IMAGES
Pre-op Planning			
Mechanism of injury - twisting, non-contact			
Diagnosis/Indications - Meniscus tear, ACL			
Equipment - check availability prior to proc			
Phase 1 - Theatre and patient set up:			
Operating table, attachments and set up - E			
Patient position - Supine with high thigh to			
Apply the skirt (blue plastic cut off drape)			
EUA - Check for effusion, RDM, patellar n			
Phase 2 - Prep and Drape			
Choice of prep -alcoholic betadine: wait fo			
Area to be covered with prep - From the tourniquet to the ankle.			
Draping technique - see video: need proximal and foot shut off and extremity drape			
The camera is white balanced with a white swab as shown in the video			
Ensure all pipes are adjusted as shown in the video: lengths so that the re just enough cable for the end to stretch 6cm beyond the foot.			

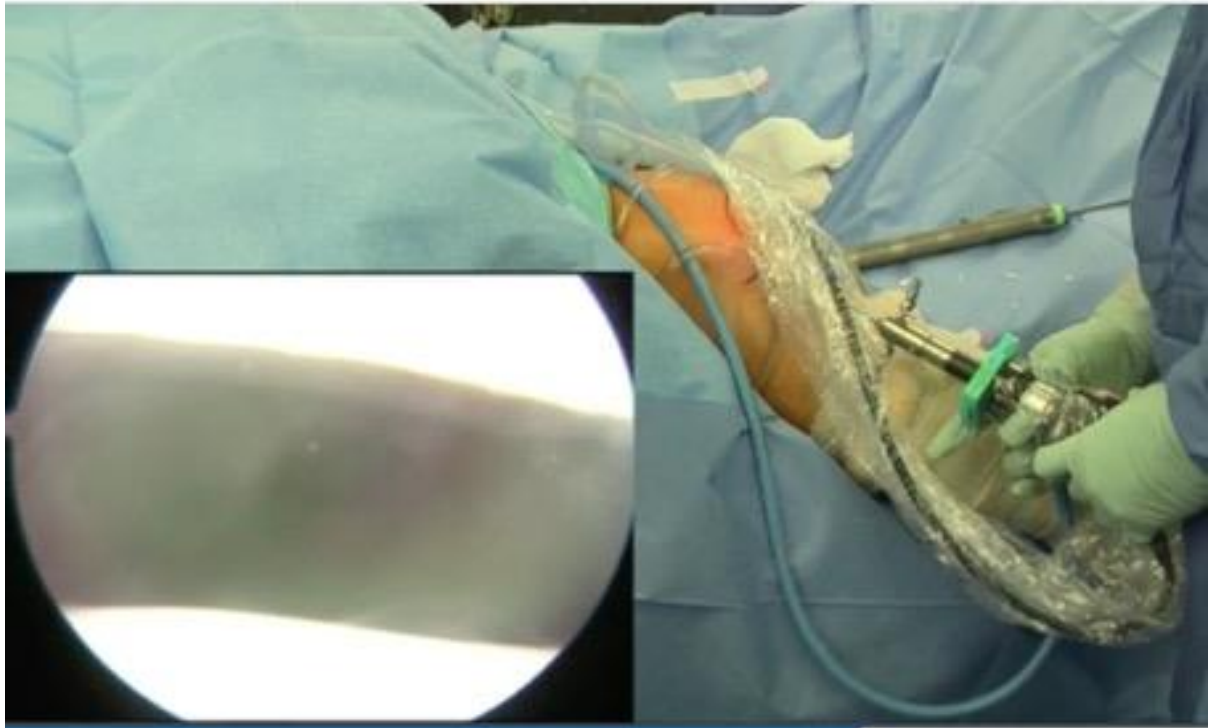


Figure 6.8: Snapshot of the IKACTA tool format showing the written information at the top (including technical steps, decision points, errors and solutions) and the video clip (including the audio voice recordings) at the bottom.

6.4 Discussion

Arthroscopy requires a different skill set to open surgery and often trainees feel less prepared to perform this in the operating theatre. Therefore, simulation has found an increasing role in arthroscopy training. As described previously, VR and cadaveric simulation has demonstrated significant benefits in arthroscopy training (24),(29). However, they are expensive and not readily accessible (31). In this setting innovative, more accessible adjuncts are required. Our IKACTA tool (figure 6.8) is the first CTA tool described for diagnostic knee arthroscopy. It includes comprehensive information on the technical steps, cognitive decision making behind the technical steps and potential pitfalls and solutions to deal with the pitfalls. A sound modified Delphi technique has ensured that three experts in the field have used their knowledge and expertise to design this tool. The video clips and superimposed audio recordings will allow learners to use written, audio and visual modalities simultaneously to learn each step of this procedure.

Most CTA's described in the surgical literature involves only written steps (44),(44). Whilst they are still of excellent educational value, our multimedia design caters for a greater variety of learners. Luker et al (64) also described a multimedia design for their CTA on flexor tendon repair. However, their study used written information, images and videos independent of each other. Our IKACTA tool, combines the written and audio-visual information which caters for simultaneous use by the learners. This makes our tool not only educationally novel but also technologically innovative.

The next chapter of this thesis describes the results for validation of the IKACTA tool.

Chapter 7: Randomized controlled trial to evaluate the effectiveness of the IKACTA tool to train novice surgeons in diagnostic knee arthroscopy (*an adaptation of this chapter has been published in the JBJS Am journal (81)*)

7.1 Introduction

Following the design of the IKACTA tool, we undertook a Randomized Controlled Trial (RCT) to evaluate the effectiveness of this tool to train novice surgeons in diagnostic knee arthroscopy. Previous studies have used various methods of assessment to evaluate benefits of simulation training. This includes cadaveric (29), (24), VR and benchtop models (83). Howells et al.(30) have demonstrated transfer validity of skills learned on a benchtop knee simulator to the operating theatre. Cannon et al. (74) have shown similar transfer validity of skills learnt on a high-fidelity VR simulator to the operating theatre. Therefore, objective benefits demonstrated in the simulation setting indicate improved performance in the operating theatre.

Various methods of assessment have been tried to evaluate arthroscopic skills gained in the simulation setting (87). Amongst these, Global Rating Scales have emerged the most popular. The GRS most commonly used are ASSET (78), IGARS (88), modified BAKSSS (89) scores for objective assessment of arthroscopic skills. Middleton et al. (87) compared these GRS to assess superiority. 63 participants were recruited of varying surgical experience. 31 were classified as novices (no independent arthroscopy experience), 21 as trainees (< 100 independent arthroscopies), 11 as experts (> 100 independent arthroscopies). They were randomized to either a knee or a shoulder VR simulator model. Performance was

analyzed by two independent raters using the three GRS (ASSET – figure 7.1, IGARS – figure 7.2 and BAKSSS – figure 7.3). Validated objective motion analysis was also used. All three GRS demonstrated construct validity. Each level and arthroscopic task showed significant differences between novices and experts. Inter rater reliability was excellent for all three tools. This study concluded that all these three scores were reliable assessment tools and may be used to assess arthroscopic skill. There was no further need to develop any other GRS to assess arthroscopic performance using similar domains. In our study, we decided to use the ASSET global rating scale as this was simple and easy to use.

The ASSET scoring system (figure 7.1) was developed by Koehler et al. (78). The content of this global rating scale was developed from seven experts using the Delphi technique. 28 residents of varying experience and two attending surgeons (sports medicine fellowship trained knee arthroscopists) performed a diagnostic knee arthroscopy on a cadaveric specimen according to a pre-determined checklist. They were assessed by two independent raters. This study demonstrated construct and content validity for the ASSET score. The intraclass correlation coefficient between two raters was 0.90 which demonstrated high inter-rater reliability. The test-retest reliability assessment demonstrated a significant positive correlation ($r=0.79$, $p<0.01$) for the mean ASSET scores between the first and the second procedure for each subject. This study concluded that the ASSET was a useful, reliable and valid method for assessing skills in diagnostic knee arthroscopy.

Aim: The aim of this study was to evaluate the effectiveness of a novel CTA tool to train novice surgeons in diagnostic knee arthroscopy in high fidelity phantom limb simulation.

Safety	1 – Novice	2	3 - Competent	4	5- Expert
	Significant damage to articular cartilage or soft tissue		Insignificant damage to articular cartilage or soft tissue		No damage to articular cartilage or soft tissue
Field of View	1 – Novice Narrow field of view, inadequate arthroscope or light source positioning	2	3 - Competent Moderate field of view, adequate arthroscope and light source positioning	4	5- Expert Expansive field of view, optimal arthroscope and light source positioning
Camera Dexterity	1 – Novice Awkward or graceless movements, fails to keep camera centered and correctly oriented	2	3 - Competent Appropriate use of camera, occasionally needs to reposition	4	5- Expert Graceful and dexterous throughout procedure with camera always centered and correctly oriented
Instrument Dexterity	1 – Novice Overly tentative or awkward with instruments, unable to consistently direct instruments to targets	2	3 - Competent Careful, controlled use of instruments, occasionally misses targets	4	5- Expert Confident and accurate use of all instruments
Bi-Manual Dexterity	1 – Novice Unable to use both hands or no coordination between hands	2	3 - Competent Uses both hands but occasionally fails to coordinate movement of camera and instruments	4	5- Expert Uses both hands to coordinate camera and instrument positioning for optimal performance
Flow of Procedure	1 – Novice Frequently stops operating or persists without progress, multiple unsuccessful attempts prior to completing tasks	2	3 - Competent Steady progression of operative procedure with few unsuccessful attempts prior to completing tasks	4	5- Expert Obviously planned course of procedure, fluid transition from one task to the next with no unsuccessful attempts
Quality of Procedure	1 – Novice Inadequate or incomplete final product	2	3 - Competent Adequate final product with only minor flaws that do not require correction	4	5- Expert Optimal final product with no flaws
Autonomy	1		2		3
	Unable to complete procedure even with intervention(s)		Able to complete procedure but required intervention(s)		Able to complete procedure without intervention
Added Complexity of Procedure					
1		2		3	
No difficulty		Moderate difficulty (mild inflammation or scarring)		Extreme difficulty (severe inflammation or scarring, abnormal anatomy)	

Figure 7.1: ASSET global rating scale (78) to assess arthroscopic skills – shows the 8 domains which are assessed and a total score of 38. 24/38 is deemed to be competent and 38/38 is expert level.

TABLE I The Imperial Global Arthroscopy Rating Scale (IGARS)* for Assessing Arthroscopic Performance

Observer ID: _____

Video ID: _____

1. Makes the portals (or inserts the arthroscope and instruments) with the correct angles of insertion to access the targeted space
 - 1- Many unsystematic attempts and very inefficient access to the targeted point with randomly chosen angles of insertion.
 - 2-
 - 3- Several attempts before getting into the targeted space. Once found, maintains the correct arthroscope and instrument angles most of the time.
 - 4-
 - 5- Efficient angles of insertion, perfect access to the targeted space within the joint.
2. Respect for tissue (looking at the smoothness of the movements)
 - 1- Often used unnecessary force on tissue. Damage caused by inappropriate use of the instruments.
 - 2-
 - 3- Careful handling of tissue but occasionally rough movements or caused inadvertent damage.
 - 4-
 - 5- Consistently handled tissues appropriately, with minimal damage.
3. Proficiency in handling the arthroscope
 - 1- The view of the anatomy is not coherent (for example, randomly oriented upside-down). Incoherent turns of the optics and the camera. Repeatedly makes tentative or awkward movements with the arthroscope.
 - 2-
 - 3- Competent use of the arthroscope, coherent view of the anatomy although occasionally appeared stiff or awkward. Inefficient use of the optics turn.
 - 4-
 - 5- Fluid moves with the arthroscope, adequate use of camera and optics turns, and no awkwardness. If adequate, takes advantage of using different portals.
4. Proficiency in handling the instruments (excluding the arthroscope)
 - 1- Repeatedly makes tentative or awkward movements with instruments.
 - 2-
 - 3- Competent use of instruments, although occasionally appeared stiff or awkward.
 - 4-
 - 5- Fluid moves with instruments and no awkwardness.
5. Depth perception
 - 1- Constantly overshoots target. Slow to correct.
 - 2-
 - 3- Some overshooting or missing of target.
 - 4-
 - 5- Accurately directs instruments in the correct plane to target.
6. Bimanual dexterity and triangulation
 - 1- Noticeably awkward with non-dominant hand, poor coordination between hands. Unable to locate or great difficulty in locating the instrument.
 - 2-
 - 3- Uses both hands but does not maximize interaction between hands. Locates the instrument after a moderate time, but in a systematic way.
 - 4-
 - 5- Expertly uses both hands in complementary manner to provide optimum performance. Locates the instrument quickly and efficiently.
7. Efficiency and time
 - 1- Many unnecessary, inefficient movements. Constantly changing focus or persisting without progress.
 - 2-
 - 3- Slow, but planned movements are reasonably organized with few unnecessary or repetitive movements.
 - 4-
 - 5- Confident, clear economy of movement and maximum efficiency.

TABLE I (continued)

8. Knowledge of anatomy and orientation
 - 1- Deficient knowledge of the anatomy. Feeling of being lost within the joint. Clear mistakes when recognizing or looking for anatomical structures.
 - 2-
 - 3- No mistakes when recognizing the anatomy. Good orientation and knowledge of where the arthroscope and instruments are. Moderate knowledge of the anatomical structures and pathologies.
 - 4-
 - 5- Demonstrated familiarity with all the anatomical structures and pathologies. Excellent orientation.
 9. Knowledge of specific procedure and/or tasks to be performed (related to each particular exercise)
 - 1- Deficient knowledge of the operative steps, even with help.
 - 2-
 - 3- Able to follow the operative steps (or tasks) with moderate help.
 - 4-
 - 5- Demonstrated familiarity with all aspects of the operation and the operative steps to be performed.
 10. Overall individual performance and competence (related to each particular exercise)
 - 1- Very poor
 - 2-
 - 3- Competent
 - 4-
 - 5- Clearly superior
- Observations:
- Strengths:
- Suggestions for improvements:

*The portable scale is designed to be used in both the operating room and in simulated environments. It allows an anonymous assessment that is independent of time and place.

Figure 7.2: IGARS (88) global rating scale for assessing arthroscopic performance in the simulated environment and the operating room. The overall score is out of 50. 30/50 is deemed competent and 50/50 is expert level.

Appendix 1: Modified BAKSSS Global Rating Scale Instrument handling

- 1- Repeatedly makes tentative or awkward movements with instruments
- 2-
- 3- Competent use of instruments, although occasionally appeared stiff or awkward
- 4-
- 5- Fluid moves with instruments and no awkwardness

Depth perception

- 1- Constantly overshoots target, slow to correct
- 2-
- 3- Some overshooting or missing of target
- 4-
- 5- Accurately directs instruments in the correct plane to target

Bimanual dexterity

- 1- Noticeably awkward with nondominant hand, poor coordination between hands
- 2-
- 3- Uses both hands but does not maximize interaction between hands
- 4-
- 5- Expertly uses both hands in complementary manner to provide optimum performance

Flow of operation and forward planning

- 1- Frequently stopped operating or needed to discuss next move
- 2-
- 3- Demonstrated ability for forward planning with steady progression of operative procedure
- 4-
- 5- Obviously planned course of operation with effortless flow from one move to the next

Knowledge of instruments

- 1- Frequently asked for the wrong instrument or used inappropriate instrument
- 2-
- 3- Knew the names of most instruments and used appropriate instrument for the task
- 4-
- 5- Obviously familiar with the instruments required and their names

Efficiency

- 1- Many unnecessary, inefficient movements, constantly changing focus or persisting without progress
- 2-
- 3- Slow but planned movements are reasonably organized with few unnecessary or repetitive movements
- 4-
- 5- Confident, clear economy of movement and maximum efficiency.

Knowledge of specific procedure

- 1- Deficient knowledge, needed specific instruction at most operative steps
- 2-
- 3- Knew all important aspects of the operation
- 4-
- 5- Demonstrated familiarity with all aspects of the operation

Autonomy

- 1- Unable to complete entire task, even with verbal guidance
- 2-
- 3- Able to complete task safely with moderation guidance
- 4-
- 5- Able to complete task independently without prompting

Quality

- 1- Very poor
- 2-
- 3- Competent
- 4-
- 5- Clearly superior

Figure 7.3: Modified BAKSSS global rating scale (89) for assessment of knee arthroscopic skills: total score of 45; 27/45 highlights competency; 45/45 is expert level

7.2 Methods

(1) Experimental Design to evaluate the effectiveness of the IKACTA in the simulation setting

This was a double blinded, randomized controlled trial. The participants were not aware whether they belonged to the intervention or the control group throughout the study. The two independent assessors grading the participants were not aware whether they belonged to the intervention or the control group.

(2) Recruitment and ethical approval

Ethical approval for this study was obtained from our institutional Medical Education Ethics Committee (MEEC) (reference number: 1617-08). The application to the MEEC committee included detailed information on the study with the study protocol, a sample of the participant consent form, description of the tasks required to be undertaken by the participants, a detailed description of the ethical issues involved in the study and a sample of the advertisement for recruitment. The application was reviewed by the committee and approved.

(3) Participants

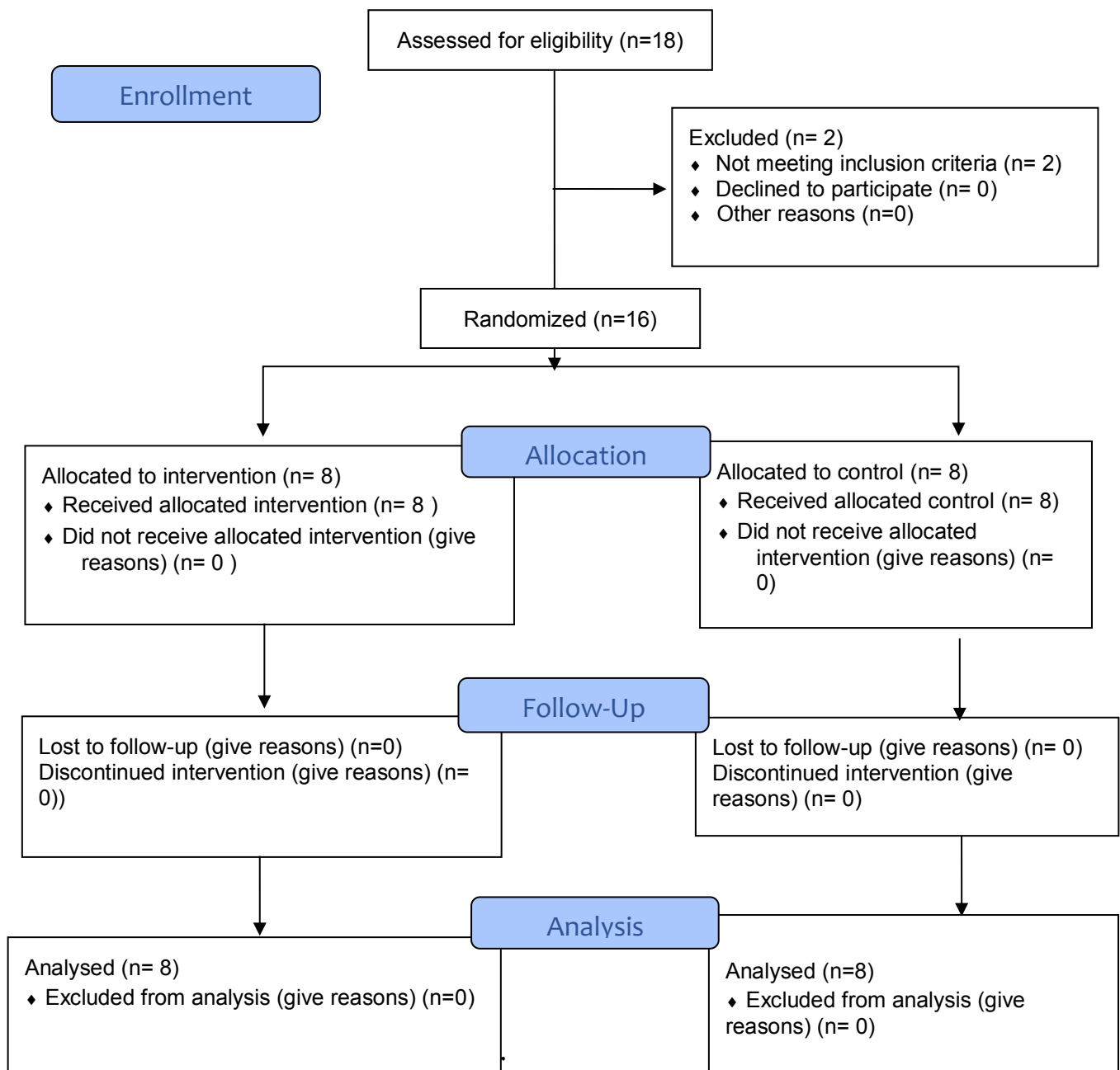
The study was advertised through various sources. These included: the laboratory website, the Royal College of Surgeons England website (courses section), the British Orthopaedic

Association (BOA) website – education section and the local hospital trust noticeboard. 18 junior orthopaedic trainees registered their interest in participating in the study. They completed a questionnaire assessing their experience in performing a diagnostic knee arthroscopy. The inclusion criteria for novice knee arthroscopists was having performed less than 10 diagnostic knee arthroscopy procedures in theatre supervised by a senior surgeon. 16 candidates were recruited in the study who matched the inclusion criteria. 2 were excluded because their experience level was more than the desired criteria. This ensured that the group was homogenous and included novice surgeons with little prior experience in knee arthroscopy. All participants gave written consent to participate in the study.

(4) Randomization

The participants were randomized into two equal groups (n=8) using the random number generator function on Microsoft Excel (Microsoft Corporation, Redmond, Washington, United States). This generated two sets (each set n=8) of random numbers from 1 to 16. These were divided into two groups (A = IKACTA intervention group, B = control group). All assessors were blinded to the intervention and the control group. We followed the CONSORT protocol for the recruitment and randomization – figure 7.4.

Figure 7.4 CONSORT diagram for recruitment of participants – describes the flow of the participants in the study including follow-up and number of participants analyzed in the intervention and the control groups



(5) Trial

Study groups

Group A (intervention) was given the IKACTA learning tool 10 days prior to their assessment date. There were no restrictions or time limits given to them for the use of their tool. This was a pragmatic approach given that trainees can use a learning tool any number of times prior to attending the operating theatre to perform that procedure.

Group B (control) were given no additional learning tools. This reflected the learning they received from their current apprenticeship training. This would allow the evaluation of the effectiveness of the IKACTA tool to serve as an adjunct to the apprenticeship model.

All participants were given a flowchart showing the sequence of steps that they were expected to perform in a diagnostic knee arthroscopy.

Assessment

All 16 participants were assessed on a high-fidelity phantom knee model with actual arthroscopic instruments and stacks. The phantom knee model was a plastic model representative of normal knee anatomy. This was set up on a vice holder and the medial and lateral sides on the model were pre-marked.

The arthroscopy stack was the standard one used in our hospital trust. The company manufacturing these stacks provided four stacks with real instruments for the purpose of this study. The participants were given basic instructions on the type of arthroscope and

instrument set available to them and instructed to perform a diagnostic knee arthroscopy, as they deemed appropriate. No additional help or guidance was provided. Participants attempted the knee arthroscopy on their own with monitoring by an investigator but no assistance. The videos for each participant were recorded from the arthroscopy stack for future grading and evaluation by an expert surgeon without knowing the identity of the participant or which group the participant belonged to.

Two blinded, independent, fellowship-trained expert knee surgeons graded all videos using the validated ASSET score (figure 7.1) and the Task Completion Score (TCS – figure 7.5) part of the ASSET study. These scores were compared between the two groups and analyzed to evaluate objective difference in performance between both groups.

The ASSET has a maximum score of 38. It tests eight domains. These include: safety, field of view, camera dexterity, instrument dexterity, bi-manual dexterity, flow of procedure, quality of procedure and autonomy. The first seven domains are scored from 1 to 5 (1- novice, 3 – competent, 5 – expert) and the last domain is scored out of 3 (1 – unable to complete procedure even with intervention, 2 – able to complete procedure with intervention, 3 – able to complete procedure without intervention). 38/38 indicates expert level performance. 24/38 demonstrates competent level performance. For example, a UK based orthopaedic trainee who has completed their training requirement in this procedure would be expected to score 24/38 thereafter progressing further towards the expert level after they gain experience in their fellowship and early consultant years.

The Task Completion Score (TCS) part of the ASSET (78) study is a checklist of steps that need to be completed to adequately perform a diagnostic knee arthroscopy. The steps include: inspection of the suprapatellar pouch, evaluation of the patella-femoral articulation, evaluation of the patella (superior, inferior, medial, lateral), inspection of the lateral gutter, inspection of the popliteus tendon and recess, inspection of the medial gutter, inspection and probing of the medial femoral condyle and medial tibial plateau, inspection and probing of the anterior, middle and posterior medial meniscus, inspection and probing of the ACL, PCL and ligamentum mucosum, inspection and probing of the lateral femoral condyle and lateral tibial plateau, inspection and probing of the anterior, middle and posterior lateral meniscus and evaluation of the passive patella tracking in the trochlear groove. This has a maximum score of 14. A trained surgeon should ideally be scoring maximum points on this checklist.

Task Checklist - Diagnostic Arthroscopy (Knee)	Completed?
Inspect suprapatellar pouch	☐ Yes ☐ No
Evaluate patellofemoral articulation	☐ Yes ☐ No
Evaluate patella (medial/lateral and inferior/superior)	☐ Yes ☐ No
Inspect the lateral gutter	☐ Yes ☐ No
Inspect the popliteus tendon and recess	☐ Yes ☐ No
Inspect medial gutter	☐ Yes ☐ No
Inspect and probe medial femoral condyle	☐ Yes ☐ No
Inspect and probe medial tibial plateau	☐ Yes ☐ No
Inspect and probe anterior, middle and posterior medial meniscus	☐ Yes ☐ No
Inspect and probe ACL/PCL/Ligamentum	☐ Yes ☐ No
Inspect and probe lateral femoral condyle	☐ Yes ☐ No
Inspect and probe lateral tibial plateau	☐ Yes ☐ No
Inspect and probe anterior, middle and posterior lateral meniscus	☐ Yes ☐ No
Evaluate passive tracking of patella in trochlear groove	☐ Yes ☐ No

Figure 7.5 (78): TCS part of the ASSET study - This is a task checklist for a diagnostic knee arthroscopy procedure to ensure all aspects of the knee joint have been examined adequately

All participants were provided the IKACTA learning tool following their assessment. They rated the tool on 7 parameters (**table 7.1**) using the Likert rating scale (1 = Strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, 5 = strongly agree). The three expert knee surgeons who designed the IKACTA tool agreed on these parameters.

No.	Parameter
1	This tool was useful to understand the key technical steps required to perform this procedure
2	This tool was useful to understand the decision-making process behind the key technical steps involved in this procedure
3	This tool was useful in highlighting the common potential errors that can occur whilst undertaking this procedure
4	This tool will be a useful training adjunct to learning how to perform a diagnostic knee arthroscopy in the operating theatre
5	This tool is easy to use
6	You enjoyed using this tool
7	You would like to use this tool prior to attending a theatre session on diagnostic knee arthroscopy

Table 7.1: IKACTA tool rating parameters – these had 100% consensus from the three-expert knee arthroscopists who designed the IKACTA tool

(7) Statistical Analysis

A priori power calculation was conducted using mean percentage scores from a previous pilot study whereby group A scored 52.0% vs. group B scored 25.7% with an $\alpha=5\%$ and $\beta=20\%$ resulting in a power=80%. The sample size resulted in minimum $n=6$ per group. The difference of scores was also deemed clinically significant according to the expert surgeons.

The data obtained from the study was input into the SPSS version 23 software for analysis. It was deemed to be non-parametric based on the Q-Q plots, histograms and skewness assessments.

The median ($\pm$ SD) ASSET scores were calculated for both groups. The Mann Whitney U test was used where p-value of <0.05 was statistically significant. Box plots for each group were also devised.

The intra-class correlation coefficients (ICCs) were used to evaluate the inter-observer reliability of the ASSET scoring of two raters. An ICC of 0.41 to 0.60 was considered to represent moderate agreement; 0.61 to 0.80, substantial agreement; and 0.81 to 1.00, almost perfect agreement (90).

7.3 Results

(1) Participant demographics

All 16 participants (male =14, female=2) who were included, completed the study. All participants were junior orthopaedic trainees and matched the inclusion criteria for novice knee arthroscopists (performed ≤ 10 procedures under senior supervision). The median number of diagnostic knee arthroscopies performed (all supervised by consultants) by the participants in Group A was 3.5 (± 3.1 , range 0-10) compared to 3 (± 3.3 , range 0-10) in group B ($p=0.56$) prior to the study.

(2) ASSET score

The median ASSET score in group A was 20.5 (± 3.67 ; range 14-25) compared to 10 (± 2.32 ; range 9-16) in group B (**figures 7.6, 7.7**). The improvement in the median ASSET scores between groups A and B was 10.5 ($p = 0.002$; 95% CI = 7.63-10.11). The ICC between the two raters was 0.795.

(3) Task completion score (TCS)

The median TCS score in group A was 11.5 (± 2.87 ; range 4-13) compared to 3 (± 1.58 ; range 1-6) in group B (figures 7.6,7.8). The improvement in the median TCS scores between groups A and B was 8.5 ($p = 0.002$, 95% CI = 6.18 – 8.06). The ICC between the two expert raters was 0.893.

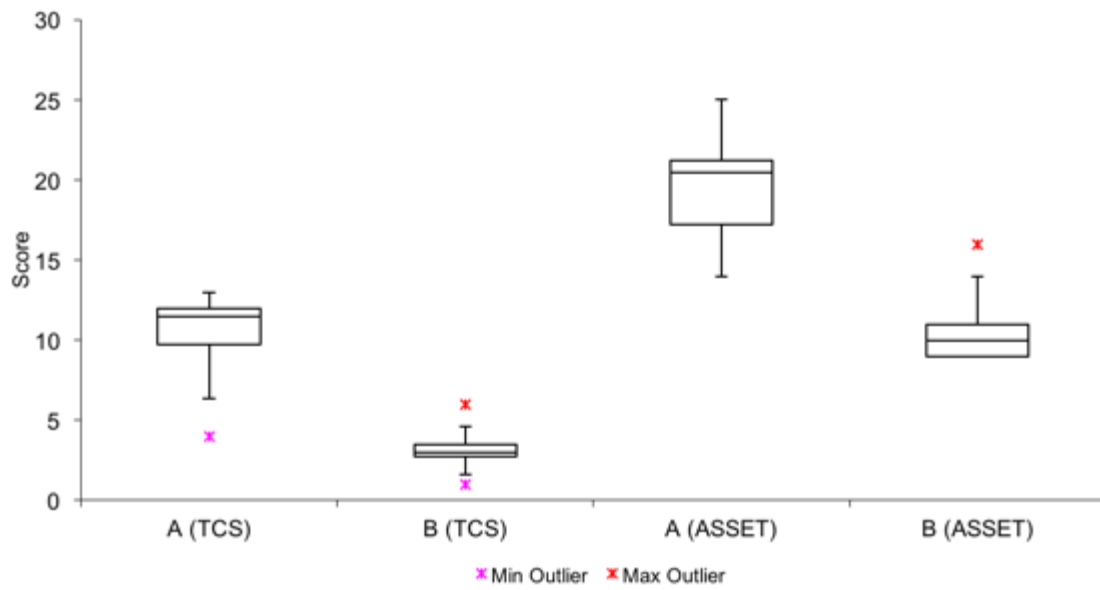


Figure 7.6: Box and Whisker Plot showing distribution of TCS and ASSET scores amongst groups A and B

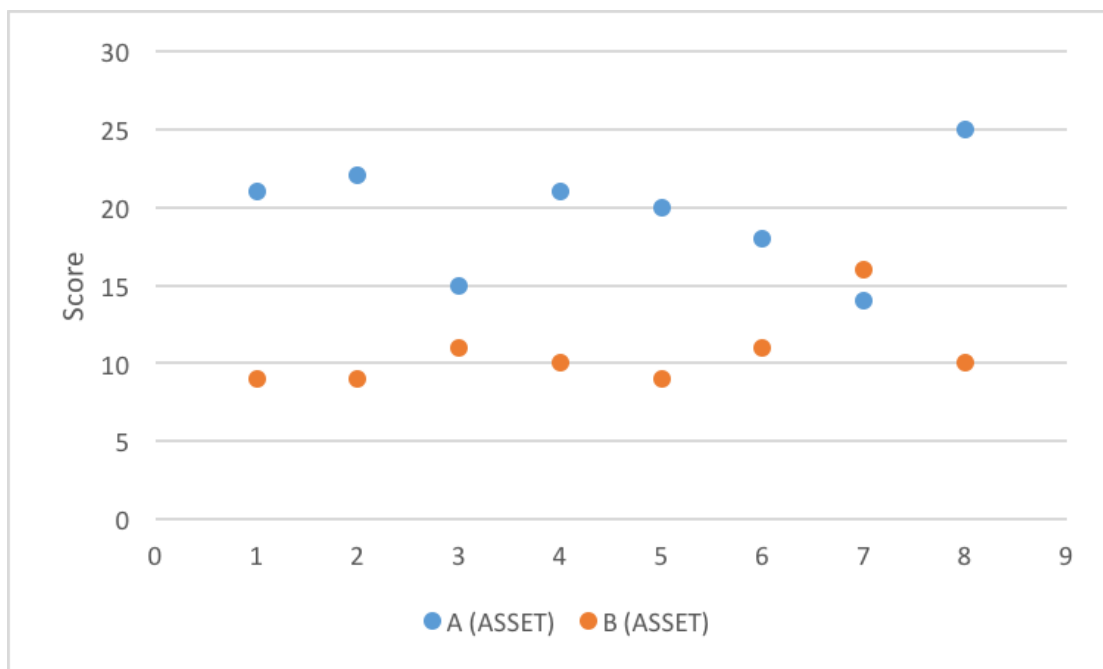


Figure 7.7: Scatter plot showing difference in ASSET scores between groups A and B

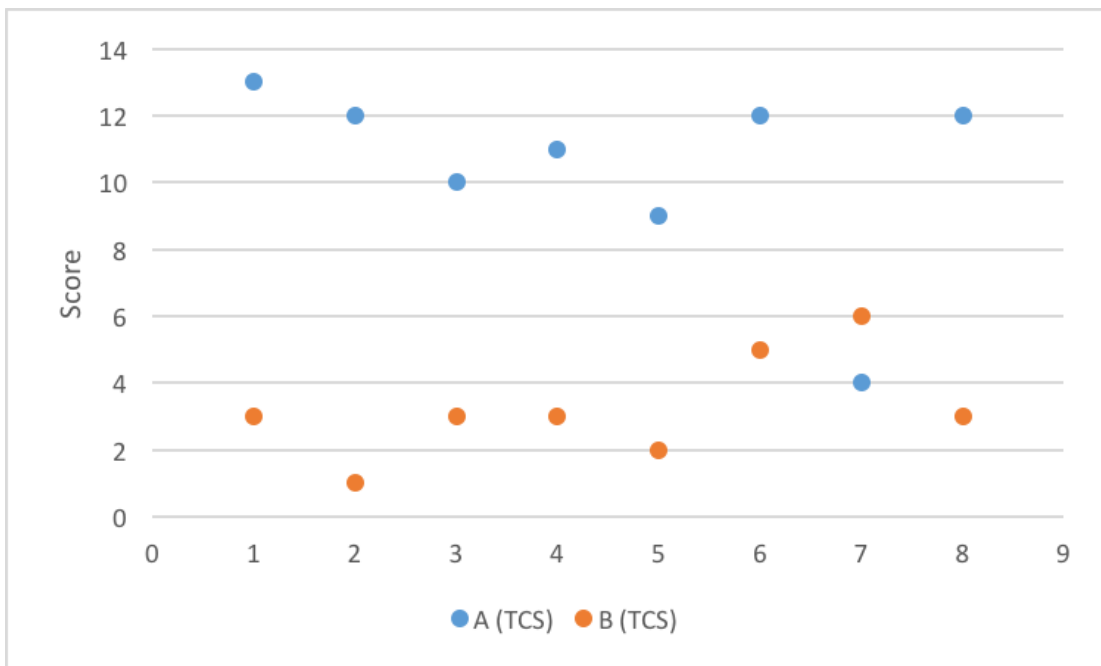


Figure 7.8: Scatter plot showing difference in TCS scores between groups A and B

(4) IKACTA tool rating analysis

All participants agreed on parameters 1-4 and 7 on the rating analysis. 15/16 (94%) agreed on parameters 5 and 6 (table 7.2).

No.	Parameter	Agreed (>3 on Likert scale)	
1	This tool was useful to understand the key technical steps required to perform this procedure	16	100%
2	This tool was useful to understand the decision-making process behind the key technical steps involved in this procedure	16	100%
3	This tool was useful in highlighting the common potential errors that can occur whilst undertaking this procedure	16	100%
4	This tool will be a useful training adjunct to learning how to perform a diagnostic knee arthroscopy in the operating theatre	16	100%
5	This tool is easy to use	15	94%
6	You enjoyed using this tool	15	94%
7	You would like to use this tool prior to attending a theatre session on diagnostic knee arthroscopy	16	100%

Table 7.2 – IKACTA rating analysis

7.4 Discussion

Our study showed that the IKACTA is an effective tool for learning diagnostic knee arthroscopy. There was significant improvement in the objective ASSET and TCS scores amongst the trainees who used the IKACTA compared to the control group. There was an improvement in both technical skills as demonstrated from the improvement in the ASSET scores and the recall of steps (significant improvement in the TCS scores) with the use of

IKACTA. The scores breakdown from the ASSET study (78) indicate that a minimum score of 24/38 needs to be achieved to be competent at a diagnostic knee arthroscopy thereafter progressing towards the expert level. This score is also likely to be achieved after repeated exposure to the simulation whereas our participants only had one attempt recorded. The expert level score is 38/38. Although the median score in the intervention group was 20.5, there was a significant improvement by 10.5 points compared to the control group. IKACTA brought trainees closer to the competency score, that too on the first attempt. The significant improvement in the TCS score highlights that this tool provides a user-friendly interface to aid both comprehension and recall of the steps required to complete a diagnostic knee arthroscopy procedure.

The IKACTA was designed to be an adjunct to training in the operating theatre alongside the traditional proctorship model. Its use allows trainees to improve their technical skills and understanding of cognitive steps and errors prior to performing this procedure in theatre. This will reduce the learning curve in theatre and allow easier and quicker progression towards achieving competency in this procedure. This is a key requirement in the current climate of reduced training hours, increased malpractice lawsuits and lengthier training time.

Howells *et al.* (30) has shown transfer validity of arthroscopic skills from a benchtop knee simulator to the operating theatre. Cannon *et al.* (74) has shown similar transfer validity of skills gained on a high-fidelity VR knee arthroscopy simulator to the operating room. Therefore, although our assessments were carried out in a simulation setting, the findings

from the above studies (30),(74) indicate that the IKACTA tool may result in improved performance in the operating theatre.

Cadaveric and VR simulation have proven efficacy in knee arthroscopy training (29),(24),(74),(25),(91). However, a major advantage of the IKACTA tool compared to VR and cadaveric simulation is that it is easily available and inexpensive. It allows repeated sustained use, which is the key aim of simulation training. Karam *et al.*(31) have reported that a quarter of the orthopaedic training programs do not have simulation facilities in the USA because of the expenses involved. The problem is identical in the UK and worldwide. In this setting, the IKACTA can be an invaluable simulation tool for trainees to develop a sound foundation before performing knee arthroscopy in the operating room. Even in the regions where cadaveric and VR simulation facilities are available, our tool will act as a useful adjunct. This study has validated the IKACTA tool.

The subjective assessment of the tool by the trainees showed that the vast majority felt this tool significantly aided their understanding of the technical steps, cognitive decision making underpinning these steps and the common errors involved in a diagnostic knee arthroscopy. The majority agreed that the tool was easy to use and they enjoyed using it. They believe that it is a useful adjunct to learning this procedure in the operating theatre and they would like to use the tool prior to performing this procedure on patients.

Strengths and Limitations

The strengths of the study include that it is a prospective, double-blind randomized controlled study (level 1 evidence) with a comparable intervention and control group. We used a sound modified Delphi technique to design the IKACTA tool. This tool is novel and has shown significant benefits in training in diagnostic knee arthroscopy compared to the control group in the simulation setting. There was relatively strong agreement amongst raters on the ICC score.

Our goal is for trainees to use this tool prior to attending the operating theatre to give them a robust foundation before they perform knee arthroscopy on actual patients. Hence the limitation for this study currently is not having observed the transfer validity into theatre which carries its own ethical implications. We were obliged to demonstrate the efficacy of our CTA in a high-fidelity simulation setting, prior to using it in the operating theatre. A study (30) has previously shown transfer validity from a bench top simulator to the operating theatre in diagnostic knee arthroscopy. We intend to observe this CTA in the operating theatre as our next study.

Application

With ever-increasing demands of a consultant-led service and reduced training hours, simulation-training techniques have increasingly been encouraged in recent times (31),(92). The major limitation so far has been the expense and availability of simulation facilities to

trainees worldwide. We have designed a new user-friendly, inexpensive CTA learning tool that has demonstrated significant benefits in training in diagnostic knee arthroscopy. This has never been studied before in the field of orthopaedic training and we believe that similar CTA learning tools can have a wide application and impact within trauma and orthopaedic training in the future.

7.5 Conclusion

This is the first study to demonstrate the effectiveness of a CTA in elective orthopaedic surgery training. The IKACTA is a beneficial learning tool in diagnostic knee arthroscopy and can be used by novice surgeons to enhance their cognitive understanding and technical skills before they perform this procedure on patients. Additionally, all participants in this study advocated the use of this tool prior to attending the operating theatre. We recommend using this tool in orthopaedic training programs.

Chapter 8: Discussion

8.1 Summary of findings

This research has designed and validated the first CTA learning tools in the orthopaedic literature. The GCTA wizard provides a thorough framework for trauma experts worldwide to create procedure specific CTA's on any orthopaedic trauma procedure. This has the potential to develop into a trauma CTA library which will be an invaluable educational resource for future orthopaedic trainees. Furthermore, its generic nature may find application within other surgical specialties.

We have designed a novel, multimedia CTA tool on femoral intramedullary nailing (IFINCTA) using the GCTA wizard. This uses written and audio-visual modalities simultaneously to teach operative steps. It has shown significant objective benefits in training novices over traditional learning using standard operative technique manuals. We recommend using this tool as an adjunct to the apprenticeship model to provide learners with a strong foundation in the cognitive understanding of this procedure. This will reduce their initial steep learning curve and improve utilization of theatre training time.

We also designed and validated the IKACTA tool, which is a multimedia CTA learning tool on diagnostic knee arthroscopy. This demonstrated significant objective benefits in training novice surgeons in diagnostic knee arthroscopy. Junior orthopaedic trainees can use this tool to enhance their cognitive understanding and technical skills prior to performing this procedure on patients.

Surgical training has changed significantly in recent years because of working time restrictions (3), (5), (6), (7), increased senior involvement in service provision (10), (12), (13), (14) and increasing complexity of surgical procedures (17), (18). Trainees have found it difficult to meet their training needs and targets. Simulation, therefore has found an increasing role within surgical training. Cadaveric, synthetic bone and more recently VR simulation have been used within orthopaedic training with success (20-29). The specific advantages and disadvantages of these simulation techniques have been detailed in chapter 1 (section 1.3) of this thesis. The key problem is the expense (31) and therefore lack of availability to the trainees. This prevents repeated sustained practice which is the cornerstone of simulation. In this setting, newer, innovative and accessible adjuncts to the apprenticeship model such as the CTA tools described in this thesis will be of great value to trainees to reduce their learning curve in the operating theatre.

Potential of CTA within orthopaedic training

As our validation studies have shown, these CTA tools will help novices to gain sound cognitive understanding and technical skills prior to attending the operating theatre. This will enhance the effectiveness of their theatre training. The main advantage of these tools is that they are easily accessible to trainees and therefore can be used repeatedly and at their convenience. Our tools are the first CTA's described in the orthopaedic literature. The positive results we have found may form the foundation to the development of further tools in various orthopaedic sub-specialties. Our GCTA wizard tool can be used to create a digital CTA library for orthopaedic trauma which may form an invaluable learning resource for

trainees in the future. The ongoing success of this form of cognitive simulation may pave the way for its inclusion in the formal orthopaedic training curriculum. Furthermore, our CTA format may find application in other surgical specialties which have already explored this method of simulation successfully (40), (44), (45).

A potential disadvantage of our CTA tools is that they do not contain any objective metrics. This limits its use as an assessment tool. Further research in future can be undertaken in this area to develop in built metrics as part of these tools to enhance its use.

Although these CTA tools are very beneficial on its own as an adjunct to the apprenticeship model, ideally, they should form part of a simulation training ladder. A formal curriculum should be developed where cognitive simulation is integrated with VR simulation to further improve technical skills in the simulation setting. Currently, however the lack of uniform availability of VR simulation (31) limits the use of this concept currently. This may be an area which may require further development in the future.

8.2 Limitations

The main limitation of this research was that the CTA tools were not analyzed in the operating theatre setting (transfer validity). Since, these tools are new to orthopaedic training, we were ethically obliged to evaluate its effectiveness first in the simulation setting. Both the IFINCTA and the IKACTA tools have shown significant objective benefits in the simulation setting for novices. As part of future research, our aim is to evaluate whether

these benefits translate into the operating theatre. Howells et al (30) has previously shown transfer validity of knee arthroscopy skills learnt in the benchtop knee simulator to the operating theatre. Cannon et al. (74) have demonstrated transfer validity of skills learnt on a VR simulator for knee arthroscopy. These studies have shown that skills learnt in the simulation setting can be translated to the operating theatre thereby helping novice trainees reduce their initial steep phase of their learning curve and improve efficiency of their theatre training time.

Another potential limitation may be the use of three experts to design out CTA tools. We decided to use three experts because majority of the CTA-based studies reported in the surgical literature used three experts successfully to design the CTA (44),(45),(64),(70). As discussed in chapter 2 of this thesis, too many experts in a setting where a new tool is being designed may make the Delphi process laborious and confusing. This may in turn reduce the productivity of the Delphi method. Conversely, fewer than three experts may make it like an expert opinion. However, there have been no studies performed thus far that have investigated the effect of the number of experts required in the modified Delphi method to design a learning tool. This may be investigated in future research studies. Since our generic trauma, CTA wizard tool will be freely and widely available, we could apply the modified Delphi technique for specific trauma procedures with any number of experts submitting their CTAs to create a larger consensus in the future.

A focus of further development of our CTA learning tools in future maybe to incorporate in built metrics in the tools. This may allow the use of these as assessment tools by providing objective measures of performance. This will expand the overall utility of the CTA tools.

8.3 Future work

We have designed novel CTA learning tools which have shown significant benefits in training in the simulation setting. Our next step, is to evaluate the effectiveness of these tools to improve learning in the operating theatre (transfer validity).

Example design of a future study to evaluate transfer validity of the IKACTA tool

Ethical approval

The study protocol will be submitted to an appropriate ethics committee for approval. The Integrated Research Application System (IRAS) application form will be used for this purpose.

Recruitment and randomization

We will recruit junior orthopaedic trainees who are novices in diagnostic knee arthroscopy (performed ≤ 10 diagnostic knee arthroscopy procedures under supervision). A prior sample size calculation will be performed from our previous data to ensure minimizing the chances

of a type 2 error. These candidates will be randomized using a computer-generated program using a random set of numbers. The randomization process will be undertaken by a research secretary blinded to the details of the study.

Trial

The baseline demographics and experience levels of both the groups will be compared prior to the study to ensure that the groups are homogenous to minimize recruitment bias. The intervention group will be given the IKACTA tool for 10 days prior to assessment. The control group will be given no additional learning material. There will be no time limit provided for the use of the tool. All candidates will be provided a basic checklist of how to perform a diagnostic knee arthroscopy.

Assessment - The candidates will be assessed in the operating theatre performing a diagnostic knee arthroscopy on a real patient. They will be first familiarized with the equipment being used. They will be supervised by an expert (consultant knee surgeon) throughout the assessment. The videos of their assessment case will be recorded from the arthroscopy stack and analyzed by two experts (fellowship trained knee surgeons) using the validated ASSET (78) global rating scale.

Statistical analysis

The data will be entered in the SPSS version 23 statistical software. We will analyze the data to assess for normality using histograms, skewness and kurtosis measures. Appropriate statistical tests will be used to assess statistical significance of the results of our study. The Intraclass correlation coefficient (ICC) will be used to ensure inter-rater reliability between the two raters for the ASSET scores.

A similar study design will be used to evaluate transfer validity of the IFINCTA tool.

Our future vision, is for multiple CTA learning tools designed and validated within orthopaedic surgical training which can be incorporated in the formal teaching curriculum. This will help to deal with some of the major limitations currently faced within surgical training.

8.4 Conclusion

In conclusion, we have designed and validated the first CTA learning tools within orthopaedic surgery training. This has paved the way for a new form of learning which has the potential to be part of the formal orthopaedic curriculum. The generic nature of our tools may also find application within other surgical specialties which will enhance the impact of our research presented in this thesis.

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Appendix 1:

Ethics documentation

PROJECT ETHICS APPROVAL

m.schachter@imperial.ac.uk, Schachter, Michael

to me,

23.12.2016

Dear Rahul

I am pleased to confirm approval of your project entitled *Research into design and validation of Cognitive Task Analysis in trauma and knee surgery* Ref 1617-08. Hope it goes well.

Kind regards

Dr Mike Schachter

Chair, MEEC

EMAIL ON 25/11/2016

Email sent on behalf of Dr Mike Schachter, Chair - Medical Education Ethics Committee:

Dear Mr Chinmay Gupte,

The Medical Education Ethics Committee have now reviewed your application entitled “Training safer trauma and orthopaedic surgeons: Cognitive Task Analysis (CTA) design and validation for femoral intramedullary nailing and effect of virtual reality simulation to train ACL surgeons of the future (MEEC1617-08; copy below)”. MEEC would be happy to approve your study subject to the following amendments:

- ☐ *Information on how long the participants will be taking part in the study should be added to the information sheet and this should also be added to the shout out.*

If you can reply to this email (copying me in) with these details as soon as possible we will expedite review and approve via Chairs action.

Kind Regards

Mike

Medicine Education Ethics Committee Coordinator

Faculty Education Office (Medicine)

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ETHICS APPROVAL APPLICATION DOCUMENTS

Study Protocol Template

Project Title: Training safer trauma and orthopaedic surgeons: Cognitive Task Analysis (CTA) design and validation for femoral intramedullary nailing and effect of virtual reality simulation to train ACL surgeons of the future

Principal Investigator: Mr Chinmay M Gupte

Co-Investigators: Mr Rajarshi Bhattacharya, Mr Rahul Bhattacharyya, Mr Kapil Sugand

Contact Information: MSk Lab, Laboratory Block, Charing Cross Campus, Imperial College London, London W6 8RP

Study Start date: 01/09/2016

Study end date: 03/08/2017

Summary of planned research & study protocol (500 words)

Background

With the introduction of the European Working Time Regulation there are significant strains on surgical training. Simulation provides a safe and controlled environment for trainees to learn and develop basic surgical skills required for a procedure before operating on patients. This minimises the risk of complications and prioritises patient safety.

Research Question: Is cognitive task analysis and virtual reality simulation a useful tool to teach and train future orthopaedic surgeons?

Aims

- to develop a generic Cognitive Task Analysis (CTA) tool for AO trauma
- to develop a Femoral Intramedullary Nailing (FIN) CTA – FIN CTA
- to validate and investigate the training effect of the FIN CTA

- to investigate the efficacy of an ACL reconstruction learning module on a Virtual Reality (VR) knee arthroscopy simulator

Methods

1) Generic CTA tool

3 expert orthopaedic trauma surgeons will be interviewed to generate a list of operative steps and decision points that are applicable to any trauma procedure. The Delphi technique will be used to generate a master generic CTA tool. A computer software engineer will create a web application that can be used as a skeleton framework to create a CTA for any orthopaedic trauma procedure. This will form the basis of an AO trauma CTA library that will be an extremely useful educational resource for orthopaedic trainees worldwide.

2) CTA for FIN

In this phase of the study we will develop a specific CTA for femoral intramedullary nailing. 3 expert orthopaedic trauma surgeons will be interviewed to generate a list of operative steps and decision points required to perform a femoral intramedullary nailing. Common errors and solutions will also be identified. The Delphi technique will be used to generate the final FIN CTA.

3) Validation of FIN CTA

We will recruit between 20 medical students with no prior experience of femoral IM nailing. They will be briefed about the project and will also be shown a standard video of femoral IM nailing without any guidance on the procedure. This will serve as an introduction to the operation. They will be randomised into 2 equal groups. Group A will be given the FIN CTA and group B will be given a standard femoral nailing op-tech manual. They will be

assessed on the validated touch surgery (iOS and android app) assessment. This will validate this FIN CTA tool against existing training methods.

Efficacy of ACL reconstruction training module of a Virtual Reality Knee

Arthroscopy simulator

We will recruit 20 medical students for this part of the study. They will be divided into 2 equal groups. Group 1 will be trained with the learning module on the simulator. Group 2 will be provided a standard operative technique manual and a video (available on Vumedi – orthopaedic teaching website) demonstrating this procedure. They will then be tested on the assessment module on the simulator. This will demonstrate efficacy of the simulator to teach the basic steps of ACL reconstruction surgery against current available methods prior to experience in the operating theatre.

Study participants & recruitment (maximum 200 words)

In this study we are investigating the efficacy of cognitive task analysis as a learning tool for femoral intramedullary nailing against current learning methods. We are also investigating the efficacy of an ACL reconstruction-learning module on a virtual reality simulator against a standard operative technique manual. We therefore need participants who have some understanding of medicine and methods of assessment within medicine but no specific knowledge in intramedullary nailing or ACL reconstruction. Therefore, medical

students would be very suitable participants in this study. Furthermore, it will be an exciting opportunity for them to participate in cutting edge research, which is supported by the AO Foundation and is in collaboration with other leading research centres around the world.

Methods of recruitment:

- ICSMSU newsletter
- ICSMSU noticeboards
- Monthly opportunities E-bulletin from ICSMSU
- As a news item on Blackboard Learn (teaching resource for students)
- ICSM surgical society

Advertisement for recruitment

Calling Medical Student Volunteers!



Get involved in cutting edge research to train surgeons of the future! It is a global collaborative between Imperial College London, AO Foundation and other leading centres. We aim to develop and validate a Cognitive Task Analysis (CTA - list of operative steps and decision points) for an orthopaedic trauma procedure and we need your help to see if it works.

Here are some important details:

- There is NO need to prepare – just turn up!
- All data is anonymous and only used as research data
- The study will take place in Charing Cross Hospital in the MSK Lab (Level 7 East)
- The study does not involve too much time and allows flexibility
- You will need to offer an hour per week for 3 weeks

- You will receive a formal Certificate of Participation for your CV and portfolio

If you would like to participate, or you would like further information, please contact:

Mr Rahul Bhattacharyya at rahulbhattacharyya09@gmail.com



Ethics question

Please explain in sufficient detail any specific ethical issues that may arise from the project and how you will address these in your study.

This may include: informed consent, recruitment, sampling, incentives, power imbalances, confidentiality, data storage, data handling, data security, anonymity and dissemination of findings.

Informed consent – Participants will be allowed as much time as they need to read through the Participant Information Sheet and ask any questions before consenting to the study. They will sign a written informed consent form and will also have the option of dropping out of the study at stage if they wish.

Recruitment – Participants will be recruited from the Imperial College School of Medicine and therefore include no vulnerable groups. All participants will be of adult age and compus mentis with the option to drop out of the study at any point.

Conflict of interests with student examinations – The assessors in this study will not be involved as examiners/assessors in any student examinations this year.

Incentives – There is no reimbursement for taking part in this study. However, participants may view the opportunity to use novel surgical education technology as an incentive. Participants will be given an official MSk Lab certificate of study participation which can be used for their CV and portfolios. This will also act as a contribution towards clinical governance.

Confidentiality – Each participant will be given a unique ID. Results of each participant will only be viewed by the team of researchers.

Data storage, data handling, data security and anonymity – All data will be anonymised using study numbers and stored on secure password protected College computers. Only the researchers mentioned on this application will handle and have access to the data collected. No identifiable information will be stored. Data will be destroyed in either 5 years or after publication and presentation of data, whichever comes first.

Dissemination of findings – Anonymised findings will be disseminated via presentations, papers and academic theses, however no identifiable information will be disseminated.

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**Training safer trauma and orthopaedic surgeons: Cognitive Task Analysis (CTA)
design and validation for femoral intramedullary nailing and effect of virtual reality
simulation to train future orthopaedic surgeons**

Participants Information Sheet

Invitation

You are being invited to take part in a surgical training research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the study?

The purpose of the study is to develop surgical simulation in femoral intramedullary nailing and ACL reconstruction. In femoral intramedullary nailing, we aim to develop a list of essential steps and decision points including common errors and solutions from an expert panel so that trainees have an excellent understanding of the steps and common pitfalls involved in this procedure before they undertake this on patients. In ACL reconstruction, we

aim to evaluate the efficacy of a training module in a state of the art virtual reality simulator to teach trainees the key steps of this procedure prior to their operative theatre experience.

Why have I been chosen?

We are asking you to think about joining this study because you are interested in surgical education and are the potential surgical trainees of the future.

Do I have to take part?

No. It is entirely up to you. If you would like to take part, you will be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect your education.

What will happen to me if I take part?

Once you have decided to take part in this research you will be asked to come to the MSK Lab where a member of our research team will discuss the study with you and answer any questions you may have. If you are still happy to take part, we will ask you to sign the consent form.

When you come to the lab in Charing Cross Hospital, you will be informed about all the procedures and be given a chance to ask questions. We will then randomly allocate you to experiment group or control group. You will undergo training with the CTA (list of steps developed by our experts) for femoral intramedullary nailing (experiment group) or with an operative technique manual (control group). For the ACL study, you will be allocated to either the virtual simulator training group (experiment) or training with standard operative technique manual (control group).

After the training session, you will be asked to complete a standardised assessment. The results of this will be completely anonymous with no participant identifiable information.

If there is any task that you feel uncomfortable doing, you are completely free to stop immediately and inform the investigator.

You will be required for 1 hour per week for three weeks.

What are the side effects, and are there any risks in taking part?

The risks of taking part in this study are very small. With the CTA femoral nailing study there is no physical risks at all. You might feel disappointed if you do not perform well but the scores will be completely anonymised. For the ACL study, you will be required to train on a simulator for a short time. This involves use of an artificial knee and a camera and some instruments to work inside the knee. This does not involve the use of any scalpel or real drills and therefore the risk of harm is very small.

What are the possible benefits of taking part?

You will get the opportunity to participate in a global research project that Imperial College is participating in with collaboration with AO trauma also involving other leading centres around the world. This is an initiative to develop surgical simulation to help train surgeons of the future. You will also get the chance to learn about a procedure (femoral IM nailing or ACL reconstruction) that you may not get the opportunity to observe during your clinical attachments. In addition, a paper certification stating your participation in the project will be issued by MSK Lab, Imperial College London.

Will my taking part in this study be kept confidential?

Any information and data from you will be kept strictly confidential. If the study is published in a book or scientific journal, no individual information will be identified in anyway.

What will happen to the results of the research study?

The results of the study will be analysed by the research team and presented at orthopaedic conferences and published in scientific journals. No individual subject will be identified in any report or presentation arising from the research. If you would like to receive the results of the study when completed, we are happy to send it to you electronically as an email. Please tick the box in the consent form along with your details if you would like this information.

Who is organising and funding the research?

This research is organized by the research team at the MSk lab, Imperial College London in

collaboration with AO Foundation. The study is being funded by the AO Foundation.

Will I be paid for taking part in the study?

You will not be paid for your participation in the study.

Who has reviewed the study?

This study has been reviewed by the appropriate ethics committees.

Contacts for further information:

If you would like to consider this study further before you make your decision, please take your time to do so. You may ask for further information by emailing Mr Rahul Bhattacharyya (co-investigator) at – rahulbhattacharyya09@gmail.com

Researchers: Mr Chinmay Gupte, Mr Rajarshi Bhattacharya, Mr Rahul Bhattacharyya, Mr Kapil Sugand

**Training safer trauma and orthopaedic surgeons: Cognitive Task Analysis (CTA)
design and validation for femoral intramedullary nailing and effect of virtual reality
simulation to train orthopaedic surgeons of the future**

CONSENT FORM

Please Initial Box

- | | |
|---|--------------------------|
| 1. I confirm that I have read and understand the Participant Information Sheet for the above study and have had the opportunity to ask questions. | ☐ |
| 2. I confirm that I have had sufficient time to consider whether or not want to be included in the study. | ☐ |
| 3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, and without my education or legal rights being affected. | ☐ |
| 4. I agree to my data, including personal identifiable data, being stored on Imperial College London computer systems. | ☐ |
| 5. I would like to receive the results of the study when completed by email. | ☐ |

6. I agree to take part in the above study.

☐

Name of subject

Date

Signature

Name of person taking consent

Date

Signature

Participant Consent Form, Version1: 03.10.2016

PARTICIPANT CONSENT FORM FOR THE IFINCTA STUDY

Imperial College
London

Department of Surgery
and Cancer
Imperial College London

MSK Lab, 7th Floor
Charing Cross Hospital
Campus
Fulham Palace Road,
London W6 8RF
Tel: 020 3313 8833
Fax: 02033130468

Femoral Intramedullary Nailing CTA study

Researchers: Mr Chinmay Gupte, Mr Rahul Bhattacharyya

CONSENT FORM

Please tick Box

I understand that the data collected for this study will be anonymous and will not have any identifiable information. This will be used to obtain evidence on the efficacy of a learning tool for the benefit of future orthopaedic trainees. I am happy to take part in this study and the data collected in the process to be used for research purposes.

☐

Name of subject

Date

Signature

Name of person taking consent

Date

Signature

PARTICIPANT CONSENT FORM FOR THE IKACTA STUDY

Imperial College
London

Department of Surgery
and Cancer
Imperial College London

MSK Lab, 7th Floor
Charing Cross Hospital
Campus
Fulham Palace Road,
London W6 8RF
Tel: 020 3313 8833
Fax: 02033130468

Researchers: Mr Chinmay Gupte, Mr Rahul Bhattacharyya

CONSENT FORM

Please tick Box

I understand that the data collected for this study will be anonymous and will not have any identifiable information. This will be used to obtain evidence on the efficacy of a learning tool for the benefit of future orthopaedic trainees. I am happy to take part in this study and the data collected in the process to be used for research purposes.

☐

Name of subject

Date

Signature

Name of person taking consent

Date

Signature

Appendix 2:

Links to online GCTA wizard and the IFINCTA tool

Link to online GCTA wizard tool

<http://www.cta-wizard.com/>

Online link to the IFINCTA tool

1) Go to <http://www.cta-wizard.com/>

2) Then click “view CTA from list” tab

3) Open Antegrade Femoral Intramedullary Nailing tab

dated – Mar 30, 2017.

Appendix 3:

**Copyright and permissions for inclusion of my own
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Permission from author for Figure 2.1: Genealogical tree of Delphi

From Kerstin.Cuhls@isi.fraunhofer.de

Dear Rahul,

If you cite it properly, this is possible. It is our “own” figure□

Good luck!

Kerstin

Dr. Kerstin Cuhls
CC Foresight
Fraunhofer Institut für System- und Innovationsforschung ISI
Breslauer Straße 48 | 76139 Karlsruhe
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[mailto: kerstin.cuhls@isi.fraunhofer.de](mailto:kerstin.cuhls@isi.fraunhofer.de)
<http://www.isi.fraunhofer.de>

Permission for figure 5.2: “Touch surgery” assessment tool for antegrade femoral intramedullary nailing(a) demonstrating single best answer questions for cognitive decision making, (b) showing the digital swipe interactions required to complete the procedure

(Image courtesy of Mr Chinmay M Gupte, Dr Kapil Sugand and Digital Surgery Ltd from Touch Surgery App (please specify Android or iOS version) v.5 (2018))

From: eric@touchsurgery.com

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Take care and please contact me with questions.

Eric Collins – Chief Operating Officer, Touch Surgery

Eric Collins

Operations

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evaluating the effectiveness of the Imperial Knee Arthroscopy Cognitive
Task Analysis (IKACTA) tool. J Bone Joint Surg Am 2017 Oct 4;99(19):
e103.**

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Anders Rydholm - anders.rydholm@med.lu.se - From Acta Orthopaedica journal

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to me

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Good luck with your dissertation!

Best regards

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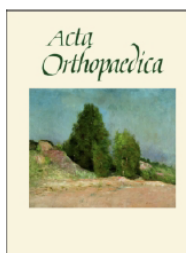
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Appendix 4:

Published papers



Trauma simulation training: a randomized controlled trial -evaluating the effectiveness of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool

Rahul Bhattacharyya, Kapil Sugand, Bilal Al-Obaidi, Ian Sinha, Rajarshi Bhattacharya & Chinmay M Gupte

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Trauma simulation training: a randomized controlled trial evaluating the effectiveness of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool

Rahul BHATTACHARYYA¹, Kapil SUGAND¹, Bilal AL-OBAIDI², Ian SINHA², Rajarshi BHATTACHARYYA², and Chinmay M GUPTA¹

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Submitted 2018-03-14. Accepted 2018-07-12.

Background and purpose — Cognitive task analysis (CTA) has been used extensively to train pilots and in other surgical specialties. However, the use of CTA within orthopedics is in its infancy. We evaluated the effectiveness of a novel CTA tool to improve understanding of the procedural steps in antegrade femoral intramedullary nailing.

Material and methods — *Design*: A modified Delphi technique was used to generate a CTA from 3 expert orthopedic trauma surgeons for antegrade femoral intramedullary nailing. The written and audiovisual information was combined to describe the technical steps, decision points, and errors for each phase of this procedure. *Validation*: A randomized double-blind controlled trial was undertaken with 22 medical students (novices) randomized into 2 equal groups. The intervention group were given the CTA tool and the control group were given a standard operative technique manual. They were assessed using the validated "Touch Surgery™" application assessment tool on femoral intramedullary nailing.

Results — The pre-test scores between the two groups were similar. However, the post-test scores were statistically significantly better in the intervention group compared with the control group. The improvement (post-test median scores) in the intervention group compared with the control group was 20% for patient positioning and preparation, 21% for femoral preparation, 10% for proximal locking, and 19% for distal locking respectively ($p < 0.001$ for all comparisons).

Interpretation — This is the first multimedia CTA tool in femoral intramedullary nailing that is easily accessible, user-friendly, and has demonstrated significant benefits in training novices over the traditional use of operative technique manuals.

There are significant strains on surgical training due to working regulations, increased malpractice cases, and reduced training time in the operating theatre (Philibert et al. 2002, RAD 1382 Consensus Statement 2008). Innovative adjuncts to the traditional apprenticeship model are required to reduce the learning curve and improve utilization of theatre training time.

Previous research has highlighted the benefits of virtual reality (VR) and cadaveric simulation in orthopedic training (Cannon et al. 2014, Rebollo et al. 2015, Sugand et al. 2015a, Camp et al. 2016, Tomlinson et al. 2016). However, these simulators are expensive and are not readily accessible to trainees worldwide. Karam et al. (2013) showed that 25% of training programs in the USA do not have a dedicated simulation facility and 87% of training program directors reported a lack of sufficient funds as the main barrier.

The burden of orthopedic trauma is greater than ever before with major trauma now affecting the elderly population in addition to the high-energy injuries in the younger age group (Kehoe et al. 2015). In this setting, newer, innovative, and easily accessible training adjuncts to the traditional apprenticeship model are necessary to help train competent orthopaedic trauma surgeons.

It is well established that cognitive learning of motor skills is key to undertaking a successful practical procedure (Spencer 1978, Flin et al. 2007, Wingfield et al. 2015, Wallace et al. 2017). Wingfield et al. (2015) defined cognitive task analysis (CTA) as a process by which experts provide complex information to trainees in a logical and simplified manner. This makes it easier to visualize and digest procedural steps. It has been extensively used to train pilots (Wingfield et al. 2015), and in other surgical specialties (Sullivan et al. 2008, Luker et al. 2008, Arora et al. 2011, Smink et al. 2012). However, it is rela-

tively new to orthopedic training. Bhattacharyya et al. (2017) reported the effectiveness of the first CTA tool in orthopedic training on diagnostic knee arthroscopy. There are no studies in the literature that have investigated the efficacy of CTA to teach orthopedic trauma procedures, which forms a major part of the orthopedic training curriculum, especially in the early years of training (BOTA Collaborators and Rashid 2018).

We evaluated the effectiveness of a novel CTA tool to improve understanding of the procedural steps in antegrade femoral intramedullary nailing.

Null hypothesis

There was no difference in objective test scores between novices learning the procedural steps of antegrade femoral intramedullary nailing from our CTA compared with the op-tech manual.

Material and methods

We first designed a CTA tool and then evaluated its effectiveness to teach the procedural steps.

Design of the Imperial Femoral Intramedullary Nailing Cognitive Task Analysis (IFINCTA) tool

Selection of experts

The inclusion criteria for experts were: consultant, fellowship-trained trauma and orthopedic surgeons, who practice trauma as part of their routine practice in a designated major trauma centre in the UK. Experts who matched the above criteria and were prepared to devote the time required for the Delphi process were selected to design the CTA. They were all male; median age 43 years (41–45); median years in consultant practice: 8 (4–8); median years in formal teaching: 8 (4–8). 2/3 experts were part of the group who received the grant from the AO Foundation for developing simulation techniques in trauma. However, the content of this CTA tool had no influence on the results of the validation part of the study as the experts were not involved in objectively scoring the participants in the trial.

Procedural steps and Delphi technique

The modified Delphi technique was used to generate the final written information of the IFINCTA tool. This technique involved a combination of independent analysis and “face to face” review from the 3 experts over 3 rounds.

Round 1: The experts were interviewed independently to generate a list of technical steps, cognitive decision points, and potential errors and solutions that are applicable to an antegrade femoral intramedullary nailing procedure. All the technical steps and decision points that were common to the 3 experts were identified in round 1.

Round 2: The steps that were common to 2 experts or exclusively generated from 1 expert were listed separately. This list

was reviewed by the experts independently and they either agreed or disagreed with these steps. The steps agreed upon by all experts in rounds 1 and 2 were listed at the end of round 2.

Round 3: This involved a “face to face” meeting of the expert panel where they reviewed all the steps that were agreed upon in rounds 1 and 2. Only those steps that had 100% consensus from all 3 experts at the end of the 3 rounds were included in the final CTA.

Audiovisual component

1 of the experts in our study recorded a video of an antegrade femoral intramedullary nailing procedure for a diaphyseal mid-shaft femoral fracture. This video was divided into separate clips reflecting each of the 7 phases. A voiceover was recorded later using a “free recall” technique with the same expert. In this technique, the same expert recorded an audio clip describing each phase of the procedure by watching the video clips retrospectively. This was superimposed on the video clips. The other 2 experts reviewed this video and a consensus was reached regarding the final content of the video so that it accurately reflected the written CTA master template.

Creation of the IFINCTA tool

The written information (Delphi method), video clips, and audio recordings were input into a “wizard” tool developed in our unit. This is a web-based tool used by experts to create CTAs. This led to the design of the IFINCTA tool (Figure 1). This tool has a split-screen format. The left side has all the written information on the technical steps, cognitive decision points, and potential errors and solutions. The right side includes the multimedia modalities (video clips, audio voice recordings).

Experimental design to evaluate the effectiveness of the IFINCTA tool

This was a double-blinded, randomized controlled trial.

Participants

Inclusion criteria: Undergraduate medical students having observed 5 or fewer antegrade femoral intramedullary nailing procedures, neither having performed this procedure nor being familiarized with similar CTA tools beforehand.

Exclusion criteria: Graduates, having performed this procedure, having been exposed to “Touch Surgery™” in the past, and observing more than 5 antegrade femoral intramedullary nailing procedures.

Recruitment: 30 undergraduate novices initially registered their interest in participating and completed a questionnaire assessing their experience in femoral intramedullary nailing. 8 novices could not attend due to other commitments coinciding with the timing of the study. The remaining 22 novices all matched the inclusion criteria and completed the study. All participants gave written consent to participate in the study. They were recruited between October 2016 and April 2017.

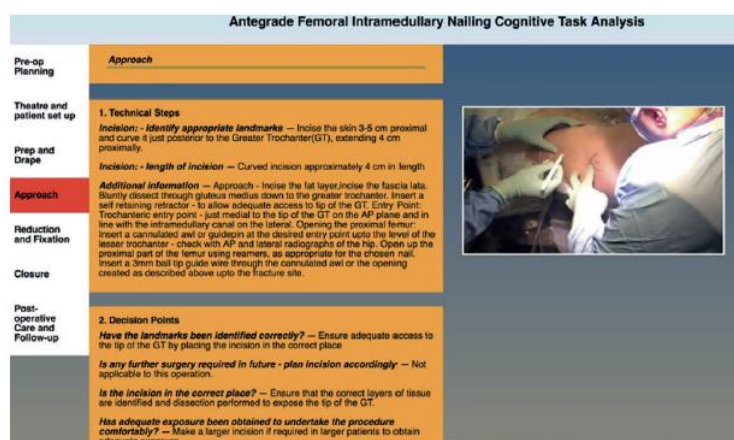


Figure 1. Snapshot of the IFINCTA tool showing the written information of the CTA on the left and the multimedia video clips and audio recordings on the right for the “approach” phase of the procedure.

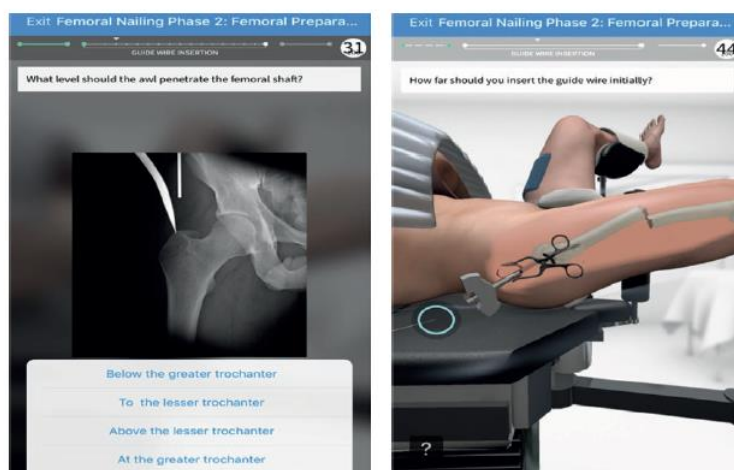


Figure 2. “Touch Surgery™” assessment tool for antegrade femoral intramedullary nailing: (left panel) demonstrating single best answer questions for cognitive decision making; (right panel) showing the digital swipe interactions required to complete the procedure.

Randomization

The participants were randomized into 2 equal groups ($n = 11$) using the random number generator function on Microsoft Excel (Microsoft Corp, Redmond, WA, USA). This generated random numbers from 1 to 22. These numbers were stored in concealed envelopes prior to being assigned to either the intervention or the control group by a person in the lab who was not directly involved in conducting the trial.

Trial

“Touch surgery™” application assessment tool

We used the “Touch Surgery™” application (Kinosis, London, UK) assessment tool for femoral intramedullary nailing validated by Sugand et al. (2015b). This is a cognitive, interactive VR application that utilizes computer animation to explain the operative steps of a surgical procedure. It is available on mobile and smart devices (free of cost). It has separate learning and assessment tools. In our study, we only used the validated assessment tool for 4 modules of this procedure (1) patient positioning and preparation, (2) femoral canal preparation, (3) proximal locking, (4) distal locking and closure). Points were scored for single best answer questions for each step of the procedure and for virtually completing manual steps (incision, drilling etc.) using finger-swipe interactions on the screen (Figure 2). The final score for each module is automatically calculated by the software and is scored as a percentage with no negative marking (Sugand et al. 2015b).

Data collection

Intervention and control groups:

The intervention group were given the IFINCTA tool developed in this study and the control group were given a standard operative technique manual for this procedure, which is representative of a common current method used by learners prior to performing this procedure in theatre.

Objective testing:

The participants were supervised during the

assessments by an independent research supervisor and were blinded to whether they belonged to the intervention or the control group. All participants completed a pre-test for analysis of baseline scores to ensure that the groups were homogeneous at baseline. They were then provided with their respective learning tools for 1 week and instructed to use them for as long as necessary in order to feel prepared before returning for the post-test. We analyzed the mean time (minutes) for which the participants in each group used their learning tools. At the end of the week the students completed the post-test using the

Table 1. IFINCTA tool rating parameters and rating analysis

No.	Parameter	Agreed ^a
1	The tool was easy to use	10/11
2	The tool made the procedure easy to understand	11/11
3	The written, visual and audio modalities being simultaneously present was useful	11/11
4	It would be beneficial to use this tool prior to attending an operating theatre session on femoral intramedullary nailing	11/11
5	You enjoyed using this tool	9/11

^a > 3 on Likert scale

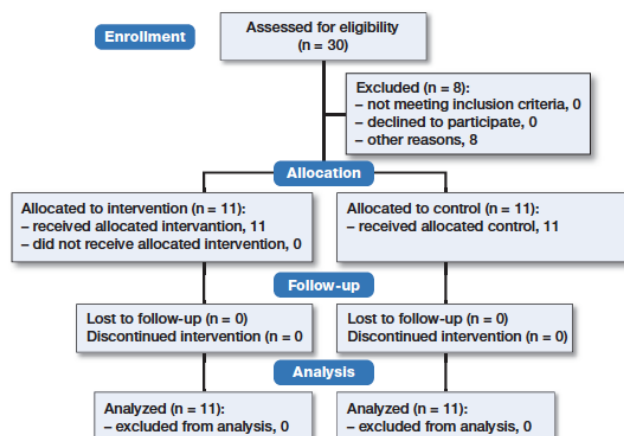


Figure 3. CONSORT diagram showing recruitment and follow-up of participants.

same assessment tool. All testing occurred in the college laboratory facilities.

- Primary outcome measures:
- The difference in the post-test scores between the intervention and the control groups.
 - The difference between the pre-test and the post-test scores in the intervention and the control groups.

Subjective testing (secondary outcome measure): The students in the intervention group (n = 11) rated the IFINCTA tool on 5 parameters (Table 1) using the Likert rating scale (1 = strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, 5 = strongly agree). The 3 expert consultant orthopedic trauma surgeons who designed the IFINCTA tool agreed on these parameters.

Statistics

Sample size calculation: An a priori power calculation was conducted using mean percentage scores from a previous pilot study whereby the intervention group scored 80% vs. the control group which scored 55% (SD 19) in module 2 of the assessment tool with alpha = 5% and beta = 20% resulting in power = 80%. The sample size resulted in a minimum n = 9 per group. The difference of scores was also deemed significant according to the expert surgeons.

Software: The data obtained from the validation study were input into the SPSS software version 23. The analysis using histograms, QQ plots, skewness, and kurtosis data showed that the data were nonparametric.

Results: The median (interquartile range) scores for the 4 modules were calculated for both groups. The Mann–Whitney U test was used for independent data and the Wilcoxon signed rank test was used for paired data. A p-value of < 0.05 was considered to be statistically significant.

Ethics, registration, funding, and potential conflicts of interest

Ethical approval was obtained from our institutional Medical Education Ethics Committee (MEEC—reference number: 1617-08).

Funding was received from the AO Foundation, Switzerland, under the AO Strategy Fund Project “Multipurpose Virtual Surgical Simulator”. The AO Foundation currently collaborates with the Touch Surgery™ group; however, there was no association between the design of the IFINCTA tool in this study and the Touch Surgery™ femoral nailing module, which was developed earlier and independent of the AO Foundation. The authors declared no conflicts of interest.

Results

Participant demographics, baseline characteristics, and flow through the study (Figure 3)

All 22 medical students (median age 23 years, 17 males) who matched the inclusion criteria completed the study. The median age was 22.5 years. The median year of undergraduate studies was 4 (1–5) in the intervention group compared with 5 (1–5) in the control group. The median number of ante-grade femoral intramedullary nailing procedures observed in the operating room prior to the study in the intervention group was 1 (0–5) compared with 1.5 (0–5) in the control group. The mean time (minutes) for which the participants used their learning tool in the intervention group was 55 (45–65) compared with 57 (35–70) minutes in the control group.

‘Touch Surgery™’ objective assessment

Pre-test scores: There was no statistically significant differ-

Table 2. Comparison of pre-test “Touch Surgery™” assessment scores between intervention and control groups. Values are median scores (interquartile range)

Module	Intervention (IFINCTA)	Control “op tech”	p-value ^a
1. Patient positioning and preparation	50 (40–55)	45 (25–55)	0.4
2. Femoral canal preparation	53 (50–59)	56 (38–62)	1
3. Proximal locking	57 (50–60)	50 (50–57)	0.4
4. Distal locking and closure	57 (53–63)	58 (51–63)	0.7

^a Mann–Whitney U test for median difference in scores

Table 3. Comparison of post-test “Touch Surgery™” assessment scores between intervention and control groups. Values are median scores (interquartile range)

Module	Intervention (IFINCTA)	Control “op tech”	Difference (%)	p-value ^a
1. Patient positioning and preparation	80 (75–82)	60 (45–72)	20	< 0.001
2. Femoral canal preparation	79 (67–84)	58 (48–67)	21	0.001
3. Proximal locking	77 (70–82)	67 (52–72)	10	< 0.001
4. Distal locking and closure	82 (81–86)	63 (53–78)	19	< 0.001

^a Mann–Whitney U test for median difference in scores

Table 4. Comparison between pre-test and post-test scores for the intervention and the control groups. Values are difference between pre-test and post-test median scores

Module	Intervention (IFINCTA)	p-value ^a	Control “op tech”	p-value ^a
1. Patient positioning and preparation	30	< 0.001	15	< 0.001
2. Femoral canal preparation	26	< 0.001	2	0.4
3. Proximal locking	20	< 0.001	17	0.04
4. Distal locking and closure	25	< 0.001	5	0.04

^a Wilcoxon signed rank test

ence in the median pre-test scores between the intervention and the control groups to demonstrate homogeneity of participants, and avoiding selection bias (Table 2).

Post-test scores (primary outcome measure 1): The post-test scores were statistically significantly better in the intervention group compared with the control group for all 4 modules in the “Touch Surgery™” assessment tool for antegrade femoral intramedullary nailing (Figure 4 and Table 3).

Comparison between the pre- and post-test scores for both groups (primary outcome measure 2): Both groups showed

“Touch Surgery™” assessment scores

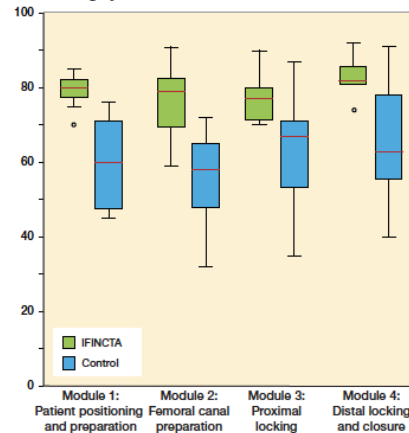


Figure 4. Box and whisker plot comparing post-test “Touch Surgery™” assessment scores between the IFINCTA and control groups for modules 1–4. Red lines are median values, boxes are interquartile ranges, whiskers are ranges of the data sets, and circles are 2 outliers.

improvement in the post-test compared with the pre-test but this was much greater in the intervention group compared with the control group (Table 4).

IFINCTA tool rating analysis (secondary outcome measure)

All participants agreed (> 3 on the Likert scale) on parameters 2–4 on the rating analysis. 10/11 participants agreed that the tool was easy to use and 9/11 enjoyed using the tool (Table 1).

Discussion

This study adds to previous evidence supporting the use of CTA in orthopedic training (Bhattacharyya et al. 2017). The tool utilizes written and audiovisual information simultaneously to describe each step of antegrade femoral intramedullary nailing. The learner is equipped with knowledge on the technical steps, cognitive decision-making behind performing each technical step, and potential errors and solutions involved in this procedure.

This study showed substantially significantly better “post-test” scores in the group using the IFINCTA tool compared with the control group. Although there were improvements in both groups between the pre-test and post-test, the difference was much greater in the IFINCTA group compared with the control group. Our analysis rejected the null hypothesis and demonstrated that the IFINCTA is an effective tool to improve the cognitive understanding of an antegrade femoral intramedullary nailing procedure for novice learners. It is also superior

compared with a standard operative technique manual, which is the gold-standard resource for learning surgical procedures prior to operating on patients.

Previous research has demonstrated benefits and a training effect of the “Touch Surgery™” application to teach femoral intramedullary nailing (Sugand et al. 2015a, 2015b). “Touch Surgery™” uses computerized animations and written information to teach procedural steps. There are no defined cognitive decision points and description of specific errors and solutions in this application. Furthermore, our tool has video clips (with superimposed audio voiceovers) recorded in an actual operating theatre demonstrating the entire procedure in real-time. The IFINCTA help the learners to truly appreciate the technical challenges in each procedural step involved and the cognitive reasoning behind performing each technical step, while also bringing to their attention potential errors and solutions using simultaneous written and audiovisual multimodal multimedia modalities. This makes our tool both educationally novel and technologically innovative.

Studies have highlighted the effectiveness of VR and cadaveric simulation to teach orthopedic trauma procedures (Leong et al. 2008, Sugand et al. 2015a). However (Karam et al. 2013), these are expensive and not readily accessible to trainees. Our CTA tool is web based and easily accessible. It allows repeated sustained practice, which is key in simulation training. Using this tool prior to attending the operating theatre will provide learners a sound understanding of the technical steps and the decision-making involved in this procedure. This will reduce their initial steep phase of the learning curve and allow more effective utilization of operating theatre training time. This is key in the current environment of reduced training hours (Chikwe 2004) available to achieve competency and can pave the way for CTA-based learning of complex surgical procedures in the future.

The subjective assessment of the tool indicated that the entire intervention group agreed that the tool aided their understanding of the procedure and was easy and enjoyable to use. The participants believed that this tool is a useful adjunct to learning in the operating room and they would prefer to use our tool prior to operating on patients.

Strengths and limitations

The strengths of this study are: it is a prospective, double-blind randomized controlled trial with a comparable intervention and control group. We used a sound modified Delphi technique to design the IFINCTA tool. This tool has demonstrated significant benefits to improve the cognitive understanding of the procedure for novice students.

Our goal is for learners to use this tool prior to attending the operating theatre to give them a robust foundation in the understanding of this procedure, which will complement their learning in theatre. The limitation of this study is that we have not yet analyzed the impact of this tool to improve operating theatre performance (i.e., transfer validity), which carries its

own ethical implications. We were obliged to demonstrate the ability of our CTA in a simulation setting to improve cognitive understanding prior to using it in the operating theatre, which will form part of our future work. Another potential limitation was that gender differences amongst the participants or the experts was not accounted for in this study.

Application

With an ever-increasing rise of orthopedic trauma workload (Kehoe et al. 2015) and reduced training hours (Chikwe 2004), simulation-training techniques have increasingly been encouraged (Robbins et al. 2010). We have designed a user-friendly, accessible CTA learning tool that has demonstrated significant benefits in improving the knowledge of novice learners in antegrade femoral intramedullary nailing. We believe that similar CTA learning tools can be used in other orthopedic sub-specialties, thereby increasing its impact within orthopedic training.

Conclusion

The IFINCTA tool has shown significant benefits in the cognitive understanding of novices in antegrade femoral intramedullary nailing. We recommend using our user-friendly, online tool to provide a strong foundation and a shorter cognitive learning curve for novices prior to starting their apprenticeship training in the operating theatre.

Study and tool design: RB, KS, RB, and CMG. Data collection and analysis: RB, KS, and BA. CTA tool Delphi: IS, RB, and CMG. Writing and editing the manuscript: RB, KS, RB, and CMG.

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TOPICS IN TRAINING

Knee Arthroscopy Simulation

A Randomized Controlled Trial Evaluating the Effectiveness of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) Tool

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Background: Virtual-reality and cadaveric simulations are expensive and not readily accessible. Innovative and accessible training adjuncts are required to help to meet training needs. Cognitive task analysis has been used extensively to train pilots and in other surgical specialties. However, the use of cognitive task analyses within orthopaedics is in its infancy. The purpose of this study was to evaluate the effectiveness of a novel cognitive task analysis tool to train novice surgeons in diagnostic knee arthroscopy in high-fidelity, phantom-limb simulation.

Methods: Three expert knee surgeons were interviewed independently to generate a list of technical steps, decision points, and errors for diagnostic knee arthroscopy. A modified Delphi technique was used to generate the final cognitive task analysis. A video and a voiceover were recorded for each phase of this procedure. These were combined to produce the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) tool that utilizes written and audiovisual stimuli to describe each phase of a diagnostic knee arthroscopy. In this double-blinded, randomized controlled trial, a power calculation was performed prior to recruitment. Sixteen novice orthopaedic trainees who performed ≤ 10 diagnostic knee arthroscopies were randomized into 2 equal groups. The intervention group (IKACTA group) was given the IKACTA tool and the control group had no additional learning material. They were assessed objectively (validated Arthroscopic Surgical Skill Evaluation Tool [ASSET] global rating scale) on a high-fidelity, phantom-knee simulator. All participants, using the Likert rating scale, subjectively rated the tool.

Results: The mean ASSET score (and standard deviation) was 19.5 ± 3.7 points in the IKACTA group and 10.6 ± 2.3 points in the control group, resulting in an improvement of 8.9 points (95% confidence interval, 7.6 to 10.1 points; $p = 0.002$); the score was determined as 51.3% (19.5 of 38) for the IKACTA group, 27.9% (10.6 of 38) for the control group, and 23.4% (8.9 of 38) for the improvement. All participants agreed that the cognitive task analysis learning tool was a useful training adjunct to learning in the operating room.

Conclusions: To our knowledge, this is the first cognitive task analysis in diagnostic knee arthroscopy that is user-friendly and inexpensive and has demonstrated significant benefits in training.

Clinical Relevance: The IKACTA will provide trainees with a demonstrably strong foundation in diagnostic knee arthroscopy that will flatten learning curves in both technical skills and decision-making.

Disclosure: There was no source of external funding for this study. The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (<http://links.lww.com/JBJS/E420>).

There are considerable strains on surgical training due to working regulations, increased malpractice cases, and reduced training time in the operating room^{1,2}. Training programs need a defined number of index procedures and assessments to be undertaken before the successful completion of training can be achieved. This puts pressure on trainees to attain the necessary level of skill and competency within a limited timescale.

Knee arthroscopy is the most common orthopaedic procedure performed in the United States³. It requires a different skill set from open surgery and often trainees feel less prepared in the operating room. Complications of knee arthroscopy are rare but devastating. They include infection, hemarthrosis, articular cartilage damage from arthroscopic instruments, and instrument breakage from the use of excessive force. Previous research has highlighted the efficacy of virtual-reality and cadaveric simulations in knee arthroscopy training⁴⁻⁶. However,

these are expensive and are not readily accessible to trainees worldwide. In the United States, it has been estimated that 25% of training programs do not have a dedicated simulation facility and 87% of training program directors reported a lack of sufficient funds as the main barrier⁷. In this setting, newer, innovative, and easily accessible training adjuncts to the traditional apprenticeship model are necessary to help to meet training needs.

It is well established that cognitive learning of motor skills is key to undertaking a successful practical procedure⁸⁻¹².

Cognitive task analysis allows experts to provide complex information to trainees in a logical and efficient manner, which makes it easier to comprehend, visualize, and digest procedural steps⁸. It has been extensively used to train pilots, musicians, and military personnel⁹, and it has been shown to improve performance in Olympic athletes¹³. Wingfield et al. reported

DIAGNOSTIC KNEE ARTHROSCOPY CTA		
TECHNICAL STEPS	DECISION POINTS	ERRORS and SOLUTION: VIDEO/IMAGES
Pre-op Planning		
Mechanism of injury - twisting	Review current clinical picture	Equipment availability n/No videos for this phase
Diagnosis/Indications - Meniscus	Review the imaging available i	MRI incorrectly read/reported
Equipment - check availability	Ensure all equipment available on the shelf	depending on what procedure is required to be performed
Phase 1 - Theatre and patient set up:		
Operating table, attachments an	Ensure enough valgus stress pc	Poor theatre set up and See video - phase 1
Patient position - Supine with hi	Ensure the leg can go in the figure of four position to work in the lateral compartment.	
Apply the skirt (blue plastic cut	The skirt is applied to ensure cleansing fluid does not collect under the drape and cause tourniquet burn.	
EUA - Check for effusion, ROM	Anterior Drawer/ Lachmans - ACL, Posterior drawer - PCL, valgus stress - LCL, valgus stress - MCL, Dials test	

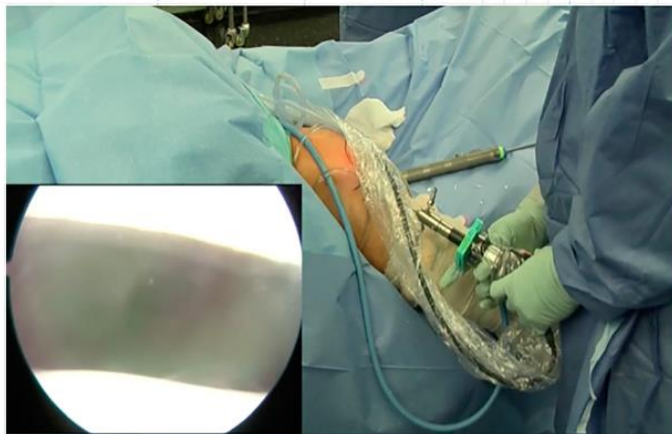


Fig. 1

Snapshot of the IKACTA learning tool. CTA = cognitive task analysis, MRI = magnetic resonance imaging, EUA = examination under anesthetic, ROM = range of motion, ACL = anterior cruciate ligament, PCL = posterior cruciate ligament, LCL = lateral collateral ligament, and MCL = medial collateral ligament.

that cognitive task analysis improves surgical outcome parameters, including time, precision, accuracy, and error reduction in both simulated and real-world environments⁸. Cognitive task analysis has been used successfully in other surgical specialties for procedures such as colonoscopy and flexor tendon repair¹⁴⁻¹⁶. However, it is in its infancy in orthopaedics. To our knowledge, there have been no studies in the existing literature that have investigated the efficacy of cognitive task analysis to train residents in diagnostic knee arthroscopy.

The purpose of this study was to evaluate the effectiveness of a novel cognitive task analysis tool to train novice surgeons in diagnostic knee arthroscopy in a high-fidelity, phantom-limb simulation.

Materials and Methods

In this study, we first designed the cognitive task analysis tool using the modified Delphi technique. Then we performed a randomized controlled trial to evaluate the benefits of this cognitive task analysis in high-fidelity, phantom-knee simulation for diagnostic knee arthroscopy.

Design of the Imperial Knee Arthroscopy Cognitive Task Analysis (IKACTA) Learning Tool

Procedural Steps and Delphi Technique

Three expert orthopaedic knee surgeons who perform knee arthroscopy as part of their routine clinical practice participated in this study. They were interviewed separately to gener-

ate a list of technical steps, cognitive decision points, and common errors. These were divided into 7 phases: (1) operating room and patient setup, (2) preparation and draping, (3) anterolateral portal placement, (4) examination of the patellofemoral joint and the lateral compartment, (5) examination of the medial compartment and anteromedial portal placement, (6) examination of the intercondylar notch and the lateral compartment, and (7) postoperative care and rehabilitation. These steps were then reviewed and were consolidated into 1 document by the primary investigator. The modified Delphi technique was used to generate the final master template. In this technique, a further series of interviews were conducted with the 3 experts. During this process, all of the steps that were common to all 3 experts were listed. Then the steps that were not agreed upon by all 3 experts were listed in a separate document and were discussed with the experts individually. Only those steps that had the consensus of all 3 experts were included in the final cognitive task analysis. Finally, the master template was created and was approved by all 3 experts.

Audiovisual Stimuli

The supervising consultant of the study recorded a video of a diagnostic knee arthroscopy. This video was divided into separate clips reflecting each of the 7 phases. A voiceover describing each step was superimposed on the video. The other 2 experts reviewed this video and a consensus was reached regarding the final content of the video so that it accurately

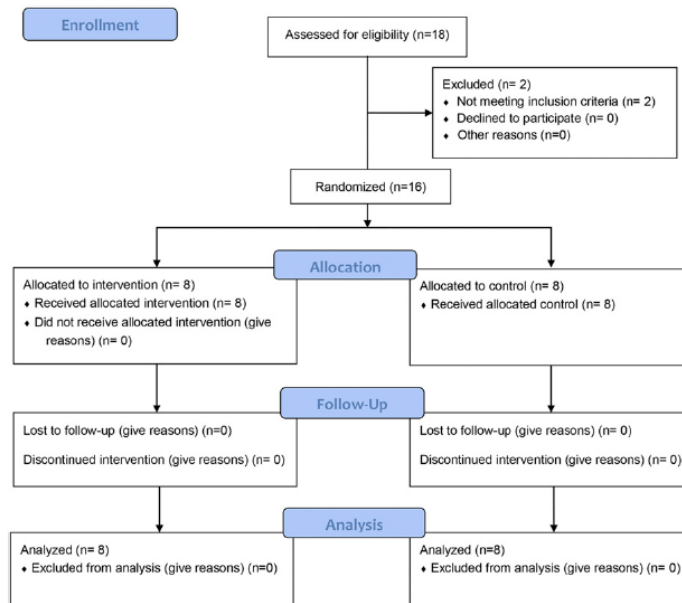


Fig. 2
CONSORT flowchart for recruitment of participants.

TABLE I IKACTA Tool Rating Parameters

No.	Parameter
1	This tool was useful to understand the key technical steps required to perform this procedure.
2	This tool was useful to understand the decision-making process behind the key technical steps involved in this procedure.
3	This tool was useful in highlighting the common potential errors that can occur while undertaking this procedure.
4	This tool will be a useful training adjunct to learning how to perform a diagnostic knee arthroscopy in the operating theater.
5	This tool is easy to use.
6	You enjoyed using this tool.
7	You would like to use this tool prior to attending a theater session on diagnostic knee arthroscopy.

stimuli helped trainees to understand the technical skills required, the reason underpinning each skill, and the potential errors that can occur during this procedure based on the knowledge and experience of experts in this field.

Recruitment

Approval from our institutional Medical Education Ethics Committee (MEEC) was obtained for this study (reference number: 1617-08). Eighteen junior orthopaedic trainees registered their interest in participating in the study. They completed a questionnaire assessing their experience in performing a diagnostic knee arthroscopy. The inclusion criterion for novice knee arthroscopists was having performed ≤ 10 diagnostic knee arthroscopic procedures in the operating room supervised by a senior surgeon. Sixteen candidates who matched the inclusion criterion were recruited in the study. Two candidates were excluded because their experience level was more than the desired level. This ensured that the group was homogenous and included novice surgeons with little prior experience in knee arthroscopy. All participants gave written consent to participate in the study.

Randomization

The participants were randomized into 2 equal groups ($n = 8$) using the random number generator function in Excel. This generated 2 sets ($n = 8$ each) of random numbers from 1 to 16. These were divided into 2 groups, the IKACTA intervention group and the control group. All assessors were blinded to the intervention group and the control group. We followed the Consolidated Standards of Reporting Trials (CONSORT) protocol for the recruitment and randomization (Fig. 2).

Trial

The intervention (IKACTA) group was given the IKACTA learning tool 10 days prior to their assessment date. The control group was given no additional learning tools. All participants were given a flowchart showing the sequence of steps that they were expected to perform in a diagnostic knee arthroscopy. All 16 participants were assessed on a high-fidelity, phantom-knee model with actual arthroscopic instruments and equipment. They were given basic instructions on the type of arthroscope and instrument set available to them and

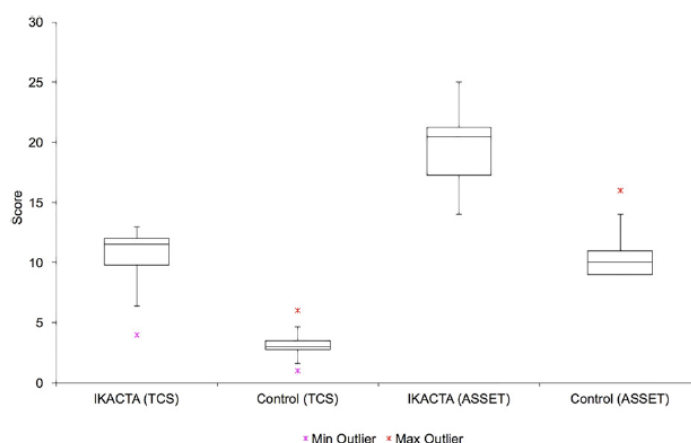


Fig. 5

Box-and-whisker plot showing the distribution of Task Completion Scores (TCS) and ASSET scores between the IKACTA group and the control group. The whiskers indicate the minimum and maximum values.

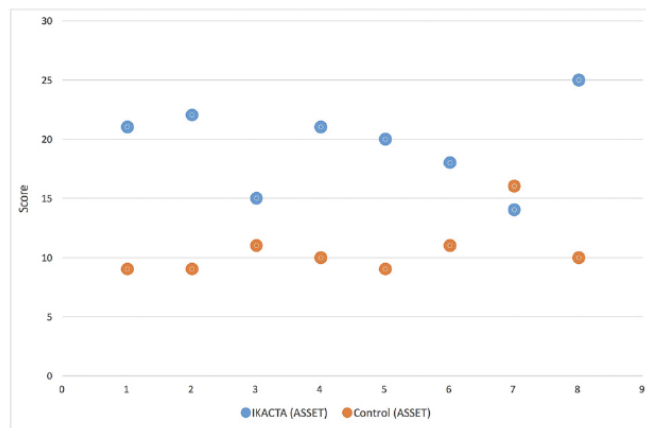


Fig. 6
Scatterplot showing the difference in ASSET scores between the IKACTA group and the control group.

were instructed to perform a diagnostic knee arthroscopy as they deemed appropriate. No additional help or guidance was provided. Participants attempted the knee arthroscopy on their own with monitoring by an investigator but no assistance. The videos for each participant were recorded from the arthroscopy stack for future grading and evaluation by an expert surgeon who did not know the identity of the participant or to which group the participant belonged.

Two blinded, independent, fellowship-trained expert knee surgeons graded all videos using the validated Arthroscopic Surgical Skill Evaluation Tool (ASSET) score (Fig. 3)

and the Task Completion Score part of the ASSET study (Fig. 4)¹⁷. These scores were compared between the 2 groups and were analyzed to evaluate the objective difference in performance between both groups.

All participants were provided the IKACTA learning tool following their assessment. They rated the tool on 7 parameters (Table I) using the Likert rating scale (1 indicates strongly disagree, 2 indicates disagree, 3 indicates neither disagree nor agree, 4 indicates agree, and 5 indicates strongly agree). The 3 expert knee surgeons who designed the IKACTA tool agreed on these parameters.

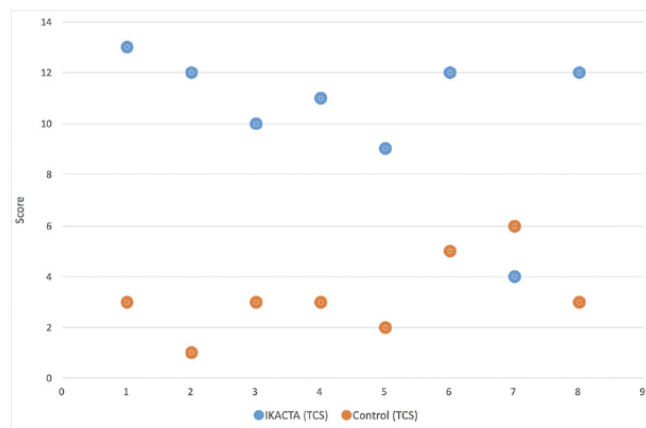


Fig. 7
Scatterplot showing the difference in Task Completion Scores (TCS) between the IKACTA group and the control group.

TABLE II IKACTA Rating Analysis

No.	Parameter	No. of Participants Who Agreed*
1	This tool was useful to understand the key technical steps required to perform this procedure.	16 (100%)
2	This tool was useful to understand the decision-making process behind the key technical steps involved in this procedure.	16 (100%)
3	This tool was useful in highlighting the common potential errors that can occur while undertaking this procedure.	16 (100%)
4	This tool will be a useful training adjunct to learning how to perform a diagnostic knee arthroscopy in the operating theater.	16 (100%)
5	This tool is easy to use.	15 (94%)
6	You enjoyed using this tool.	15 (94%)
7	You would like to use this tool prior to attending a theater session on diagnostic knee arthroscopy.	16 (100%)

*The values are given as the number of participants, with the percentage in parentheses, who agreed with the parameter (>3 on the Likert scale).

Statistical Analysis

An a priori power calculation was conducted using the mean percentage scores from a previous pilot study, whereby the IKACTA group scored 52.0% and the control group scored 25.7% with an alpha of 5% and beta of 20%, resulting in a power of 80%. The sample size calculation resulted in a minimum number of 5 per group. The difference in scores was also deemed clinically important according to the expert surgeons.

The mean ASSET score (and standard deviation) was calculated for both groups. The Mann-Whitney U test was used in which significance was set at $p < 0.05$. Box plots for each group were also devised.

Intraclass correlation coefficients (ICCs) were used to evaluate the interobserver reliability of the ASSET scoring of 2 raters. An ICC of 0.41 to 0.60 was considered to represent moderate agreement; 0.61 to 0.80, substantial agreement; and an ICC of 0.81 to 1.00, almost perfect agreement¹⁸.

Results

Participant Demographic Characteristics

All 16 participants (14 male and 2 female) who were included completed the study. All participants were junior orthopaedic trainees and matched the inclusion criterion for novice knee arthroscopists (performed ≤ 10 procedures under senior supervision). The median number of diagnostic knee arthroscopies performed (all supervised by consultants) by the participants was 3.5 arthroscopies (range, 0 to 10 arthroscopies) in the IKACTA group compared with 3 arthroscopies (range, 0 to 10 arthroscopies) in the control group ($p = 0.56$) prior to the study.

ASSET Score

The mean ASSET score (and standard deviation) was 19.5 ± 3.7 points (range, 14 to 25 points) in the IKACTA group and 10.6 ± 2.32 points (range, 9 to 16 points) in the control group (Fig. 5). The improvement in the mean ASSET scores between the intervention (IKACTA) group and the control group was 8.9

points (95% confidence interval [CI], 7.63 to 10.11 points) ($p = 0.002$). The score was determined as 51.3% (19.5 of 38) for the IKACTA group, 27.9% (10.6 of 38) for the control group, and 23.4% (8.9 of 38) for the improvement (Fig. 6). The ICC between the 2 raters was 0.795.

Task Completion Score

The mean Task Completion Score (and standard deviation) was 10.38 ± 2.87 points (range, 4 to 13 points) in the IKACTA group and 3.25 ± 1.58 points (range, 1 to 6 points) in the control group (Fig. 5). The improvement in the mean Task Completion Scores between the IKACTA group and the control group was 7.13 points (95% CI, 6.18 to 8.06 points). The score was determined as 74.1% (10.38 of 14) for the IKACTA group, 23.2% (3.25 of 14) for the control group, and 50.9% (7.13 of 14) for the improvement (Fig. 7). The ICC between the 2 expert raters was 0.893.

IKACTA Tool Rating Analysis

All participants agreed on parameters 1 through 4 and 7 on the rating analysis. Fifteen participants (94%) agreed on parameters 5 and 6 (Table II).

Discussion

Our study showed that the IKACTA is an effective tool for learning diagnostic knee arthroscopy. There was significant improvement in the objective ASSET score and Task Completion Scores between the group of trainees who used the IKACTA and the control group. There was an improvement in both technical skills and recall of steps with the use of the IKACTA. The score breakdown from the ASSET study¹⁷ indicated that a minimum score of 24 (63.2%) of 38 needs to be achieved to be competent at a diagnostic knee arthroscopy, thereafter progressing toward the expert level. This score is also likely to be achieved after repeated exposure to the simulation, whereas our participants only had 1 attempt recorded. The expert

level score is 38 (100%) of 38. Although the mean score in the intervention group was 51.3%, there was a significant improvement by 23.4% compared with the control group. The IKACTA brought trainees closer to the competency score, also on the first attempt. The significant improvement in the Task Completion Score highlights that this tool provides a user-friendly interface to aid both comprehension and recall of the steps required to complete a diagnostic knee arthroscopic procedure.

The IKACTA was designed to be an adjunct to training in the operating room alongside the traditional proctorship model. Its use allows trainees to improve their technical skills and understanding of cognitive steps and errors prior to performing this procedure in the operating room. This will reduce the learning curve in the operating room and will allow easier and quicker progression toward achieving competency in this procedure.

Howells et al.¹⁹ have shown transfer validity of arthroscopic skills from a bench-top knee simulator to the operating room. Cannon et al.⁵ showed a similar transfer validity of skills gained on a high-fidelity, virtual-reality knee arthroscopy simulator to the operating room. Therefore, although our assessments were performed in a simulation setting, the findings from those studies^{5,19} indicate that the IKACTA tool may result in improved performance in the operating room.

Cadaveric and virtual-reality simulations have proven efficacy in knee arthroscopy training^{4,6,20}. However, a major advantage of the IKACTA tool compared with virtual-reality and cadaveric simulations is that it is easily available and inexpensive. It allows repeated sustained use, which is the key aim of simulation training. Karam et al.⁷ reported that a quarter of the orthopaedic training programs do not have simulation facilities in the United States because of the expenses involved. The problem is identical in the United Kingdom and worldwide. In this setting, the IKACTA can be an invaluable simulation tool for trainees to develop a sound foundation before performing knee arthroscopy in the operating room. Even in the regions where cadaveric and virtual-reality simulation facilities are available, our tool will act as a useful adjunct. This study has validated the IKACTA tool.

The subjective assessment of the tool by the trainees showed that the vast majority believed that this tool substantially aided their understanding of the technical steps, the cognitive decision-making underpinning these steps, and the common errors involved in a diagnostic knee arthroscopy. The majority agreed that the tool was easy to use and they enjoyed using it. They believed that it is a useful adjunct to learning this procedure in the operating room and they would like to use the tool prior to performing this procedure on patients.

The strengths of the study include that it is a prospective, double-blinded, randomized controlled study with comparable intervention and control groups. We used a sound modified Delphi technique to design the IKACTA tool. This tool is novel and has shown significant benefits in training in diagnostic knee arthroscopy compared with the control group in the simulation setting. There was relatively strong agreement among raters as shown by the ICC score. A post hoc power analysis resulted in 100% power, confirming that our initial power calculations were correct.

Our goal is for trainees to use this tool prior to attending the operating room, to give them a robust foundation before they perform knee arthroscopy on actual patients. Hence, the limitation of the current study is that we did not demonstrate transfer validity by evaluating transfer of the skills into the operating room, which would have carried its own ethical implications. We were obliged to demonstrate the efficacy of our cognitive task analysis in a high-fidelity simulation setting, prior to using it in the operating room. One study¹⁹ has previously shown transfer validity from a bench-top simulator to the operating room in diagnostic knee arthroscopy. We intend to observe the cognitive task analysis in the operating room as our next study.

Orthopaedic surgeons have traditionally been resistant to change in surgical training. However, with the ever-increasing demands of a consultant-led service and reduced training hours, simulation-training techniques have increasingly been encouraged^{7,21}. The major limitation so far has been the expense and availability of simulation facilities to trainees worldwide. We have designed a new, user-friendly, inexpensive, cognitive task analysis learning tool that has demonstrated significant benefits in training in diagnostic knee arthroscopy. To our knowledge, this has never been studied before in the field of orthopaedic training, and we believe that similar cognitive task analysis learning tools can have a wide application and impact within trauma and orthopaedic training in the future.

To our knowledge, this is the first study to demonstrate the effectiveness of a cognitive task analysis in orthopaedic surgery training. The IKACTA is a beneficial learning tool in diagnostic knee arthroscopy and can be used by novice surgeons to enhance their cognitive understanding and technical skills before they perform this procedure on patients. Additionally, all participants in this study advocated the use of this tool prior to attending the operating room. We recommend using this tool in orthopaedic training programs. ■

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