THE FLEXIBLE CADAVER KNEE MODEL AS A TRAINING
MODEL FOR THE DEVELOPMENT OF BASIC ARTHROSCOPIC
SKILLS

by

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Abstract

**Goal:** Develop an effective high-fidelity model for the purpose of training orthopaedic surgeons.

**Objectives:** This study had two objectives; I) the development of a flexible cadaver model for training orthopaedic surgery residents in basic arthroscopic skills and; II) the evaluation of the educational utility of the flexible cadaver model in comparison to the fresh-frozen cadaver model.

**Hypothesis:** The flexible cadaver model is equivalent to the fresh-frozen cadaver model as a training resource for the development of arthroscopic skills.

**Materials and Methods:** A human body was embalmed with a phenol-based embalming solution to create a flexible cadaver. A knee model was then developed and introduced to orthopaedic surgery residents and faculty at an arthroscopic skills training workshop. SurveyMonkey® was utilized to create and administer an online survey asking participants to rate a variety of statements regarding the educational utility of the flexible cadaver model and fresh-frozen cadaver models on Likert-type scales. Mean response values between the two models were calculated and compared.

**Results:** The phenol-embalmed cadaver produced a high-fidelity knee model that workshop participants were unable to differentiate from the fresh-frozen cadaver model, except for some differences in colour. Survey responses supported our hypothesis that the flexible cadaver model is equivalent to the fresh-frozen cadaver model as a training resource for the development of basic arthroscopic skills.

**Conclusions:** Two conclusions can be drawn from this study; I) the flexible cadaver model is at least equivalent in educational utility compared to the fresh-frozen cadaver model for the development of basic arthroscopic skills and; II) the flexible cadaver model is a promising resource for the development of arthroscopic skills.
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Chapter 1

Introduction

1.1 Preamble

In 1210 AD the apprenticeship model was employed as the first educational mode of training residents in surgical skills. This model of surgical educational has endured thousands of years of adaptation and remains the gold standard of surgical education training. Although this educational system is believed to be an effective means of resident training, modern medicine has introduced new variables into the educational equation that are challenging the viability of this educational model (1). This is especially true for minimally invasive surgery (MIS) techniques such as arthroscopy, which require a broad spectrum of skills including challenging technical and motor skills, decision-making, surgical judgment, cognitive knowledge and teamwork (2). With the increasing technical difficulty of surgical techniques, resident work hour restrictions, public concern regarding quality of care, and pressure on surgical educators to improve cost-effectiveness within the operating theater, new methods of educating residents in arthroscopic skills are necessary to surmount these challenges and provide residents with efficient and effective surgical education (3, 4). Many residency-training programs are now including surgical models within their curriculum to help surmount these challenges. Some research has shown that training on simulators is transferable to the operating room (3, 5) and may represent a crucial supplement to traditional surgical training (5). One promising area for exploration is the development of a soft-embalmed cadaver model capable of providing high-fidelity surgical skills training.
1.2 Surgical Education Model

1.2.1 Structure

Sir William Halsted introduced the German residency training system to North America at the beginning of the 19th century. This educational approach, which is still widely utilized within medical education, emphasizes graded responsibility through the apprenticeship model (6). Halstead believed that trainees should experience graduated exposure to operative experience under the guidance of expert surgeons (7).

This form of graded responsibility is the traditional method by which residents are trained in most surgical disciplines including neurosurgery, plastic, paediatric and orthopaedic surgery. Residents are progressively exposed to increasing levels of surgical responsibility; beginning with the observation of several operations performed by experienced surgeons. Residents are then permitted to play a more active role in procedures beginning with basic skills, and progressing to more complex procedures. In the final stage, residents assume a more autonomous role as the primary surgeon (2, 8).

The observation of experts performing surgical skills allows residents to gain insight into many aspects of surgical procedures such as specific skills, protocol knowledge, anatomical knowledge, teamwork, patient positioning, etc. This however, is likely not an effective or efficient way to learn the complex motor and cognitive skills required for minimally invasive surgeries, such as arthroscopy (2). Success within this type of training model is highly dependent on three variables including the quality of the trainee, the quality of the mentor and the quality of the training resources (9).
1.2.2 Challenges Facing Surgical Education

Surgical educators have recognized that although the operating room is an indispensable component of the surgical training regime, it is not the optimum environment for learning basic surgical skills. The public is becoming increasingly aware of their personal well being and health care, and are expressing concern regarding the utilization of the operating room as a skills training resource for residents (3). The public is also demanding better surgical outcomes, shorter waiting times and simplified processes, all of which compete with the needs of surgical skills training programs. Residents acquire a significant amount of surgical skills through operative rotations at the expense of increasing operating times and the potential risk of surgical complication. Errors occurring during operative procedures, although rare, are highly scrutinized by society. They are also often reported in the general media and medical literature (10). Many teaching hospitals are also experiencing a decrease in the number, and variability of patients available for teaching (11). These hospitals are also receiving increasingly complex surgical cases, requiring evaluation and treatment by the attending senior medical staff (3).

Academic hospitals, along with the rest of the health care system are under constant scrutiny to ensure optimal patient care at the most economic means possible (9, 11-13). The additional time required to train residents in the operating room contributes to the economic strain facing the health care system and residency training programs. Surgeons are being given less time to teach, and residents’ opportunities to learn and practice are correspondingly decreasing (5). Bridges and Diamond (12) estimated the cost of lost time during operations in which surgical residents assisted amounted to US$47,970 per resident over four years of surgical residency. This amounted to a $53 million annual cost for training residents in the operating room. The direct
economic cost of training residents on patients suggests that more productive and efficient processes need to be examined, developed and implemented.

The operating room is a complex and notoriously stressful environment that is not conducive to learning (9, 14). Minimal levels of tension have been shown to enhance learning by increasing arousal; whereas the process of learning has been shown to be inhibited when tension reaches a level that creates anxiety. Physiological and psychological fatigue are two additional factors affecting the acquisition of psychomotor skills, as both are detrimental to the skill acquisition process. Residents frequently work extremely demanding operative schedules, which often extend beyond 12 hours (4). Often when given high-fidelity practice sessions outside of the operating room, such as dedicated skills training workshops, the session frequently extends over an eight-hour day (15). Wanzel et al. (14) have noted that more than 4 hours of practice per day leads to fatigue, which results in a decrease in the quality of the students’ performance.

An articulated technical training curriculum outside of the operating room, where residents can learn and practice technical exercises has been suggested as an appropriate and effective way to overcome many challenges facing surgical education (9, 11, 12). Training residents outside of the operating room could help limit financial demands placed on surgical skills training programs by generating residents who are trained in basic, introductory skills which generally require the most operative time to develop (13). Ultimately, surgical education must evolve to accommodate the many challenges that are confronting the apprenticeship model without compromising the skills and aptitude of future surgeons (9).
1.3 Arthroscopy

1.3.1 Arthroscopy of the Knee

Arthroscopy is currently one of the most widely utilized diagnostic tools and treatments for an increasing number of musculoskeletal disorders associated with synovial joints. This technique is commonly applied to larger joints including the knee, shoulder, elbow, wrist, ankle and hip (16). Buerman (17) was the first to utilize an arthroscope to evaluate the interior of joints by inserting this instrument into the joints of cadavers through a small incision. It would take more than 40 years for arthroscopic techniques to advance to a point of clinical utility for the visualization as well as the treatment of joint dysfunctions (18). Arthroscopy is currently the most commonly practiced orthopaedic procedure with techniques on the knee being the most prevalent (13).

Arthroscopic techniques have some significant limitations, including requiring a potentially greater operative time due to a more extensive and complex array of arthroscopic instrumentation, as well as demanding more challenging technical ability (19). Arthroscopic procedures require the insertion of two or more specialized instruments into a joint space to allow for the diagnosis and surgical repair of intra-articular musculoskeletal dysfunctions. An arthroscope, a small fiber optic camera, is inserted into a small incision, or portal, created in the skin and surrounding soft-tissues of the joint. One or more additional portals are also required for the insertion of additional instruments such as probes, knives and scissors (20).

1.3.2 Arthroscopic Skills

With the advancing difficulty of minimally invasive surgical procedures such as arthroscopy, residents are requiring more experience and exposure to master the surgical
techniques (5). The number and complexity of arthroscopic procedures is also increasing, leading to an increase in concern of residents and training faculty surrounding the adequacy of arthroscopic training during residency (21). Hall et al. (21) found that only 32% (27/83) of fifth-year residents believed that there was an adequate amount of time dedicated to arthroscopic training within their residency training program, compared to 66% (16/24) of program directors.

A learning curve exists with all surgical procedures but it appears to be more extreme with arthroscopy as more experience is necessary for the acquisition of required technical skills when compared to open surgical techniques (21). All minimally invasive surgical techniques including arthroscopy demand the acquisition of skills that are considerably different than those required for open surgery (22). Previously many experienced orthopaedic surgeons estimated that the performance of more than 500, and likely closer to 800 arthroscopic procedures were required before an individual can be considered proficient (23). Currently, there is little consensus among practicing surgeons regarding the number of operations required to become competent in arthroscopy (22). Hall et al. (21) administered a survey of fifth-year residents and found that only thirty-four percent (28/83) felt as prepared in arthroscopy as they did with open surgical techniques. Due to the significant number of procedures that experienced surgeons believe are required to master the skills of arthroscopy, it is critical that fundamental aspects of arthroscopic training be taught as effectively and efficiently as possible (13); including familiarity with surgical equipment, orientation, bimanual dexterity, surgical anatomy, integration of muscle strength, speed, precision, balance and spatial perception (15).

Although the operating room is a necessary component of the learning environment, there are many factors that make it a less than ideal environment, especially for development of basic knowledge and skills. It is therefore important that residents be extremely familiar with the
equipment, surgical anatomy and the motor skills required to manipulate the equipment before entering the operating room (13). The development of these basic skills is also important to limit the incidence of complications from inadvertent damage to the articular surfaces by inexperienced surgeons. This highlights the importance of developing, at minimal, basic technical skills outside of the operating room in a controlled environment (8).

Arthroscopic equipment is moderately complex and requires the development of specialized skills including triangulation, orientation and bimanual dexterity, which are essential for efficient and effective arthroscopic technique (8, 22). Introducing an additional instrument into the joint space, along with the arthroscope, so that the tip of the instrument and arthroscope form the apex of a triangle results in the tip of the instrument being brought into the field-of-view of the arthroscope (8). This complex skill, known as triangulation, requires bimanual dexterity and specialized motor skills. This type of motor movement is not commonly required for everyday tasks involving the manipulation of the external environment utilizing the hands and therefore requires substantially more motor learning for efficiency to occur than those required for open surgical skills (21).

Arthroscopes commonly have a field-of-view which is offset by 30° or 70° which leads to the movement of the probe not being directly reflected on the monitor screen (8). The action produced by the surgeon on the end of the instrument produces the inverse action on the screen thus producing a conflict between visual and proprioceptive stimuli. Additionally, the image produced on the monitor is a 2-dimensional representation of the 3-dimensional intra-articular environment that is often rotated, reflected, or magnified (22). All of these factors, along with being required to maneuver the arthroscopic instruments within the small intra-articular space,
requiring training residents to develop specialized motor skills including bimanual dexterity, orientation and triangulation (8).

1.3.3 Arthroscopic Training

Arthroscopic training traditionally begins during orthopaedic residency with additional training often being provided by a focused fellowship in arthroscopy and/or a sports medicine (24). In order to successfully perform arthroscopic techniques safely and effectively, residents need to develop manual arthroscopic skills that require specific visual–spatial abilities (3). Training usually begins with the development of rudimentary psychomotor skills using lower-fidelity bench top models such as a simple “black box” or Sawbones® models whereby basic triangulation, orientation and bimanual dexterity can begin to be developed (24). Residents are concurrently exposed to surgical procedures where they develop skills by first observing senior surgeons. Residents are then required to play a progressively more active role in the surgical procedure by assisting and eventually performing the entire operation. Many orthopaedic training programs also provided residents with the opportunity to practice arthroscopy on fresh-frozen specimens at specialized skills training workshops.

1.3.3.1 Models

Many residency-training programs are now including surgical models within their curriculum to help supplement orthopaedic residency training programs. These vary from low-fidelity bench top models, to virtual reality simulators and high-fidelity models such as animal and cadaveric specimens. Each of these resources has advantages and disadvantages but all are
currently being utilized in some capacity within residency training programs throughout the world.

1.3.3.1.1 Bench-top Models

Bench-top arthroscopic models including Sawbones® synthetic models and even simple “black box” simulators are becoming extremely popular within orthopaedic residency programs for arthroscopic skills training (3). Their use within arthroscopic education has many potential advantages including being more accessible to trainees (9), lower cost, portability, potential for repeated use, and the ability to be utilized unsupervised (3). Meyer et al. (25) argued that even a basic simulator, such as the “black box” and standard arthroscopic instrumentation, are an inexpensive means of developing basic arthroscopic skills in a laboratory environment. Anastakis et al. (3) have also shown that low-fidelity bench top training models have a strong potential for transferring technical skills to the operating room.

When examining laparoscopic skills training Scott et al. (26) found that the benefits of practicing on synthetic models are evident throughout all skill levels, but that the benefits are the most significant for novice surgeons. Rosser et al. (27) believe that competency in fundamental skills can be obtained by novice surgeons in a brief, formalized training course. Residents could utilize bench top models to develop introductory arthroscopic skills before progressing to high-fidelity training resources and assisting with procedures. Ceponis et al. (13) stated that utilizing bench models is an appropriate means of preparing surgical trainees to learn basic skills before progressing to using cadaveric specimens.

Despite the potential advantages of bench top training models, many surgeons have raised concern regarding whether surgical skills development using bench models results in
improved operative ability as ‘simulators are not the real thing’ (9). Low-fidelity models have been shown to have similar educational utility as high-fidelity models yet many residents and surgeons are skeptical of their effectiveness (28, 29) and often display substantially less enthusiasm for using low-fidelity rather than high-fidelity models (28). Wong and Matsumoto (5) argued that the effectiveness of a surgical skills training model is greatly limited if the intended users do not accept it.

Tuijthof et al. (30) stated that skills training without receiving natural feedback could lead to an offset in the individual’s motor programs, which could lead to increases in errors in the operating room. There is also significant evidence that surgeons themselves rate bench top models as a poor mode of preparation for surgical practice and as the least significant in contributing to their ability to perform arthroscopic procedures. Safir et al. (31) found that surgeons ranked simulation using low-fidelity bench top models as the least helpful for preparing a trainee for the operating room. Surgeons did however; rate high-fidelity synthetic models relatively high and cadaver specimens the highest. Vitale et al. (32) found that surgeons indicated the lowest Likert scores for practice on artificial shoulder models, along with the use of Internet resources and residency training, in contributing to their ability to perform arthroscopic rotator cuff repair.

Bench-top models also require dedicated facilities and the replacement of synthetic tissue models is expensive and many can only be used once or twice. Bench top models also require regular maintenance, repair and will eventually need to be replaced completely (9).
1.3.3.1.2 Virtual Reality Simulation

Despite the successful use of virtual reality (VR) simulators in the aviation industry for decades, their use in surgical education simulation is still quite limited (9). They are progressively gaining popularity within arthroscopic education as VR simulators are becoming capable of more accurately simulating *in vivo* arthroscopic procedures. One of the main limitations of VR is their inability to provide accurate feedback from the virtual intra-articular environment (8). Training skills without receiving natural feedback has been suggested to lead to an offset in motor programing and psychomotor skills, which could lead to an increase in operative errors (30). VR simulators must provide accurate feedback, as many intra-articular structures of the knee including the articular cartilage and menisci, are pliable and soft rather than rigid objects, such as bone. The consistencies of these intra-articular structures are essential in the diagnosis of pathology (8).

Seymour et al. (33) have provided support for VR training through a double blinded, randomized study of skill transfer from the virtual environment to the operating room. Sixteen residents were randomly assigned to obtain training on a VR laparoscopic simulator or the traditional training residents would experience in their surgical rotations. Residents who received VR training performed significantly better at laparoscopic cholecystectomy. Statistically significant differences were seen when outcome measures of time to task completion, tissue damage and performance errors were used.

The cost of VR simulators is one of their major disadvantages; usually costing in excess of CA$100,000 (9, 29), and continued maintenance would further deplete operating costs (9). Despite their high cost VR will likely play an important role in the future of arthroscopic skills training and assessment (29). VR simulators have been suggested as an ideal mode for the
objective assessment of a trainee's skill if the model is capable of being programmed with specific structured arthroscopic procedures (8).

1.3.3.1.3 Tissue Models
1.3.3.1.3.1 Cadaveric Models

The University of Calgary Orthopaedic Surgery training program currently utilizes two educational modes to teach the fundamental aspects of diagnostic arthroscopy including laboratory practice on cadaver specimens and progressive responsibility within operating room. The cadaver based skills training within the laboratory allows for training to occur in a relatively flexible environment where time and psychological pressures are minimized and the risk of damaging a patients intra-articular anatomy is non-existent (9). Cadaver models provide training surgeons with an accurate anatomical representation but the physical and visual quality may not always be representative of living tissue, especially if the cadaver has been preserved. Traditional embalming utilizing a formalin solution results in rigidity of tissues and colour changes (34). Skills training utilizing cadavers is also expensive, generally provides only a one-time use for a specific surgical procedure and the supply of cadavers is becoming limited with growing demands (5). Many have also raised concerns such as additional space requirements, supply, cost, and legal issues as well as a lack of standardization for the use of cadaver models (3, 13). Evidence supporting the belief that skills gained using cadaveric models transfers to clinical practice is also still required (9).

Ceponis et al. (13) compared two methods of teaching basic skills of diagnostic shoulder arthroscopy to novice orthopedic surgery residents including cadaver-based and composite learning environments. This study found that only the composite group, which received training
with low-fidelity models as well as videos, showed a statistically significant improvement in their mean pre- versus posttest scores. The authors concluded, “A composite teaching curriculum is at least as effective as a cadaver-based environment for teaching orthopedic surgery residents fundamental knowledge of diagnostic shoulder arthroscopy”. The authors also suggested that this form of teaching is likely a more effective method for teaching basic knowledge and that cadaver-based training may be a more applicable method for the acquisition of specific procedural skills (13).

Although the use of cadaveric specimens as arthroscopic skills training models has been met with some resistance, many experienced orthopaedic surgeons advocate their use and argue that they were one of the most important tools in the development of their arthroscopic skills (32). Vitale et al. (32) administered a twenty-eight-item survey to evaluate how orthopaedic surgeons were trained for an all-arthroscopic rotator cuff repair. Participants were asked to rate the relative importance of different training strategies on a Likert scale with “one” indicating the least significant and “five” indicating the most significant in contributing to their ability to perform arthroscopic rotator cuff repair. Participants rated the sports medicine fellowship [3.49], hands-on laboratory instructional courses [3.33], and practice in an arthroscopy laboratory on cadaver specimens [3.22] as the most significant in contribution to the development of arthroscopic skills. Surgeons indicated the lowest Likert scores for residency training [2.02], practice on artificial shoulder models [2.13], and for the use of Internet resources [2.25]. These results indicate that surgeons value practice on cadaver specimens as a more valuable training method than utilizing artificial models and residency training programs in contributing to their arthroscopic proficiency.
1.3.3.1.3.2 Live Animal Models

Live animal models have frequently been used for their high-fidelity simulation but there are many concerns regarding their use including their inability to represent exact human anatomy (3); although it is quite similar, especially when using dogs, pigs and sheep (9). These models are frequently utilized in small-scale training workshops which require significant financial investment to establish and maintain (9). There are also significant ethical concerns with the use of animal models and some studies have shown that approximately 25% of participants experience some form of moral anxiety, suggesting that viable alternatives should be available (35). Live animal workshops do not replace the training residents receive in the operating room but rather act as a complimentary training resource to this experience (9).

1.3.3.2 Arthroscopic Skills Training Workshops

Many orthopaedic training programs provided residents with the opportunity to develop their arthroscopic skills utilizing the highest fidelity model currently available, the fresh-frozen cadaver, at specialized skills training workshops. These courses are designed to supplement any deficiencies that may exist in resident training and operative caseload exposure. Although these courses can provide residents with an introduction to the elements of surgical procedures, unfortunately they only provide a limited opportunity for the practicing of surgical skills. They are generally intensive workshops conducted over a short period of time, usually between one and three days (8). Wallace (23) identified that the benefits of these courses are limited due to the fact that they generally provide only transient skills training without reinforcement during a single period of learning, or at most a few days. Dankelman et al. (2) argued that learning complex tasks at a single period of time exceeds the attentional capacity of the trainee and therefore should be
acquired in a step-wise manner, starting away from the patient with learning the basic skills first. Although these workshops can provide residents with limited additional exposure to arthroscopic training resources, unfortunately they do not provide enough time for residents to learn complex arthroscopic skills. Therefore it is imperative that residents are provided with the opportunity to develop their arthroscopic skills using these high-fidelity models over multiple training periods.

1.3.3.3 Skills Training Centres/Laboratories

In 1976 Spencer (36) identified one of the largest issues with the development of surgical skills was the lack of “a convenient method of practice.” His solution to this problem was the development and systematic utilization of surgical skills laboratories. Currently, most of the training resources discussed previously including bench-top models, VR simulators, and cadaveric specimens are accessible in skills centres that have been developed over the last decade. Many of these centres were initially created to complement the shift towards problem-based, self-directed learning environments in undergraduate medical school curricula but the potential for postgraduate skills training was soon identified. These skills training facilities along with complimentary curricula were designed to allow trainees to practice skills and be exposed to new skills in a controlled environment before application in a clinical setting (9, 29). Training by the ‘random opportunity’ afforded by resident rotations would be highly complimented with the addition of structured skills-training resources into the current educational paradigm (9).

1.4 Soft Embalming

Soft embalming is an embalming technique that utilizes very little, or no formaldehyde, to fix tissue. Soft embalming is an embalming method that is capable of preserving human tissues
without the rigidity and colour changes seen with traditional formalin fixation (34, 37). There are two main soft embalming solutions including the Thiel method, and phenol-based embalming solutions. Soft embalmed cadavers have a minimal amount of detectable odor and maintain a flexible, lifelike mobility to the tissues (34, 38). This tissue mobility allows for movement of joints to be maintained, making them an appropriate training tool for orthopaedic surgical training (34). Grechenig et al. (39) have presented an anecdotal argument for an educational model for learning and training arthroscopy utilizing soft-embalmed cadavers.

Soft-embalmed cadavers offer significant advantages over more traditional educational models such as fresh-frozen cadavers and other simulators in teaching clinical procedures such as intubation, lumbar puncture, central line placement, thoracocentesis, as well as surgical skills such as laparoscopy (40). The most significant advantage of soft-embalmed cadavers is that residents are able to learn skills with an extremely high-fidelity model, not only in anatomical representation, but also in tissue quality. Soft-embalmed cadavers have already been employed in postgraduate medical courses including endoscopy, thoracic surgery, colon and rectal surgery (34). There are however, many potential applications for the soft-embalmed cadaver that have yet to be investigated.

1.4.1 Thiel Embalming

Walther Thiel developed this new embalming technique and published his method in 1992 (37). This soft-embalming solution has proved to be very useful in surgical skills training and is currently used in skills training programs across the world. The Thiel embalming technique however, is quite complex and requires the creation of two stem solutions (A and B), which are then combined with formalin and sodium sulphite (34).
1.4.2 Phenol-based Embalming

Phenol-based embalming is a type of soft-embalming technique utilizing a solution composed of four components: phenol, glycerol, ethanol and water. The origin of this solution remains unknown but it has been cited in some research from the United Kingdom where it was utilized to embalm cadavers for dissection by gynaecological oncologists (38). There are two Canadian institutions, McMaster University and the University of Toronto, who are utilizing phenol-based soft embalmed cadavers for surgical skills training, each of which has altered the composition of the solution based on their experiences.

1.4.2.1 Phenol

In embalming, phenol, or carbolic acid, is classified as a preservative although it is can be utilized for many other applications in including acting as a drying agent, cautery agent, bleaching agent, and most importantly, a germicide and fungicide. The bleaching ability of phenol results in tissues turning a ‘putty gray’ colour (41).

1.4.2.2 Glycerol

Glycerol, or glycerin, prevents tissue dehydration and retains tissue moisture and is therefore an essential part of soft-embalming formulae. Within the soft-embalming solution, glycerol acts as a solvent, along with water, for the other components of the solution. Glycerol has no germicidal or bactericidal properties but is an integral part of the soft-embalming solution which maintains tissue moisture and limits dehydration (41).
1.4.2.3 Ethanol

Ethanol, also called ethyl alcohol, is a volatile, flammable, colorless liquid. Ethanol is an important component of the soft-embalming solution due to its antimicrobial, anti-fungal and antibacterial properties. Ethanol acts to kill organisms by denaturing proteins and dissolving lipids, which adversely affects metabolic functioning and cellular integrity. Ethanol is effective against most bacteria and fungi, and many viruses, but is ineffective against bacterial spores. Ethanol’s antibacterial action is achieved by degradation of the cell, which leads to cell lysis (42).

1.5 Summary

The changing educational environment for surgical skills is requiring the development of new methods for teaching residents arthroscopic skills. Many residency training programs are now including surgical models within their curriculum to help supplement residency training programs. High-fidelity training models, including cadaveric specimens, are frequently discussed by experienced orthopaedic surgeons as one of the most important tools in the development of their arthroscopic skills (32). The development of soft-embalmed cadavers for use as educational models is one promising area for exploration. The most significant advantage of soft-embalmed cadavers is that residents are able to learn surgical skills by training on an extremely high-fidelity model, not only in anatomical representation, but also in tissue quality. Wong and Matsumoto (5) argued that the effectiveness of a surgical skills training model is greatly limited if the intended users do not accept it. Therefore, the evaluation of the opinion of orthopaedic residents and surgeons is an important step in identifying the future utility of flexible cadaver models within arthroscopic education.
Chapter 2

Hypothesis and Objectives

2.1 Hypothesis

The flexible cadaver model is equivalent to the fresh-frozen cadaver model as a training resource for the development of arthroscopic skills.

2.2 Study Objectives

I) Model development - Develop a flexible cadaver model for training orthopaedic surgery residents in basic arthroscopic skills.

II) Model evaluation - Evaluate the educational utility of the flexible cadaver model in comparison to a fresh-frozen cadaver model.
Chapter 3

Study Rationale

3.1 Overview of Study Rationale

The design of this experiment was based on the research goals of the project and the resources available to the researcher. All components of the study were designed with ethical, financial and timeline considerations in mind. This study was approved for ethical compliance by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board. The Federalwide Assurance number is: #FWA00004184 and #IRB00001173.

3.2 Objective I – Model Development

3.2.1 Embalming Solution

A phenol-based soft embalming solution was chosen as the embalming fluid as it has been shown to preserve human tissue without the rigidity and colour changes seen with traditional embalming method. Soft embalming retains moisture, flexibility and plasticity of cadaveric tissue, which allows the joints to remain freely moveable, making them an appropriate model for the training of orthopaedic surgery residents (34). Soft embalmed cadavers allow training surgeons to be exposed to human tissue that closely mimics in vivo tissue characteristics of fresh-frozen cadavers without the risks of exposure to infectious agents (43).

3.2.2 Embalming Protocol

The embalming protocol utilized for traditional formalin fixation at Queen’s University was modified based on suggestions from the experiences of technical staff at McMaster University. A closed embalming system was used to limit the loss of tissue and embalming
fluids, as well as to limit the number of openings in the donor’s skin as this can increase the rate of decomposition (41).

3.2.3 Model Preparation

The left knee of the flexible cadaver was removed from the donor body to simulate the appearance, preparation and placement of fresh-frozen knees utilized in arthroscopic training workshops within the current arthroscopic training curriculum. Two portals, an anterolateral and anteromedial, were created in the flexible cadaver model by the primary course instructor, an assistant professor in the Orthopaedic Residency Training Program at Queen’s University. These two portal placements were chosen due to their common use in arthroscopic procedures of the knee (20).

3.2.4 Model Storage

The flexible cadaver model was kept in cold storage at a temperature between 4-6°C to limit the rate of evaporation of the embalming solution and bodily fluids. This temperature was also important to limit the potential for development of fungal growth as well as delaying the onset of tissue degradation and putrefaction (41). The hands, feet and head of the cadaver were wrapped in a cotton material soaked with moistening solution to limit the rate of dehydration of the extremities of the model. The entire body was kept in a plastic bag to limit dehydration as well.
3.3 **Objective II – Model Evaluation**

Kirkpatrick (44) developed a four-level model for assessing training effectiveness. The first level focuses on measuring how participants in a training program react to it. A survey was chosen as the mode to evaluate the flexible cadaver model to attempt to answer questions regarding the participants’ perceptions of the model. Kirkpatrick (44) suggested that this level of evaluation should be done first and that a positive reaction does not guarantee learning will result, but stated that a negative reaction likely reduces its possibility.

3.3.1 **Exposure of Participants to the Model**

Annually, the Orthopaedic Residency Training Program at Queen's University organizes an arthroscopic training workshop for orthopaedic residents; this presented an ideal opportunity to introduce training orthopaedic surgeons, and practicing surgeons, to the flexible cadaver model. Workshop attendees were provided with the opportunity to use the flexible cadaver model, as well as a fresh-frozen cadaver, the model currently utilized within their education curriculum. All workshop participants were required to sign a waiver before exposure to the flexible cadaver model relinquishing the Department of Biomedical and Molecular Sciences at Queen’s University, their director(s), specimen suppliers, agents, consultants and employees from any responsibility for any injury, disease, or other damage which could have resulted in any way from participation in the workshop (Appendix A).

3.3.2 **Survey Mode**

An online survey was chosen as the mode of administration due to the small cost associate with its use, easy of creation and utilization, response speed, ability to disseminate the
survey to the entire target population, as well as providing participants the opportunity to complete the survey at their own convenience. Administering a survey utilizing a computer, also known as neutralized administration, has also been shown to decrease the occurrence of social desirability, a phenomenon where subjects being interviewed or answering questionnaires choose a response which they view as being more socially acceptable (45).

3.3.3 Survey Design

Participants were not required to submit identifying information in order to minimize the potential that they may have felt directly or personally associated with their responses; this could have also provided participants with a feeling of detachment from their responses and reassurance of anonymity (46). SurveyMonkey®, an online survey software and questionnaire tool, was utilized to create the formal online questionnaire due its ease of use, familiarity of faculty with the resource and its use in past research studies within the Department of Biomedical and Molecular Sciences at Queen’s University.

The survey consisted of 26 items in total; the first seven of these items were of demographic nature, and the remaining 19 were items relating specifically to the second study objective of evaluating the educational utility of the model (Appendix B). This length of survey was chosen as it has been suggested that online surveys should consist of approximately 20 questions (47). The survey was designed with the demographic items first. The first item required participants to identify if they were an orthopaedic surgery resident or a practicing orthopaedic surgeon; skip-logic was then utilized to direct participants to the stream of demographic questions specific to their population.
Participants who identified themselves as residents were then asked for their current year of orthopaedic residency training, and were also required to indicate their previous exposure to arthroscopy and arthroscopic training resources. These two items were included as they may have been helpful in explaining variations in responses due to previous exposure of the residents to arthroscopic techniques and training.

Participants who identified themselves as practicing orthopaedic surgeons were asked how long they had been teaching orthopaedic residents arthroscopic skills. This item was included as it may have been helpful in explaining variations in survey responses from faculty based on the duration of their experience with arthroscopic education.

The final demographic item required all participants to “check-off” which models they had utilized during the workshop; this item was included to allow for the removal of survey responses from participants who did not utilize both the flexible and fresh-frozen cadaver at the workshop.

Demographic questions were followed by 18 Likert-type questions that were grouped together based on the response scale appropriate to each item. A Likert-type question format was chosen, as they are the most frequently used procedure in attitude assessment, and have been developed and tested considerably (48). Participants are likely familiar with this type of question format, which could have contributed to a decrease in response error. Two different scales were chosen based on the desired response format and precision of the scale to measure the desired attribute. The first 13 questions were assigned to an extent response scale (Figure 3.1) and the final five were assigned to a likelihood response scale (Figure 3.2). Questions were assigned to response scales based on the items content and the specificity of the scale to measure the items desired attribute.
Response scales were organized in a logical order with the most positive response first and progressively less positive responses sequentially below (Figure 3.1, Figure 3.2). Numeric values associated with each response scale used the highest numerical value (5) to correspond to the most positive anchors (A Great Deal/ Very Likely). The response scales were organized in this manner because respondents had likely been previously exposed to Likert-type questionnaires and would have expected the “positive” scale anchors to come first in the list of scale anchors and that higher numbers had more positive meanings. It was also suggested that deviating from this could lead to participant confusion and response error (49).
The survey concluded with an open-ended question asking for their opinion of the educational utility of the flexible cadaver model within the Orthopaedic Residency Training Program at Queen’s University. The question included suggested subject areas for commenting to facilitate responses on desired topics.

3.3.4 Pre-notification

At the end of the arthroscopic training day the researcher informed participants that they would receive an email invitation from the researcher asking them to participate in a survey about the educational utility of the models they had the opportunity to utilize at workshop. Pre-notification served to request participant cooperation, alerted potential participants of the future study and introduced and personalized the researcher (50). Pre-notification can also help to establish the legitimacy and importance of the study (51).

3.3.5 Inviting Potential Participants

Electronic invitations were chosen as the mode to contact potential participants due to the popularity of this type of communication and the ability to provide participants with easy access to the survey via a hyperlink within the electronic invitation to participate (Appendix C). Electronic invitations were emailed to workshop participants the day following the workshop by the researcher. Email addresses were obtained from workshop participation waivers (Appendix A). The course instructor was not chosen to disseminate the electronic invitations because, although the survey was anonymous, it was possible that some participants may have felt pressure to participate in the survey due to the perception that their future academic evaluation may be effected.
Electronic invitations were sent on the day following the workshop to provide participants the opportunity to rest before being asked for feedback after the workshop; this was done to minimize individuals rushing through the survey at the end of the training day. A follow-up electronic invitation (Appendix D) was sent to participants of the workshop two days after the initial electronic invitation as response rates to e-mail surveys have been shown to increase by 25% when a reminder message is sent (52), and a reminder sent two days after the initial invitation has been shown to have a more positive effect on response rates (53). A final follow-up email was sent one week following the initial electronic invitation (Appendix E). The date and time which the survey would remain open for participation was indicated in both follow-up electronic invitations to decrease the likelihood of potential participants delaying immediate participation due to the belief that the survey could be completed at a much later date. It was believed that this would create a sense of urgency and hopefully increase participation.

Electronic invitations included a description of the study, its purpose, risks, benefits, details regarding withdrawal from the study and details of confidentiality, as well as a hyperlink to the online survey. This information was detailed to provide potential participants the opportunity to make an informed decision to participate. Participants were informed that by clicking the hyperlink provided in the invitation email and beginning the online survey they were giving consent to participate in the study.

3.3.6 Response Collection

All responses were collected and stored on SurveyMonkey® in the researchers password protected account. Once the survey closed all responses were downloaded into Microsoft Excel Spread sheets to allow for easy access and to create customized charts and diagrams.
3.3.7 Statistical Analysis

After administration of the survey, two methods of “item analysis” were utilized to evaluate the ability of each individual item to measure the desired attribute of the response scale assigned to the entire group of items for each of the two scales. This was performed to allow for the removal of items that were not consistent with the desired attribute of each response scale; though none of the survey items required removed this ensured that each scale was unidimensional (54). Two tools were utilized: item-total correlation, which acted to identify scale items that were not consistent with others, and the alpha coefficient, which served to evaluate each scale's overall degree of internal consistency (48). An item-total correlation value less than 0.3 indicated that the corresponding item did not correlate well with the individual items and the response scale (55, 56). Nunnally (57) suggested that a scale requires a minimum 0.70 alpha coefficient to be acceptable; a lower alpha value indicates that the items in the scale have little in common, or that there are too few items. Items with a low item-total correlation were eliminated if their removal also produced an increase in the alpha coefficient; this was done to increase the unidimensionality of the scale items used.

Non-parametric Spearman correlations were also calculated to assess the association between the questionnaire totals, and independent samples t-tests (confirmed with the non-parametric Mann-Whitney U) were used to compare the totals for the flexible and fresh-frozen cadaver groups. Comparisons were made to identify if any response trends were evident in the overall response value given to each model. Higher overall response values were considered to have a stronger attributed value than those scoring lower.
Chapter 4

Materials and Methods

4.1 Objective I – Model Development

4.1.1 Materials

4.1.1.1 Human Body

A body from the Queen’s University Human Body Donor program was embalmed over a three-day period using a phenol-based soft embalming solution. All steps of the embalming procedure were conducted in the morgue located in Botterell Hall at Queen’s University.

4.1.1.2 Embalming Solution

The body was embalmed over a three-day period using a phenol-based soft embalming solution (Table 4.1). The four chemical components of the soft embalming fluid were combined together in a 25 L plastic carboy. All components of the phenol-based embalming solution were obtained from VWR International (Pennsylvania, USA).

<table>
<thead>
<tr>
<th>Volume</th>
<th>Component</th>
<th>Percent of Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8L</td>
<td>Phenol (liquid)</td>
<td>8.26%</td>
</tr>
<tr>
<td>8.0L</td>
<td>95% Ethanol</td>
<td>36.70%</td>
</tr>
<tr>
<td>4.0L</td>
<td>Glycerine</td>
<td>18.35%</td>
</tr>
<tr>
<td>8.0L</td>
<td>Water</td>
<td>36.70%</td>
</tr>
</tbody>
</table>

Table 4.1 Phenol Based Embalming Solution
4.1.1.3 Additional Model Materials

4.1.1.3.1 Mount for the Model

The femur of the flexible cadaver model was secured to a Sawbones® short stem bone clamp, item # 1605-2 (Figure 4.), which was then attached to a Sawbones® short tower assembly, item # 1653 (Figure 4.) and placed onto a Sawbones® extremity holder, item # 1650 (Figure 4.).
4.1.1.3.2 **Arthroscopic Equipment**

A ConMed Linvatec true HD 1080p camera system (Figure 4.) was utilized including a 32” HD LCD flat panel display, True HD 1080p Camera Controller (IM4000), True HD 1080p Camera Head (IM4120) (Figure 4.), 300 Watt Xenon HD Light Source (LS7700), AdvantageTM Shaver/Power Console (D3000), Inflow/Outflow/Suction Fluid Management Pump (24K) and a Ergonomic HD Video Cart (VP8500 series). A ConMed Linvatec HD4300 scope was attached to the True HD 1080p Camera Head (IM4120); this scope was 4mm in diameter and the lens was at a 30° angle. The inflow/outflow/suction fluid management pump was connected to a 110 volt
Sawbones® Suction System, item # 1416, which includes a vacuum pump, item #100186, a three
gallon carboy and all necessary tubing (Figure 4.).

Figure 4.3 ConMed Linvatec Camera System. (CONMED Corporation, Florida, USA)
Figure 4.4 Linvatec True HD 1080p Camera Head (IM4120). (CONMED Corporation, Florida, USA)

Figure 4.5 The Sawbones® 110 volt Suction System including a vacuum pump and the necessary tubing. (Pacific Research Laboratories, Washington, USA)
4.1.2 Methods

4.1.2.1 Embalming Protocol

Once the body was appropriately prepared (disinfected, washed, shaved, etc.) an incision was made using a Rüttgers 3 scalpel with a No. 11 Paragon surgical blade in the right femoral triangle in order to expose the femoral sheath. Once exposed, the femoral artery was isolated and raised above the skin and a 10 mm longitudinal incision was made in the artery wall using the same scalpel and blade. A probe was then inserted into the femoral artery and was then replaced with a straight threaded arterial tube with a stopcock between it and the injection device, a Porti-Boy Mark IV, containing the embalming solution. This embalming technique is considered a closed system because no veins were exposed and cut to allow for drainage. On day one, one liter of the solution was pumped into the right leg and five liters were pumped into the rest of the body. On day two, six liters were pumped into the body and digital injections were made into all 20 digits using a syringe and hypodermic needle. Percutaneous injections were made to areas of the body that appeared to have not received sufficient embalming solution. On day three, six liters were pumped into the body. The volume of fluid and pressure used were dependent on the donor’s composition. Once complete the cannulae were removed, the femoral artery was ligated, and the incision was closed.

4.1.2.2 Model Storage

When embalming was not being performed, and after it was completed, the flexible cadaver was kept in a plastic bag in the morgue refrigerator at Botterell Hall Queen's University, which maintains a temperature between 4-6 °C. The flexible cadaver was then transferred to the School of Medicine morgue refrigerator, which maintained the same temperature range. The
hands, feet and head of the donor were wrapped in a cotton material soaked in moistening solution containing Dettol®, glycerol and sodium acetate. The model was left to rest for a month to allow sufficient time for the embalming solution to diffuse throughout the donor’s tissue.

4.1.2.3 Model Preparation

Although an entire body was embalmed, the evaluation of the model focused on the development of basic arthroscopic skills on the knee joint. The left femur of the flexible cadaver was cut transversely at the junction of the proximal 2/3 of its longitudinal length and the distal 1/3 using a hand saw. Two inches of soft tissue surrounding the remaining distal 1/3 of the femur was then dissected exposing the femur. The tibia and fibula were also cut transversely at approximately mid-shaft length to remove the distal tibia, fibula and foot (Figure 4.). Once removed from the flexible cadaver, the flexible cadaver knee joint was placed into a plastic bag and placed in the morgue refrigerator.

Figure 4.6 Anterior view of the flexible cadaver knee (left) model.
On the day of the workshop the knee model was removed from the refrigerator and secured with a Sawbones® short stem bone clamp which placed the knee in 90° flexion on a arthroscopic training station (Figure 4.).

![Image of knee model secured with bone clamp](image)

**Figure 4.7 Photograph of the flexible cadaver model secured the Sawbones® short stem bone clamp and extremity holder.**

Once secure, the primary course instructor, an assistant Professor in the Department of Surgery, Queen's University created two portals for placement of the arthroscopic camera and probe. An anterolateral portal located 1cm superior to the joint line, the palpable space between the femoral and tibia condyles, and 1cm lateral to the lateral border of the patellar tendon was used for the arthroscopic camera (Figure 4.). An anteromedial portal located 1cm above the joint...
line and within 1cm medial to the medial border of the patellar tendon was used for the placement of the arthroscopic probes (Figure 4.).

![Figure 4.8 Schematic diagram showing anteromedial and anterolateral portal placement for knee arthroscopy (adapted from(20)).](image)

**Figure 4.8** Schematic diagram showing anteromedial and anterolateral portal placement for knee arthroscopy (adapted from(20)).

4.2 **Objective II – Model Evaluation**

4.2.1 **Materials**

4.2.1.1 **Participants**

Participants were recruited from attendees of an arthroscopic training workshop organized by the Orthopaedic Residency Training Program at Queen’s University, sponsored by the Division of Clinical and Functional Anatomy, University of Ottawa, and hosted at the Queen’s University School of Medicine on October 1st, 2011. Workshop attendees included
residents from the Orthopaedic Residency Training Program at Queen’s University and the University of Ottawa Orthopaedic Surgery Residency Program, and some faculty members from the Orthopaedic Residency Training Program at Queen’s University. Potential participants were sent an email invitation to participate (Appendix C).

4.2.1.2 Fresh-frozen Cadaver Model

One fresh-frozen cadaver was obtained from the Queen’s University Human Body Donor program. The fresh-frozen model was prepared in the same manner as the flexible cadaver model (see 4.1.2.3). Once removed from the cadaver, the knee joint was placed into a plastic bag and returned to the freezer of the Queen’s School of Medicine at a temperature of approximately -20 °C. Forty-eight hours before the workshop the fresh-frozen cadaver knee was placed into the refrigerator at a temperature of 4-6 °C to allow for thawing of the tissues and to prevent excess tissue degradation.

![Figure 4.9 Anterior view of the fresh-frozen cadaver knee (left) model.](image)

On the day of the workshop the fresh-frozen knee model was set-up adjacent to the flexible cadaver knee model. It was removed from the refrigerator and secured to a Sawbones® short stem bone clamp which placed the knee in 90° flexion on a custom arthroscopic training station. Once secure, the primary course instructor created the two portals in the same location as those created in the flexible cadaver model for placement of the arthroscopic camera and probe (See 4.1.2.3).

4.2.1.3 Evaluation Mode

A survey was utilized to evaluate the educational utility of the flexible cadaver model in comparison to the fresh-frozen cadaver model (Appendix B). The survey was designed using SurveyMonkey®, an online survey software and questionnaire tool.

4.2.2 Methods

4.2.2.1 Model Exposure

The flexible cadaver model was included in the arthroscopic training workshop on October 1st, 2011. This workshop focused primarily on the development of skills required to perform arthroscopy of the shoulder but presented the opportunity to expose workshop attendee’s to the flexible cadaver knee model (Figure 4.), and a fresh-frozen cadaver knee (Figure 4.). The restricted dissection lab at Queen's University School of Medicine was utilized as the location for the arthroscopic training workshop, which is classified as having a level 2 biohazard rating. The room is equipped with localized room ventilation. Participants were required to sign workshop participation waivers before being exposed to the flexible cadaver model (Appendix A).
Participants were also required to take the personal protective measures including the use of nitrile gloves (Medical Mart 616MF101) and surgical gowns (Medical Mart 565-PM4-506).

Figure 4.10 Flexible cadaver knee model being utilized by a workshop attendee.
4.2.2.2 Inviting Participants

Electronic invitations were emailed to participants the day following (October 2nd, 2011) the arthroscopic skills training workshop that took place on October 1st, 2011 (Appendix C). Electronic invitations included an electronic invitation link (https://www.surveymonkey.com/s/-Flexiblecadavermodel) that by clicking, brought participants directly to the online survey. Email addresses were obtained from workshop participation waivers (Appendix A). The electronic invitations included a description of the study, its purpose, risks, benefits and details of confidentiality and a link to the online survey. Workshop attendee’s chose to participate in the survey by clicking the link provided in the invitation email and beginning the online survey.
Workshop attendee’s were also sent follow-up reminder invitations on October 4th and October 9th, 2011, two and seven days following the initial invitation to participate (Appendix D; Appendix E).

4.2.2.3 Survey Design

Question design began with the identification of a list of desired research goals; two to three questions capable of supporting each goal were then created. Two different response scales were then chosen; 13 questions were assigned to an extent response scale and five questions were assigned a likelihood response scale; questions with the same response scale were then grouped together. The survey consisted of a total of 26 items: 18 Likert-type questions, which asked participants to rate a variety of statements about the educational value of each model, and seven demographic items which preceded the Likert-type items. The first survey item required participants to indicate if they were an orthopaedic surgeon or orthopaedic surgery resident; skip-logic was employed to have residents and surgeons respond to differing demographic questions. Residents were then asked two demographic questions; the first asking for their current year of residency, and the second asking about previous exposure to arthroscopic training resources. Surgeons were then asked three demographic questions; the first asking if they were currently, or have been involved with resident education in arthroscopic skills, the second asking how many years they had been teaching orthopaedic residents arthroscopic skills and the third asking them to indicate the number of years practicing arthroscopic techniques. The last demographic question required all participants to indicate what model(s) they used during the workshop. The survey finished with an open-ended question asking participants for their opinion of the educational utility of the flexible cadaver model within the Orthopaedic Residency Training Program. In total
those who indicated themselves as residents completed a 23-item survey, and those who indicated themselves as a surgeon completed a 24-item survey.

The survey then went through an editing process to refine questions, response formats and the overall survey design. Questions were evaluated for inclusion value, content validity, grammar and appropriate phrasing; response formats were evaluated for appropriateness, precision and measurement validity. The Queen’s University Writing Centre reviewed the survey for language bias, clarity and grammatical error. The survey was also examined by a consultant from StudentVoice!, a service available through Student Affairs Research and Assessment which provides support, information and feedback on the design and delivery of electronic surveys.

The questions were then arranged into a formal survey through SurveyMonkey®, an online survey software and questionnaire tool.

4.2.2.4 Response Collection

Response collection was performed by SurveyMonkey® by utilizing a web-link which was accessed from invitations to participate. Response collection ended at midnight, Monday October 10th, 2011. Responses were stored on the SurveyMonkey® website in the researcher’s login. Through the password protected login responses could be viewed individually, as a subset or as the complete sample. Responses were collected and transferred to a laptop and input into Microsoft Excel spreadsheets.

4.2.2.5 Statistical Analysis

Initial data analysis was performed by SurveyMonkey® including response counts, rating averages, and response percentages. Responses transferred to the password protected laptop were
also utilized for further analysis and for the creation of figures and charts. All response ratings were transferred into Microsoft Excel Spread sheet. Data were then imported into IBM SPSS (version 19.0 for Windows) for statistical analyses, including mean scale response scores and standard deviation, inter-item and item-total correlations for both the flexible cadaver items (Appendix F; Appendix G) and for the fresh-frozen cadaver items (Appendix H; Appendix I). Reliability statistics (Cronbach’s alpha) were also calculated. In addition, non-parametric Spearman correlations (Appendix J) were calculated to assess the association between the questionnaire totals, and independent samples t-tests (confirmed with the non-parametric Mann-Whitney U) were used to compare the totals for the flexible and fresh-frozen cadaver groups (Appendix K).

4.2.2.5.1 Item-scale Correlation

To determine item-scale correlation, participants scores on individual items of the same response scale were compared to the average score of all items assigned to that scale for each model: this identified a coefficient of correlation, which measures the degree of relationship between two interval variables. A correlation value less than 0.3 was considered to be low and indicated that the corresponding items did not correlate well with the response scale (55, 56). An overall mean correlation value for each scale was also calculated to determine the alpha coefficient.

4.2.2.5.2 Cronbach’s Alpha

Cronbach's alpha formula was utilized to calculate the alpha coefficient, which is based on the correlation matrix among all the items and the number of items in the scale. A low alpha value, which was considered as a value below 0.70, indicated that the items in the scale have little
in common, or that there were not enough items to evaluate. Alpha increases as the number of 
elements in the scale increases, and as their mean correlation increases (48). Items with a low 
item-scale correlation value were eliminated if their removal also produced an increase in the 
alpha coefficient.
Chapter 5

Results

5.1 Introduction

Orthopaedic Residency Training Program at Queen's University organized an arthroscopic training workshop for orthopaedic residents; this presented the opportunity to introduce training orthopaedic surgeons, and practicing surgeons, to the flexible cadaver model. Fifteen workshop participants were contacted via electronic invitations, which successfully recruited 10 participants (66.7%).

5.2 Participants

Of the 10 participants, seven were orthopaedic surgery residents (70%) and three were practicing orthopaedic surgeons. One survey was incomplete and was not included in analysis; therefore, nine complete survey responses were analyzed (60%), seven orthopaedic surgery residents (82%), and two orthopaedic surgeons (18%). Orthopaedic residents consisted of five fourth-year residents (57.1%), and the remaining four were fifth-year residents (42.9%). All residents indicated having previously performed one or more arthroscopic procedures (Figure 5.1), and five residents (57.1%) indicated previous exposure to other arthroscopic training models including virtual reality simulation and Sawbones® knee models. Both arthroscopic surgeons were currently practicing and currently teaching, or had taught orthopaedic surgery residents arthroscopic skills. All nine participants indicated that they had used both the flexible cadaver knee model and the fresh-frozen cadaver knee model at the arthroscopic training workshop.
5.3 Response Analysis

5.3.1 Extent Response Scale Items

All participants responded to all of the 13 items assigned to the extent response scale; these corresponded to items eight through 20 of the survey. The mean response value for the flexible cadaver model was $4.65 \pm 0.40$ and $4.66 \pm 0.40$ for the fresh-frozen cadaver model (Appendix L). Eleven of the 13 items received identical ratings amongst each individual participant for both the flexible (4.67) and fresh-frozen cadaver models (4.67). The overall average rating for all participants on the 13 items of this response scale was also identical between the flexible and fresh-frozen cadaver models (Figure 5.1). Two items received different average ratings between the flexible and fresh-frozen cadaver models.
Participants rated the flexible cadaver model (4.67) as superior to the fresh-frozen cadaver (4.56) when asked if the model is a valuable training resource for developing basic arthroscopic skills (Figure 5.2).

![Bar chart showing comparison between flexible cadaver model and fresh-frozen cadaver training models.]

**Figure 5.2** Average response rating illustrating a difference in values given to the flexible cadaver training model, and fresh-frozen cadaver training model. Response Scale; 5 = A Great Deal, 4 = Considerably, 3 = Moderately, 2 = Slightly, 1 = Not At All.

Participants rated the fresh-frozen cadaver (4.44) superior to the flexible cadaver model (4.33) when asked if using the model increased their confidence in performing basic arthroscopic skills (Figure 5.3).
Interestingly, on another similar survey item participants rated the flexible (4.44) and fresh-frozen cadavers (4.44), as equivalent when asked if using the model would increase their confidence when performing arthroscopic procedures on patients.

5.3.2 Likelihood Response Scale Items

All participants responded to all of the five items assigned to the likelihood response scale, which corresponded to items 21 through 25 of the survey. Each item received different response ratings amongst each individual participant for both the flexible and fresh-frozen cadaver models. The mean response value for the flexible cadaver model was $4.89 \pm 0.33$ and $4.60 \pm 0.57$ for the fresh-frozen cadaver model (Appendix L). The average rating for all participants on the five items of this response scale were also different with the flexible cadaver...
Participants responded with a higher rating of the flexible cadaver model (4.89) than the fresh-frozen cadaver (4.56) when asked how likely they would be to utilize the model for further development of basic arthroscopic skills (Figure 5.4).

![Figure 5.4](image)

**Figure 5.4 Average response rating illustrating a difference in values given to the flexible cadaver training model, and fresh-frozen cadaver training model. Response Scale; 5 = Very Likely, 4 = Moderately Likely, 3 = Neither Likely Nor Unlikely, 2 = Moderately Unlikely, 1 = Very Unlikely.**

Participants also indicated that they would be more likely to supplement their current arthroscopic education by using the flexible cadaver model (4.89) than the fresh-frozen cadaver (4.67) (Figure 5.5).
Figure 5.5 Average response rating illustrating a difference in values given to the flexible cadaver training model, and fresh-frozen cadaver training model. Response Scale: 5 = Very Likely, 4 = Moderately Likely, 3 = Neither Likely Nor Unlikely, 2 = Moderately Unlikely, 1 = Very Unlikely.

The flexible cadaver model (4.89) received a higher likelihood rating than the fresh-frozen cadaver (4.56) when participants were asked if they would recommend the model to their peers to develop basic arthroscopic skills (Figure 5.6).
Figure 5.6 Average response rating illustrating a difference in values given to the flexible cadaver training model, and fresh-frozen cadaver training model. Response Scale; 5 = Very Likely, 4 = Moderately Likely, 3 = Neither Likely Nor Unlikely, 2 = Moderately Unlikely, 1 = Very Unlikely.

Participants also indicated that they would be more likely to utilize the flexible cadaver model (4.89) than the fresh-frozen cadaver (4.67) for self-directed learning outside of regular laboratory hours (Figure 5.7).
Figure 5.7 Average response rating illustrating a difference in values given to the flexible cadaver training model, and fresh-frozen cadaver training model. Response Scale; 5 = Very Likely, 4 = Moderately Likely, 3 = Neither Likely Nor Unlikely, 2 = Moderately Unlikely, 1 = Very Unlikely.

Participants also indicated that they were more likely to want to utilize the flexible cadaver model (4.89) again than the fresh-frozen cadaver model (4.56) (Figure 5.8).
Figure 5.8 Average response rating illustrating a difference in values given to the flexible cadaver training model, and fresh-frozen cadaver training model. Response Scale; 5 = Very Likely, 4 = Moderately Likely, 3 = Neither Likely Nor Unlikely, 2 = Moderately Unlikely, 1 = Very Unlikely.

5.3.3 Open-ended Question

Eight of the nine participants chose to respond to the open-ended item, which asked for their opinion of the utility of the flexible cadaver model within the Orthopaedic Residency Training Program. All respondents expressed positive opinions about the utility of the flexible cadaver model and many expressed excitement at the potential of having access to the flexible cadaver model describing it as “fantastic”, “highly useful” and “excellent!”. One respondent stated that they believed the flexible cadaver model “would be beneficial prior to starting rotations involving arthroscopy”.

Four respondents commented on the realism of the model, including comments relating its realism to fresh-frozen cadavers. One respondent stated the flexible cadaver model was “very similar to live tissues, and no better way to simulate a live joint”. The three other comments
stated that the flexible cadaver model was “essentially equivalent to the fresh-frozen model” and “an exceptional model with no downside compared to the gold standard (fresh-frozen)” and that there existed a “significant upside when you consider long term-costs, availability, longevity, and potential decreased biohazard level”.

Two respondents commented on potential greater implications to the utilization of the model including “this would be useful not only for arthroscopy but also for the study of anatomy and surgical approaches” and that it “may represent more economic means of facilitating arthroscopic and other surgical training”.

5.4 Statistical Analysis

5.4.1 Item-scale Correlations & Cronbach’s Alpha

5.4.1.1 Flexible Cadaver Model

5.4.1.1.1 Extent Response Scale; Items 1-13

Correlations between items and the item-total average were calculated and although some items had an item-total scale value less than 0.3 (Appendix F), indicating that they did not correspond well with other items. Cronbach’s alpha was 0.909, indicating a very high degree of internal consistency of the scale. Removal of items with a low item-total score did not result in an increase in Cronbach’s alpha and therefore no scale items were removed.

5.4.1.1.2 Likelihood Response Scale; Items 14-18

Correlations between items and the item-total average were calculated and receive prefect correlation (Appendix G). Cronbach’s alpha was 1.00 indicating perfect internal consistency of the scale.
5.4.1.2 Fresh-frozen Cadaver Model

5.4.1.2.1 Extent Response Scale; Items 1-13

Correlations between items and the item-total average were calculated and although some items had an item-total scale value less than 0.3 (Appendix H), indicating that they did not correspond well with other items. Cronbach’s alpha was 0.908, indicating a very high degree of internal consistency of the scale. Removal of items with a low item-total score did not result in an increase in Cronbach’s alpha and therefore no scale items were removed.

5.4.1.2.2 Likelihood Response Scale; Items 14-18

Correlations between items and the item-total average were calculated and receive very high inter-item correlation values (Appendix I). Cronbach’s alpha was 0.956 indicating a very high degree of internal consistency of the scale.

5.4.2 Non-parametric Spearman Correlations

Analysis of correlation of overall responses between the flexible and fresh-frozen cadaver models illustrated a correlation coefficient of 0.966 (p<0.001) for the extent response items. The correlation coefficient between the overall responses for the flexible and fresh-frozen cadavers for the likelihood items was 0.450 (p=0.224) (Appendix J).

5.4.3 Student’s t-test

Independent samples tests between mean response score of the flexible and fresh-frozen cadaver models for items of the extent response scale were almost identical (p=0.965); those for
items of the likelihood response scale did illustrate response differences (p=0.210), although not statistically significant (Appendix K). Due to the small sample size, the non-parametric Mann-Whitney U was used to confirm the results of the t-test. Both remained non-significant, although the difference between the items on the likelihood response scale did strengthen to p=0.146, which, within this small sample size, could be considered a trend (Appendix K).

5.5 Anecdotal Results

5.5.1 Visual Inspection

5.5.1.1 External Appearance

One visual inspection of the external appearance of the flexible cadaver knee and the fresh-frozen cadaver knee (Figure 5.9) by workshop attendees it was noted that the flexible cadaver model had a greyer appearance than the fresh-frozen cadaver knee, which appeared pinker. Workshop attendee’s were able to identify the flexible cadaver model due to this colour difference but only after the colour difference was brought to their attention.
5.5.1.2 *Intra-articular Appearance*

On arthroscopic inspection of the intra-articular anatomy of the flexible cadaver model by the primary course instructor it was indicated that its appearance accurately represented the anatomy seen within the fresh-frozen cadaver and that of a live patient. It was noted that the intra-articular anatomy of the flexible cadaver model had a whiter appearance (Figure 5.10)
relative to that of the pink coloured intra-articular tissue of the fresh-frozen cadaver model (Figure 5.11), similar to the differences seen in external appearance.

Figure 5.10 Photograph of the arthroscopic view of an arthroscopic probe illustrating the anterior cruciate ligament and the surrounding intra-articular anatomy of the flexible cadaver model. Note the white appearance of the tissues relative to Figure 5.11.
Figure 5.11 Photograph of the arthroscopic view of an arthroscopic probe examining the anterior cruciate ligament and the surrounding intra-articular anatomy of the fresh-frozen model. Note the pink appearance of the tissues relative to Figure 5.10.

Workshop attendee’s indicated that they were unable to distinguish between the two models when examining the intra-articular appearance of the joints with arthroscopy. Workshop participants did however agree with the identification of differences in colour once brought to their attention. This variation in colour was identified as being the only characteristic allowing for the differentiation of the intra-articular anatomy of the two models.

5.5.2 Tactile Inspection

5.5.2.1 External Palpation

Workshop participants indicated that the flexible cadaver model and fresh-frozen cadaver felt extremely similar with palpation on the muscles and surrounding connective tissue of the leg. No palpable differences could be identified.
5.5.2.2 Intra-articular Probing

Upon examination by the primary course instructor and workshop attendee’s no differences could be identified with the probing of the intra-articular tissues of the flexible cadaver model (Figure 5.12) and the fresh-frozen cadaver model (Figure 5.13). The primary course instructor also indicated that the “feel” of the cartilage, menisci and intra-capsular ligaments of the flexible cadaver was equivalent to that of the fresh-frozen cadaver and consistent with that of a live patient.

Figure 5.12 Photograph of the arthroscopic view of arthroscopic probing of the medial meniscus and articular cartilage of the medial tibial plateau of the flexible cadaver model.
Figure 5.13 Photograph of the arthroscopic view of arthroscopic probing of the articular cartilage of the fresh-frozen cadaver model. (Note the presence of arthritic changes seen in articular cartilage on the tibial plateau of this model; unsmooth, frayed surface).
Chapter 6

Discussion

6.1 **Introduction**

This research project had two main goals; the first to develop a flexible cadaver model for training orthopaedic surgery residents in basic arthroscopic skills, and the second to evaluate the opinion of orthopaedic residents and faculty regarding the educational utility of this model in comparison to the fresh-frozen cadaver model. The results of this study are suggestive that orthopaedic surgery residents and faculty believe that flexible cadaver model is equivalent to the fresh-frozen cadaver model and that the flexible cadaver model is a promising resource for the development of arthroscopic skills.

6.2 **Anecdotal Support**

At the time of conception of this research project two Canadian institutions, McMaster University and University of Toronto, were utilizing soft-embalmed cadavers for surgical training including anesthesiology, neurosurgery and orthopedic workshops. Anecdotal opinions from technicians and prosectors at McMaster University generated interest in evaluating the utility of soft-embalmed cadavers within the Orthopaedic Residency Training Program at Queen’s University. Further discussion with the Laboratory Supervisor of the Department of Biomedical and Molecular Sciences at Queen's University created further interest in exploring the use of soft-embalmed cadavers within surgical skills training within the Queen’s University Medical curriculum evident. Soft-embalmed cadavers have the potential of providing realistic, anatomically correct training models for surgical skills training, while potentially decreasing
health risks associated with the conventional fresh-frozen models used (Mr. R. Hunt, Queen's University, Personal Communication).

Faculty from the Graduate Program in Anatomy and Cell Biology within the Department of Biomedical and Molecular Sciences expressed significant interest in the development of the flexible cadaver model. Faculty identified some limitations of models currently used within the Orthopaedic Residency Training Program, specifically focusing on the fresh-frozen cadaver model, which is considered to be the gold standard for high fidelity simulation. Fresh-frozen cadavers require specialized storage facilities, advanced notice and preparation for utilization, and it is often difficult to acquire the necessary number of joints at one time due to limitations in availability. Flexible cadaver models have been claimed to last for up to two years with cold storage, which could help alleviate issues with availability as well as the potential of providing a longer-term training model for multiple surgical training applications (Dr. S. Pang, Queen's University, Personal Communication).

Faculty within the Orthopaedic Residency Training Program at Queen’s exhibited a significant degree of interest and excitement with regards to having the flexible cadaver model available for surgical skills training, such as arthroscopic skills training workshops. The realism, as well as the mobility of the soft-embalmed tissues, provides an opportunity for resident training utilizing a high-fidelity model (Dr. D. Bardana, Queen's University, Personal Communication). Interest was also expressed by the co-director of the Health Sciences Patient Simulation Lab at Queen’s University, with regards to utilizing an entire soft-embalmed cadaver for use by multiple surgical disciplines such as cardiology, endoscopy, colonoscopy, anesthesiology and orthopaedics. It was also suggested that examining the face validity of the model would be a logical first step in assessing the potential training effectiveness and utility of soft-embalmed
cadavers. Evaluation of the opinion of orthopaedic residents and faculty would provide insight into the perception of the model by future participants of surgical skills training programs utilizing flexible cadaver models (Dr. R. McGraw, Queen's University, Personal Communication).

6.3 Objective I - Model Development

The flexible cadaver model was created to function as a training resource for orthopaedic residents to develop basic arthroscopic skills. Minimally invasive surgical skills, including those required for arthroscopy, exhibit a significantly steeper learning curve requiring the development of skills considerably different than those required for open surgical techniques (22), which require considerably more time and experience for successful acquisition (21). Traditionally, orthopaedic residents received a significant amount of their surgical skills training through the apprenticeship model where they are progressively exposed to operative experience under the guidance of expert surgeons (2, 8). With the advancement of modern medicine many variables including the increasing difficulty of surgical procedures, high stress operating environments, public demands for better surgical outcomes and decreased waiting times, as well as significant pressure on academic hospitals to operate as economically efficient as possible are challenging the viability of this educational model (1).

Surgical models have become an increasingly important component of a surgical trainee’s curriculum as a supplement to the traditional surgical education received in the operating room (5). These vary from low-fidelity bench top models, to virtual reality (VR) simulators and high-fidelity models such as animal and cadaveric specimens. Bench-top models provide a cost effective, portable, potentially reusable training model that residents can utilize unsupervised (3); however, significant concerns regarding their fidelity have been raised with
residents expressing skepticism of their educational utility (28, 29). Practicing surgeons have also rated them as a poor mode of preparation for surgical practice and as the least significant resource in contributing to their ability to perform arthroscopic procedures (31). VR simulators, still in the infancy of their development and utilization within surgical skills training, have been shown to have task validity (33) and many advocate their use within surgical skills training (9); however their significant cost and inability to provide accurate feedback from the virtual intra-articular environment (8) represent two of their major disadvantages. Animal models present an extremely high-fidelity training model with respect to simulating a live patient, thought they have significant disadvantages including ethical concerns, cost, availability and do not always accurately represent human anatomy (3).

Cadaveric models represent the highest fidelity model currently available and many experienced orthopaedic surgeons advocate their use and argue that they are one of the most important tools in the development of their arthroscopic skills (32). Cadaveric specimens do however present multiple limitations including inability to be reused (5), additional space requirements, supply, disease transmission, cost, and legal issues as well as a lack of standardization for their use (3, 13). Evidence supporting their use for surgical skills training as a resource which is transferable to clinical practice is also still lacking (9).

The flexible cadaver model was designed to providing efficient training outside the operating room to overcome many of the challenges that face current educational models, in addition to increasing the efficiency of the training received within the operating room. The flexible cadaver model is an extremely high-fidelity model which workshop participants were unable to distinguish from the fresh-frozen cadaver model before being made aware of the fact that the flexible cadaver model was paler in internal and external appearance. Participants were
however, not asked questions regarding the differences between the two models in physical appearance; this represents an area for future discovery. The open-ended question did however allow for participants to comment on the fidelity of the model: “very similar to live tissues, and no better way to simulate a live joint”, “essentially equivalent to the fresh-frozen model” and “an exceptional model with no downside compared to the gold standard (fresh-frozen)”. Fresh-frozen cadaver models have frequently been considered the gold standard for surgical skills training outside of the operating room due to their exact representation of human anatomy (32); however concerns regarding the utilization of unfixed tissue, short-term utility before tissue degradation begins, the need for pre-notification before usage to allow for tissue thawing and cost are substantial limitations. The flexible cadaver model represents an equally realistic model that, with evidence from bacteriologic tests, could provide an effective educational model with a reduced risk of disease transmission. One participant stated that the flexible cadaver model presents a “significant upside when you consider long term-costs, availability, longevity, and potential decreased biohazard level”. Evidence that there is no biological activity within the flexible cadaver model would also change their biohazard rating, allowing for additional opportunity for skill development as residents could use flexible cadaver models in skills training laboratories without direct supervision (Mr. R.Hunt, Queen's University, Personal Communication).

This could help to accommodate for differences in psychomotor skills as ability varies from individual to individual (58), and surgical training programs need to provide varying amounts of psychomotor practice based on individual ability (15). This could also present the opportunity for resident training to occur more often, limiting the need to participate in demanding skills training workshops, which due to their length, limit the participants ability to
learn effectively. Wanzel et al. (14) have shown that more than 4 hours of practice per day leads to fatigue, which results in a decrease in the quality of the students’ performance. Therefore it is crucial that residents have the opportunity to develop their arthroscopic skills using these high-fidelity models over multiple training periods.

Limitations in the availability of joints for arthroscopic training workshops could also be overcome with the use of flexible cadaver models. Anecdotally, flexible cadaver models have been shown to last for up to two years in cold storage, which could help alleviate issues with availability as well as the potential for providing a more long-term high-fidelity training model. Donors could be embalmed with the flexible cadaver solution and placed in cold storage, making them readily available for immediate usage for surgical skills training workshops.

The flexible cadaver model could also present a more economical means of providing high-fidelity training by providing a useful resource for the development of multiple surgical skills though this requires further investigation. The ultimate goal of the flexible cadaver model is to keep the body intact to allow for surgical skills training from multiple surgical disciplines such as endoscopy, cardiac catheterization, arthroscopic training, and colonoscopy. McMaster University and the University of Toronto are currently utilizing soft-embalmed cadavers for surgical training including anesthesiology, neurosurgery and orthopedic workshops. The flexible cadaver model could fulfill the needs of multiple specialized skills training workshops, and be utilized afterwards for focused dissection courses for postgraduate surgical anatomy. Barton et al. (38) examined the benefits of dissection of soft-preserved cadavers for gynecological oncologists and stated that the quality of tissue for dissection with soft-preserved cadavers is far superior to that of the traditionally utilized formalin-fixed cadavers.
Anecdotally, workshop participants indicated that upon probing of the intra-articular tissues of the flexible cadaver model that no differences could be identified. The primary course instructor also indicated that the “feel” of the cartilage, menisci and intra-capsular ligaments of the flexible cadaver was equivalent to that of the fresh-frozen cadaver and consistent with that of a live patient. The degree of tactile similarity between the flexible cadaver model and that of a live patient does require further investigation. These anecdotal results do however suggest that the flexible cadaver model is capable of providing natural feedback through the arthroscopic instrumentation, a significant limitations that exist with the utilization of bench-top models as well as VR simulation.

Tuijthof et al. (30) stated that skills training without receiving natural feedback could lead to an offset in the individual’s motor programs, which could lead to increases in errors in the operating room. The use of cadaveric models has received some resistance but many experienced surgeons advocate their use and argue that they were one of the most important tools in the development of their arthroscopic skills (32). The flexible cadaver model provides natural, high-fidelity feedback that will allows training orthopaedic residents to develop psychomotor skills with a more accurate representation of in vivo surgical conditions. Although the operating room is a fundamental component to the development of arthroscopic skills, the incorporation of the flexible cadaver model into a surgical skills laboratory would allow residents the opportunity to develop skills outside of the operating room, in a controlled and potentially less stressful environment. Cadaver based skills training within the laboratory allows for training to occur in a relatively flexible environment where time and psychological pressures are minimized and the risk of damaging a patients intra-articular anatomy is non-existent (9). One participant indicated that the flexible cadaver model “would be beneficial prior to starting rotations involving
arthroscopy” suggesting that the flexible cadaver model could be a viable training resource for the training of arthroscopic skills outside of the operating room. Two participants indicated that the model “would be useful not only for arthroscopy but also for the study of anatomy and surgical approaches” and that it “may represent more economic means of facilitating arthroscopic and other surgical training”. This would theoretically, lead to community benefits by reducing operating time and waiting lists, as residents would no longer need to learn new skills in the operating room (9).

The principal limitation expressed regarding the utility of the flexible cadaver model is the degree of phenol exposure as levels experienced during the use and dissection of the flexible cadaver model have yet to be established; however, within our facilities, this could be overcome with the use of downdraft tables.

6.4 Objective II - Model Evaluation

The successful creation of the flexible cadaver model allowed for the accomplishment of the second research goal: the evaluation of its educational utility for the development of basic arthroscopic skills by orthopaedic residents and faculty.

Wong and Matsumoto (5) argued that the effectiveness of a surgical skills training model is greatly limited if the intended users do not accept it. Evaluation of the opinion of orthopaedic residents and faculty provided insight into the perception of the model by future participants of surgical skills training programs utilizing flexible cadaver models. Respondents mean response value for extent response scale items for the flexible cadaver model was 4.65 ± 0.40 and 4.66 ± 0.40 for the fresh-frozen cadaver model (Appendix L) with a correlation coefficient of 0.966 which supports our hypothesis that participants would rate the flexible cadaver model as
equivalent to the fresh-frozen cadaver model. Interestingly, the overall average rating for all participants on the 13 items of this response scale were identical between the flexible and fresh-frozen cadaver models, further supporting our hypothesis. These findings were not surprising considering workshop participants were initially unable to differentiate visually or tactiley between the flexible and fresh-frozen models. One participant also indicated that the flexible cadaver model was “essentially equivalent to the fresh-frozen model”.

Respondents mean response value for likelihood response scale items for the flexible cadaver model was 4.89 ± 0.33 and 4.60 ± 0.57 for the fresh-frozen cadaver model (Appendix L), which does not support our hypothesis as participants rated the flexible cadaver model as superior to the fresh-frozen cadaver model, though not statistically significant (p=0.210). Participants indicated that they were more likely to: want to utilize the flexible cadaver model again; utilize the flexible cadaver model for self-directed learning outside of regular laboratory hours; recommend the model to their peers to develop basic arthroscopic skills; supplement their current arthroscopic education by using the flexible cadaver model; and utilize the model for further development of basic arthroscopic skills.

Although these anecdotal results do not guarantee the effectiveness of the model as an educational tool, they do provide initial feedback on the perception of the utility of the model by individuals familiar with real-live patients and how it compares to the current gold standard of training utilizing fresh-frozen cadaver models.

6.5 Study Limitations

The small sample size of this study is a significant limitation of the study as it may not likely be a good representative of the opinion of all orthopaedic surgery residents and faculty.
Participants were also not blinded to the type of model that they were using and it is possible that having the opportunity to learn in a novel environment might have influenced positive responses for the flexible cadaver model. Another significant limitation of this study is the fact that the fresh-frozen model has yet to be established as an effective means of skills transfer to the operating room. We chose to measure the educational value of the flexible cadaver model in relation to a model that is still lacking evidence to support its own educational merits.
Chapter 7

Conclusions

Overall two important conclusions can be drawn from this research study:

I) The flexible cadaver model is at least equivalent in educational utility when compared to the fresh-frozen cadaver model for the development of arthroscopic skills.

II) The flexible cadaver model is a promising resource for the development of arthroscopic skills.
Chapter 8

Future Directions

8.1 Introduction

Replicating the results of this study is important for the verification and support of our findings. It would be beneficial for a similar study to be recreated with a large sample size more representative of the opinion of all orthopaedic surgery residents and surgeons. A longitudinal study evaluating the opinion of participants at multiple training workshops may help minimize the potential for the flexible cadaver model receiving positive responses due to participants having the opportunity to learn with a novel training resource.

8.2 Conclusion I - The flexible cadaver model is at least equivalent in educational utility when compared to the fresh-frozen cadaver model for the development of arthroscopic skills.

Comparing scores on survey items for each model provided evidence for the hypothesis that the flexible cadaver model was equivalent to the fresh-frozen cadaver model in educational utility for the development of arthroscopic skills. The ultimate determinate of whether an educational strategy is useful for surgical skill training, however, is dependent on whether the skills learned are transferrable to the operating room. Evidence supporting skill transfer from the use of fresh-frozen cadavers for surgical skills training is still deficient (9). It is therefore difficult to infer the educational benefits of the flexible cadaver model for the development of surgical skills by comparison to the fresh-frozen cadaver model as their educational utility has yet to be established. The ability of the flexible and fresh-frozen cadaver models to develop surgical skills
by measuring variability in surgical tasks needs to be evaluated. This could be achieved by having a base-line evaluation of residents skill at performing an arthroscopic task and then having them complete practical skills training using one of the models. Comparisons of baseline results to post-training results could illustrate if skills transfer occurs. The base-line evaluations and final measurements could be performed using a procedure-based assessment and a five-point global rating assessment scale (59). This would allow for the assessment of the training effectiveness of the flexible cadaver model. This would also correspond to the second level Kirkpatrick’s four-level model and help identify the construct validity of the model (44).

Workshop participants were unable to differentiate between the flexible and fresh-frozen cadaver models before being made aware of the fact that the flexible cadaver model was paler in internal and external appearance. As indicated in the discussion, participants were however, not required to answer questions regarding the differences between the two models in physical appearance. Variations in the flexible cadaver embalming solution, such as the inclusion of a red pigmentation, may be able to overcome for the variations in colour of the external and internal tissues. Future research is required to evaluate the subjective differences between the two models in both internal and external appearance. This could be accomplished by holding an arthroscopic skills training workshop where participants are blinded to the identity of the flexible and fresh-frozen models. Participants could then complete a questionnaire consisting of items designed to evaluate differences in internal and external appearance of the two models, and realism of each of model. This would allow for the identification of differences in physical appearance that could exist between the flexible and fresh-frozen models. Comparisons are also warranted between the internal and external appearance of live patients tissue and that of both the flexible and fresh-frozen cadaver models.
Similarly, workshop participants and the primary course instructor indicated that they were unable to differentiate between the flexible and fresh-frozen cadaver models upon probing of intra-articular tissues. The primary course instructor also indicated that the “feel” of the cartilage, menisci and intra-capsular ligaments of the flexible cadaver was consistent with that of a live patient. The evaluation of the degree of tactile similarity between the flexible cadaver model and that of a live patient and the fresh-frozen cadaver model are required. The anecdotal results of our study suggest that the flexible cadaver model is capable of providing high-fidelity tactile feedback that will allow training orthopaedic residents to develop psychomotor skills with a more accurate representation of in vivo surgical conditions. Research that illustrates the degree of similarity between the flexible cadaver model and live patient would further strengthen the indication of its use for high-fidelity surgical skills training. This would likely be more effectively measured by practicing orthopaedic surgeons who have had significantly greater exposure to in vivo tactile characteristics. Surgeons could be blinded to the identity of both a live patient and a flexible cadaver model and then asked to rate their tactile characteristics. This is extremely important as skills training without receiving natural feedback could lead to an offset in the individual’s motor programs, which could lead to increases in errors in the operating room (30).

8.3 Conclusion II - The flexible cadaver model is a promising resource for the development of arthroscopic skills.

Although our study results are suggestive that the flexible cadaver model is a promising resource for the development of arthroscopic skills there are many areas that need to be investigated further. First the primary limitation expressed with regards to the use of the flexible
cadaver model is the degree of phenol exposure as levels experienced with the use and dissection of the flexible cadaver model have yet to be established. Within the facilities that this study was performed there was the capacity to utilize downdraft tables; however, many institutions do not have access to these facility capabilities. There have been preliminary discussions with Queen's University Environmental Health and Safety for air quality measurements to be taken during the utilization of the flexible cadaver model for surgical skills training, as well as anatomical dissection. Evidence that phenol exposure is minimal would allow for greater application and utility of the flexible cadaver model for surgical skills training (Mr. R.Hunt and Dr.S.Pang, Queen's University, Personal Communications) and focused surgical dissection.

The flexible cadaver embalming solution is considered to be a preservative technique that is capable of fixing human tissues (34) however, there is no evidence to support that there is a reduced risk for disease transmission. Although some components of the soft-embalming solution have germicidal, antimicrobial, anti-fungal and antibacterial properties there has been no evidence to support its ability to create a biologically inactive specimen. This evidence would allow for the bio hazardous classification of the flexible cadaver model to be changed, which could result in increased accessibility. This would also limit concerns regarding disease transmission, creating a clear advantage for the use of the flexible cadaver model over the fresh-frozen cadaver model.

Although flexible preserved cadavers have been anecdotally claimed to last for a two-year period with refrigeration, there is no evidence to support these claims. The long-term viability of the flexible cadaver model needs to be established as they could provide a longer lasting high-fidelity training resource than the short-term utility of fresh-frozen cadaver models. Research could examine how long a flexible preserved cadaver model could last without
degradation of tissue quality and tissue mobility with continuous cold storage, as well as interrupted cold storage with exposure to room temperature. Interrupted cold storage would be a more accurate recreation of what the model would likely be exposed to as an educational model; being exposed to room temperature when in use and in cold storage when not. Another important variable to examine is how much tissue degradation results from use of the model for surgical skills training, providing evidence of the long-term utility of the model.

The flexible cadaver model is a promising resource for the development of multiple surgical skills and could present a more economical means of providing high fidelity surgical skills training. Significant investigation is required to establish the viability of these claims. The flexible cadaver model could fulfill the needs of multiple specialized skills training workshops, which could decrease the costs associated with each individual workshop, and could be utilized afterwards for focused dissection courses in postgraduate surgical anatomy, resulting in additional savings. The practical and financial implications of this are significant and require the dedication of additional time and financial resources for the coordination of multiple surgical skills training programs.

Investigation is also required to establish where the flexible cadaver model could fit into the orthopaedic residency training program, as well as other surgical skills training programs. Barnes (11) suggested that the first or second year of surgical training is the most critical time for the development of basic skills for optimal performance within the operating room. One participant did state that the flexible cadaver model “would be beneficial prior to starting rotations involving arthroscopy” suggesting that the model would have benefit if introduced earlier in the apprenticeship model, before beginning to perform surgical tasks. Grober et al. (28) have suggested that novice surgeons should begin training on low-fidelity models and once
proficient in basic skills, could progress to the utilization of higher fidelity models. Research is required to identify where the flexible cadaver model will have the most significant educational impact for the successful training of orthopaedic residents.

Additional financial, as well as faculty resources, would need to be dedicated for the creation of additional course work to complement the inclusion of the flexible cadaver model into the orthopaedic residency training program. Hutchison et al. (29) stated that as a general rule, the more realistic a training resource is, the more expensive it is and that is “imperative to examine whether the investment is worthwhile”. Significant consideration is required to evaluate all of the variables that would contribute to the economic and educational effects of the creation, implementation and maintenance of the flexible cadaver model within surgical education.


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