FINAL TECHNICAL REPORT

THE NATIONAL CENTER FOR COLLABORATION IN MEDICAL MODELING AND SIMULATION

NOVEMBER 2006

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Prepared For The

OFFICE OF NAVAL RESEARCH
HUMAN SYSTEMS DEPARTMENT
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November 30, 2006

CDR Russell D. Shilling
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Re: ONR Award No.: N00014-04-1-0697

Dear Russ,

I hope you are doing well.

I am pleased to enclose a copy of the Final Technical Report for The National Center for Collaboration in Medical Modeling and Simulation that covers the contractual period from July 1, 2004 through September 15, 2006.

Should you have any questions or comments concerning the report, please feel free to contact me. I hope to see you soon.

With best regards,

C. Donald Combs, Ph.D.
Principal Investigator
Associate Dean for Planning
and Health Professions

Enclosure

c: ONR Regional Office Atlanta (Transmittal Letter Only)
Defense Technical Information Center (DTIC)
Naval Research Laboratory (NRL)
Mark W. Scerbo, Ph.D.

FINAL TECHNICAL REPORT

07/1/04 – 09/15/06

National Center for Collaboration in Medical Modeling and Simulation
Eastern Virginia Medical School
and
Virginia Modeling, Analysis and Simulation Center

Background – The Office of Naval Research Human Systems Department (HSD) is comprised of two divisions: Medical and Biological Science and Technology and Cognitive, Neural and Social Science and Technology. The HSD supports basic and applied research, and advanced technology development, leading to applications for the Departments of the Navy and Defense, and U.S. industry. The HSD is committed to an active exploration program at the leading edges of medical science, human performance, biotechnology, training and human factors, neural information processing, and biorobotics. Programs supported by the divisions range from molecular biology to the development of advanced medical therapies for saving lives and strategies for preserving a healthy and fit fighting force. As part of this mission, the HSD had identified a significant problem that negatively impacts both the quantity and quality of medical care available to the U.S. Navy and Marine Corps in times of military conflict and in peace time in CONUS and other facilities. The crux of the problem is the need to train medical personnel, in relatively large quantities, to effectively deal with trauma-related combat casualties, and casualties due to chemical or biological agents.

Objective –The objective was to develop and integrate modeling and simulation technology into medical education, patient care and research, with the goal of transforming the way in which medical personnel are educated and trained and leveraging the investment made to develop these technologies by training more personnel, in less time, with more effective results; to develop modeling and simulation solutions to the planning, training, and execution of medical responses to events that produce mass casualties. In addition, this project was to (1) address the care of military personnel and their dependents in non-combat-related diagnosis and treatment, (2) apply modeling and simulation to the better prepare the military and the nation at large to respond medically to events that produce mass casualties, and (3) to influence the training of medical personnel through determining the efficacy of available simulators and their role in the medical curriculum.

General - The Contractor was to provide all necessary personnel, facilities, and equipment necessary to accomplish the work described in the following tasks. These services included, but were not limited to: validating medical simulators, developing new technologies, integrating simulators and simulations into medical curricula, and developing regional models to assist in planning, training, and decision-support in the event of an incident producing mass casualties.

Requirement – The following specific tasks were to be accomplished during the period of performance.

Task 1 - Simulator Validation

1.1 Conduct a validation experiment of the catheter insertion simulator using EVMS medical, EVMS physician's assistant, and ODU psychology students *(Completed)*

Two experiments were conducted comparing the CathSim® virtual reality simulator and simulated limbs for training phlebotomy. In the first experiment, medical students completed two one-hour training sessions using one of the two methods. Afterward, the students had their performance assessed with both simulated limbs and actual patients. The results showed that students trained using the simulated limbs as compared to the CathSim® system achieved higher scores on the posttest and on the field test with actual patients. In the second study, graduate students practiced with the CathSim® system for five hours. The results showed a significant improvement in scores from the pretest to posttest for these students; however, even after extended practice their final scores did not differ from those of the medical students in the first experiment. Critical differences in design characteristics between the two systems may explain these findings. Although a clear advantage for simulated limbs over the CathSim® system was observed, neither system faithfully represents all of steps needed to perform the procedure. Thus, training decisions may require one to consider the unique advantages afforded by each system. (See Deliverable R1B – Appendix A)

1.2 Conduct a validation experiment of the colonoscopy simulator using EVMS surgical and ODU psychology students. *(Partially Completed)*

EVMS surgical students and ODU psychology students all received initial training on the colonoscopy simulator. All psychology students (n=8) completed 10 hours of training. None of the surgical students completed training. The results for the psychology students showed significant decreases in the time needed to complete the procedure and time in red-out (an accuracy measure) after 10 hours of practice. Unfortunately, without data from the surgical residents, there is no basis for comparison.

1.3 Provide support for a validation experiment of an arthroscopy simulator using surgical staff at Portsmouth Naval Hospital and ODU psychology students. *(Partially Completed)*

Logistical support and student help were provided to staff at the Portsmouth Naval Hospital to conduct their evaluation of the arthroscopy simulator. The first phase of the virtual arthroscopy project consisted of the development and validation of a scoring system for diagnostic arthroscopy. This first study was a blinded randomized prospective study. (See Deliverable R1A - Appendix A)

1.4 Provide human factors input into the development of a high performance skill medical simulators. *(Completed)*

Human factors principles were applied in the design and construction of the wound debridement system. (See Deliverable R1B, R1C – Appendix B)

1.5 Perform literature review of research on high performance skill acquisition. *(Completed)*

A literature review examining recent research on the efficacy of simulators for training surgical skills was undertaken. In surgery, the most common type of simulators target laparscopic procedures and the Minimally Invasive Surgical Trainer Virtual Reality (MIST VR) is the most widely studied laparoscopic simulator. Despite its research exposure, however, few studies have demonstrated the transfer of skills learned on the MIST VR to procedures performed on genuine patients. Further, most of the research to date is not tied to any theories of learning. The review describes current research on laparoscopic training with simulators and discusses the need for theories of learning and skill acquisition in future research. (See Appendix C)

1.6 Organize professional meetings to address current state of modeling and simulation methods and technology and its applicability to medicine. *(Not completed)*

The prospect for hosting a professional meeting on simulation in medicine that did not duplicate existing meetings was examined. Several new forums for the exchange of technical information on this topic have emerged and a decision was made not to proceed at this time.

1.7 Continue a research program to study the practice of medicine/surgery (both research and application issues). *(Completed)*

Research continued throughout the duration of the project. A report on key user-based research issues was prepared (see Appendix D). In addition, a competency modeling approach was followed to understand excellence in surgery (see Appendix E).

1.8 Continue work on surgical skills under combat study. *(Completed)*

A group of medical students were taught to perform a tube thoracostomy on a mannequin simulator in a traditional medical school setting and demonstrate competency in that environment. Immediately afterward and again four months later, they performed the procedure in a CAVE virtual environment running a combat simulation under day and nighttime lighting conditions. The results showed that accuracy suffered in the simulation. Participants also needed more time to perform the procedures under the nighttime conditions. Further, performance did not change over the retention interval. The results suggest that although the surgical skills acquired by students in a traditional medical school setting are robust, they may still be compromised under hazardous conditions. More important, these findings show that virtual environments can provide a safe and effective venue for military medical personnel to train for dangerous duty. The last technical report on this project is included in Appendix F.

1.9 Continue work on simulated patient assessment. *(Completed)*

Human factors design and support were provided on a project examining the efficacy of training with standardized patients. Residents in the EVMS dermatology program saw standardized patients addressing the same 4 skin disorders in the Skills Center and in the field in a genuine clinical setting. Overall, the results showed that field test scores were lower than the OSCE scores from the Skills Center and suggest classical observational effects. The scores for those residents who were first observed in the field improved by about 10 points when later observed in the OSCE environment. By contrast, the scores for those residents who were first observed in the OSCE environment declined by about 4.5 points when later observed in the field. In addition, the field test scores were similar irrespective of when they were observed.

1.10 Continue work on suturing skills assessment. *(Completed)*

A workshop for teaching medical students fundamental suturing skills was conducted. Students were taught 3 basic stitches and allowed to practice them on pads of simulated skin. The workshop was only offered once.

<u>Task 2</u> – In the area of Technology Development, the Subcontractor shall:

2.1 Maintain the existing inventory of DOD medical modeling and simulation activities, current projects and points of contact. *(Completed)*

Began initial inventory of medical M&S technology. This material was subsumed within the medical M&S database project.

2.2 Develop collaborative mechanisms for medical modeling and simulation activities nationwide. *(Completed)*

Collaborations were developed and/or maintained by 1) participating in the Advanced Initiatives in Medical Simulation delegation to the U.S. Capitol, Washington, D.C. and facilitating demonstrations of medical simulation technology designed to promote patient safety in the Dirksen Senate Office Building in 2004, 2005, and 2006; and 2) serving on the Medical Simulation Task Force of the Society for Interventional Radiologists.

2.3 Demonstrate the value of using medical and surgical simulators in validation and training transfer studies. *(Completed)*

See Task 1.1 above

2.4 Survey existing tissue models and simulator technologies and begin selective development of medical and surgical simulation. *(Completed)*

Many tissue models were identified and studied including mass-spring and finite element viscoelastic models. The impact of computing technology was considered in evaluating the different models. In general, finite element models provided the best fidelity in terms of modeling the viscoelastic properties of tissue. Mass spring models lack the necessary fidelity and are difficult to tune.

At the current time, finite element models are unsuitable for deployment with the current desktop computing technology because these models cannot provide the real-time fidelity required for surgical skills training. Mass-spring models more readily provide real time performance, but not at the same fidelity. Weighing the trade-offs, the team decided to implement the prototype using a simple mass spring tissue model, and concurrently study the possibilities offered by hybrid models. A bibliography of tissue models described in the literature appears in Appendix G.

<u>Task 3</u> - In the area of Simulators and Curriculum Integration, the Subcontractor shall:

3.1 Develop detailed training simulator requirements based on the identified use cases. These requirements will form the basis for simulator design and functionality. *(Completed)*

Detailed training simulator requirements were developed for the wound debridement procedure. Wound debridement is an example of a basic open surgical procedure requiring the trainee to follow a specific sequence of steps in order to correctly complete the procedure. The team met with surgeons to determine the necessary educational content, determine the precise sequence to follow to complete the procedure, and the requirements for each. A more in-depth summary is included in Appendix B.

3.2 Based on the training simulator requirements, develop a conceptual model of high performance skill medical training simulators. *(Completed)*

A conceptual model for a wound debridement trainer was developed that incorporated several training modes including didactic and simulated training experiences. The trainer is described in more depth in Appendix B.

3.3 Develop a research plan that will support the high performance skill medical training simulator development. This effort will include both the technologies required to support the medical training simulator and the technology and methodology to support effective training tasks and transference of those to the real world. *(Completed)*

A plan for assessing performance with medical simulators was adapted from aviation training transfer paradigms. (See Appendix H)

3.4 Identify and explore haptics, auditory, simulation and visualization technologies that are available to implement high performance skill medical training simulators. This effort will include identification of a core set of technologies that are readily available and could be used to support a medical training simulator in the first quarter of calendar year 2005. *(Completed)*

The technologies identified were assessed and used to support the development of the wound debridement and augmented standardized patient trainers. Core technologies for haptics (SensAble Technologies, Phantom Premium), auditory (electronic stethoscopes, speech recognition, speech synthesis), and simulation (Derivative, literature survey) were reviewed. Decoupled from other technologies, general visualization technology was viewed to be generally adequate for most visual processing to the support medical skills training provided. Special purpose assemblies, such as the ReachIn Display, that integrates haptic and visual experiences, were viewed to be important in creating an effective training simulation.

3.5 Based on the conceptual model, develop a high performance skill medical training simulator system design that will meet the identified simulator requirements. *(Completed)*

A prototype wound debridement trainer was developed. The trainer is described in more depth in Appendices B, I, and J.

DIAGNOSTIC KNEE ARTHROSCOPY; VALIDATION OF A SCORING SYSTEM TO ASSESS RESIDENT PROFICIENCY[**/***]

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*** The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the United States Government

DIAGNOSTIC KNEE ARTHROSCOPY; VALIDATION OF A SCORING SYSTEM TO ASSESS RESIDENT PROFICIENCY

ABSTRACT

Background: The knee arthroscopy scoring system is a tool designed to objectively measure technical performance and to distinguish the novice from the proficient surgeon who requires minimal supervision. The purpose of this study is to validate this scoring system assessing resident proficiency during diagnostic arthroscopy.

Methods: Randomized prospective blinded study that included residents PGY 1-5 (n=20) and staff surgeons (n=10). Subjects were randomized and performed a diagnostic arthroscopy on a cadaver knee. Subjects were evaluated both on completeness of exam and time taken to complete the arthroscopy. The examiner viewed the arthroscopy from a remote location and was blinded to the level of training of the subjects. During the arthroscopy, 24 areas required assessment to score 75 points. An additional 25 points were awarded depending upon the time it took to complete the arthroscopy. A maximum of 100 points were available.

Results: A total of 30 subjects were enrolled and divided into three groups: Group 1 (PGY-1/2 n=12), Group 2 (PGY-3/4/5 n=8), Group 3 (Staff n=10). Group 1 performance: average total score 27.9, average time to complete scope 11.9 min, average number of structures not examined 8.67. Group 2 performance: average total score 73.8, average time 8.2 min, average structures not examined 1.75. Group 3 performance: average total score 100, average time 4.6 min, average structures not examined 0. Statistically significant differences were noted for the total score of all the groups ($p < 0.001$) and for the time of arthroscopy ($p < 0.001$). For items not examined, Groups 2 and 3 were equivalent and both had a significant difference compared to Group 1 ($p < 0.001$). Using this scoring system, staff surgeons consistently scored 100 points and were more efficient and complete compared to residents. In addition, more experienced senior residents scored higher than junior residents.

Conclusions: The knee arthroscopy scoring system is a valid method to distinguish between the novice, intermediate, and expert in diagnostic arthroscopy. Utilizing this scoring system, we can now objectively monitor a resident's progress in diagnostic arthroscopy and identify individuals that may need additional training prior to performing arthroscopy under limited supervision.

Level of Evidence: I

Figure 1

ARTHROSCOPIC SKILLS ASSESSMENT FORM – KNEE

Start Time________ Stop Time_________ Total Time________

Arthroscopic Knee Exam

Suprapatellar Pouch	☐ View all areas of pouch	(3)
Patella	☐ View medial Facet	(3)
	☐ Lateral Facets	(3)
Trochlea	☐ View Trochlear surface	(4)
Medial Recess	☐ View medial gutter / assess meniscal synovial junction	(4)
Lateral Recess	☐ View Lateral Gutter / assess meniscal junction/popliteous	(4)
Medial compartment		
	☐ Assess condyle for Chondral lesions/	(5)
	☐ Meniscus / view ant, middle, posterior	(5)
	☐ Probe superior & inferior surface	(10)
Intercondylar Notch	☐ View and inspect ACL	(5)
	☐ View and inspect PCL	(5)
Lateral Compartment	☐ Assess condyle for Chondral lesions	(5)
	☐ View meniscus / view ant, middle, posterior	(5)
	☐ Probe superior & inferior surface	(10)
	☐ View popliteus tendon	(4)

Total (75) ___________

Time

< 7min	25pts
7-10min	15pts
11-20min	10pts
21-25min	05pts
26-30min	02pts
> 30min	0pts

Cartilage Injury

No chondral injury	0 pts
Depression Cartilage	-10pts
Fraying Cartilage	-20pts
Gouge Cartilage	-30pts
≥ 2 Cartilage injuries	Stop Scope

Total possible points are 100. Cartilage injuries result in points deducted from score.
Gold standard score is 100pts

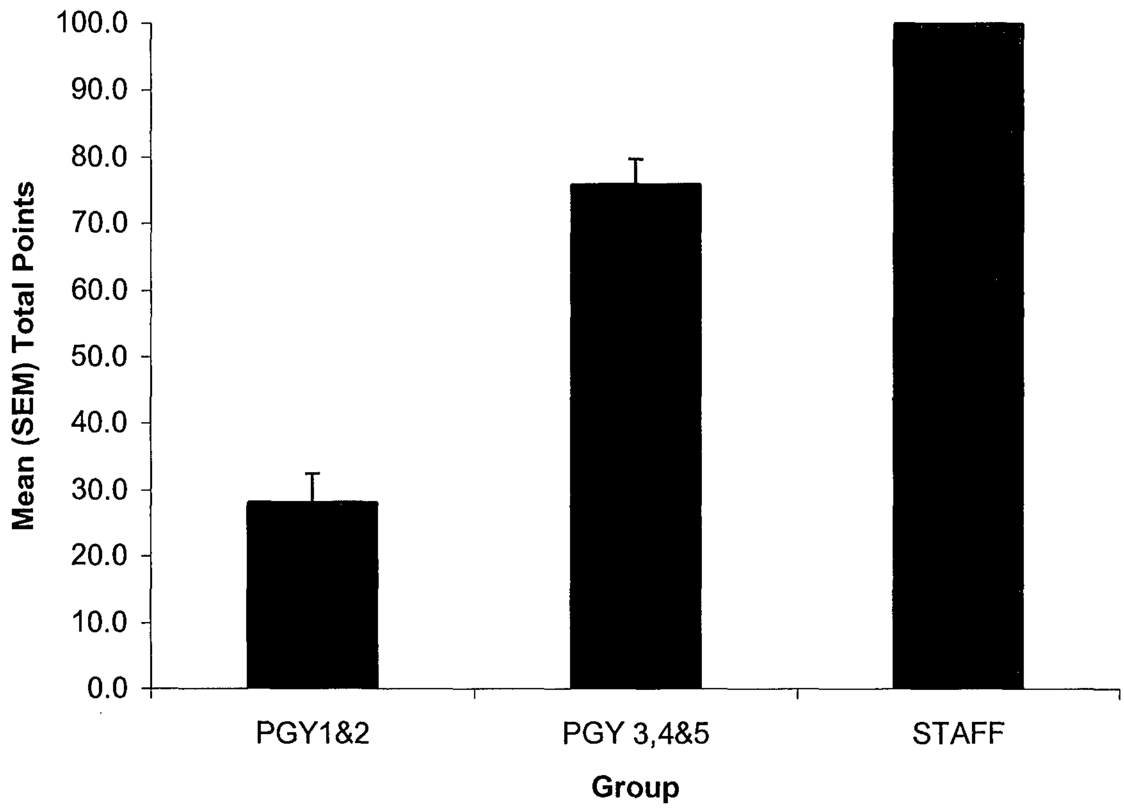
Scope Score ___________
Missed items ___________
Time Penalty ___________

Time_____+ Time penalty_____=Total Time______

Scope Score_____+Time Score_____=Total Score_____

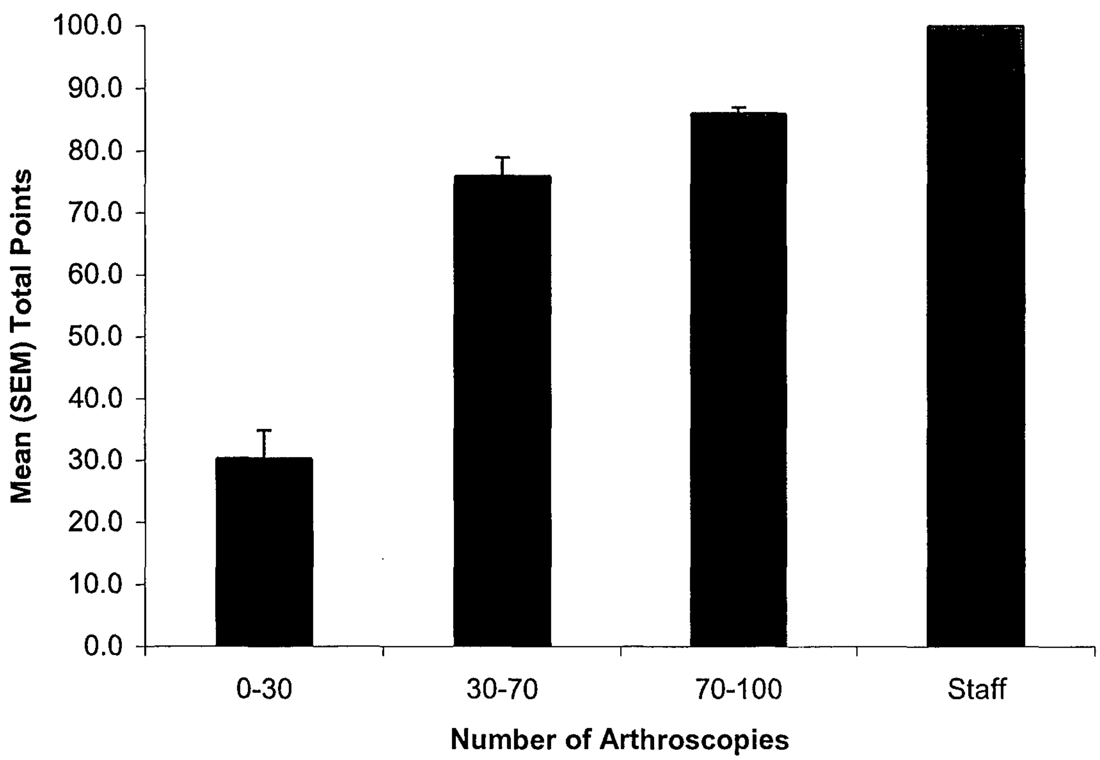
Time Penalty = 3 min per missed item

Figure 2



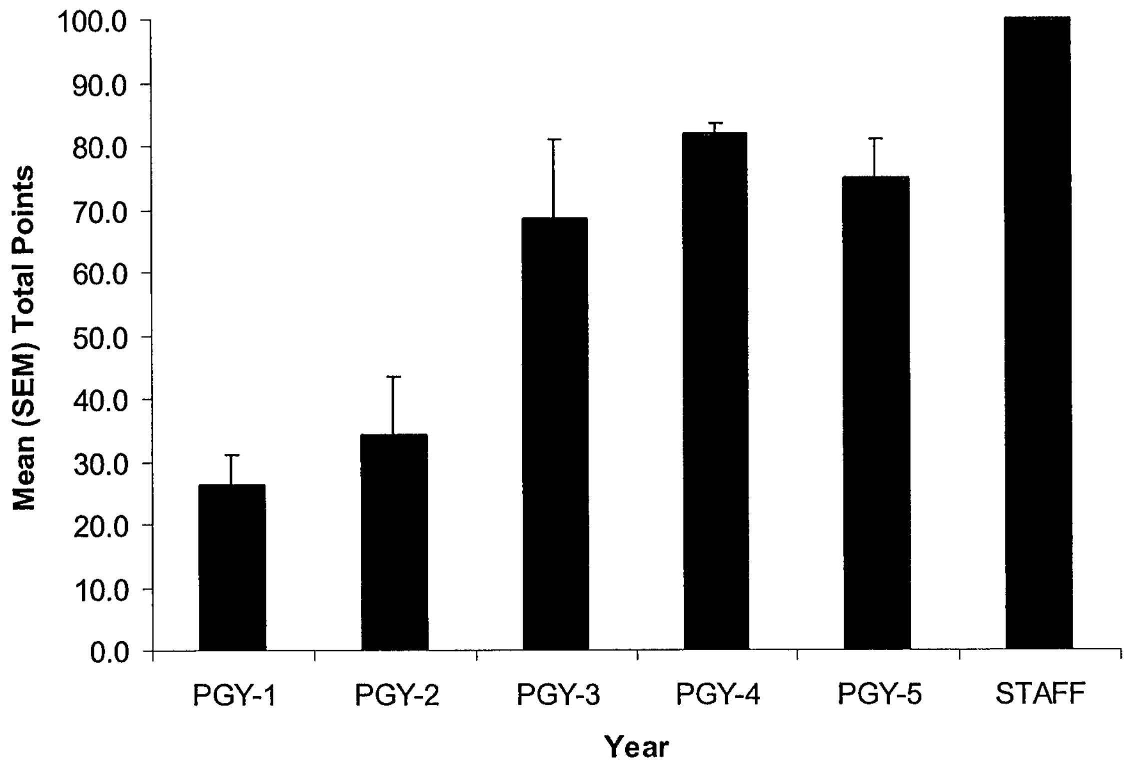
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mean (SEM) Total Points
PGY1&2
PGY 3,4&5
STAFF
Group

Figure 3



100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mean (SEM) Total Points
0-30
30-70
70-100
Staff
Number of Arthroscopies

Figure 4


100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Mean (SEM) Total Points
PGY-1
PGY-2
PGY-3
PGY-4
PGY-5
STAFF
Year

Mark W. Scerbo, PhD
Elizabeth A. Schmidt, MS
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Comparison of a Virtual Reality Simulator and Simulated Limbs for Phlebotomy Training

Abstract

The current study compared the CathSim virtual reality simulator with simulated limbs for phlebotomy training. In the first experiment, medical students completed two 1-hour training sessions using 1 of the 2 methods. Afterward, the students' performance was assessed with both simulated limbs and genuine patients. The results showed that students trained with the simulated limbs achieved higher scores on both the posttest and the field test with actual patients than those trained on the CathSim system. In the second study, graduate students practiced with the CathSim system for 5 hours. The results showed a significant improvement in scores from pretest to posttest for these students. However, even after extended practice, their final scores did not differ from those of the medical students in the first experiment. Critical differences in design characteristics between the 2 systems may explain these findings. Although the authors observed a clear advantage for simulated limbs over the CathSim system, neither system faithfully represents all of steps needed to perform the procedure. Thus, training decisions may require that the unique advantages afforded by each system be considered.

Simulation devices have been used for medical instruction throughout history. Until recently, most of these devices were physical anatomic models with very limited functionality. Currently, some of

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these physical models have evolved into mannequin-based simulator systems coupled with computers that provide dynamic physiologic responses to treatments.[1,2] Within the past 5 years, an alternative form of simulation technology also has become viable. Medical virtual reality (VR) simulators use computer systems combining visual, auditory, and haptic displays that enable individuals to see, hear, and touch objects in virtual space. Computer models generate a patient's anatomy and physiology, and the user interacts with the virtual patient via computer interface devices.

Medical simulators offer many benefits. They allow medical personnel to train on devices instead of practicing on patients. Thus, trainees can learn from their mistakes without putting patients at risk. Simulators also can provide trainees with an unlimited number of trials to acquire skills. Moreover, they offer an environment for the training of specific skills in the absence of uncontrollable environmental influences and patient interactions. Furthermore, simulators help to decrease dependence on animals and cadavers for practicing procedures.

There also are advantages unique to medical VR simulators. First, because the user interacts with a virtual patient, there is no need for expendable/replaceable parts and supplies common to many mannequin-based systems. Second, most VR simulators allow students to interact with the system and receive objective performance feedback in real time.[3] Third, virtual technology offers a more cost-effective way to create a wide range of individual patient characteristics and pathology, thereby allowing students to be more readily exposed to rare or infrequent conditions. Currently, a variety of commercially available VR simulators address specific procedures including laparoscopic skills, arthroscopic knee surgery, endoscopy, ophthalmology, and sinus surgery.[4]

• A VIRTUAL REALITY SYSTEM FOR INTRAVENOUS PROCEDURES

Recently, a VR simulator was developed for intravenous (IV) procedures.[5] The CathSim system (Immersion Medical, Inc., Gaithersburg, Md) provides training on a subset of vascular access procedures, including catheter insertion (cannulation) and phlebotomy. The physical system consists of a personal computer accompanied by their AccuTouch haptic feedback device with six degrees of freedom that simulates the needle and hub and a vinyl strip that simulates the skin. The AccuTouch device enables trainees to experience haptic force feedback when inserting a needle into the simulated skin and vein. The system also includes a variety of unique case patient training scenarios and tutorial video clips to familiarize students with many procedural details.

The user operates the system by making selections with the computer's mouse and manipulating the AccuTouch device to insert the needle. The system records many performance metrics, including procedure success, angle of needle insertion, occurrence of hematoma, session time, tourniquet placement time, and a pain factor. In addition, two visual training aids allow users to see either a representation of the needle entering the arm from a side view or a "transparent" view of the underlying vascular system.

• RESEARCH

To date, only a few published studies have examined the effectiveness of the CathSim system for teaching IV procedures. Reznek, Rawn, and Krummel[6] found that the CathSim system could distinguish among first-year medical students, third-year medical students, and surgical residents. Several investigators have compared the CathSim system and plastic arms used for training. Better success rates were observed for the trainees who used the plastic arms.[7,8] For instance, Scerbo et al[9] found that students benefited from training that used both methods, but those who trained with plastic arms showed the greatest gains in improvement. More recently, Bowyer et al[10] compared simulated limbs with the CathSim system and the Virtual IV system by Laerdal Medical, Inc. (Wappingers Falls, NY) and found some evidence for greater performance gains with the Virtual IV system.

Collectively, the findings from the studies examining the CathSim VR simulator show that it is only marginally effective in comparison with plastic arms. It is important to note that all the aforementioned research examined the cannulation procedure. None of the studies addressed phlebotomy.

• PHLEBOTOMY

Although both cannulation and phlebotomy can be considered vascular access procedures, Ernst and Ernst[11] argue that they are entirely different procedures. Whereas the objective of cannulation is to insert a needle into the patient's arm for the introduction of fluids, the purpose of phlebotomy is to access a patient's vein and collect a high-quality blood specimen that can be correctly identified and safely transported for laboratory analysis.[12]

The need for phlebotomy training is paramount. A poorly performed phlebotomy procedure can result in traumatic punctures, repeated punctures, subcutaneous hemorrhages, hematomas, chronic pain from punctures that pass through a nerve, and even concussions and bone fractures that occur during fainting spells of patients left unattended.[11,13] An improperly performed procedure also can generate erroneous laboratory results that either leave existing conditions undetected or indicate the presence of nonexisting conditions that subject the patient to additional unnecessary tests, procedures, and all the associated risks.[14]

Besides patient safety issues, there are factors that affect the clinician's ability to perform the procedure. For example, a patient's age, size, obesity, general health, and personal habits (eg, smoking or intravenous drug use) affect not only the ease with which the vein can be accessed, but also the choice of vein. Differences in specimen collection equipment and materials also affect how the procedure is performed and the order in which different collection tubes are to be filled.[15]

Furthermore, the phlebotomist also can be at risk.[16] Phlebotomy involves a variety of unique safety issues concerning the practice of collecting multiple blood samples during a single procedure and the use of sharps disposable containers. Moreover, the National Institute of Occupational Safety and Health (NIOSH) estimates that 600,000 to 800,000 needlestick injuries occur in healthcare settings each year,[17] exposing healthcare providers to as many as 20 different blood-borne diseases including HIV, hepatitis B, and hepatitis C viruses.[11]

Finally, only 1 state, California, has a licensure requirement for phlebotomists. Most states do not even have certification requirements. Moreover, there are no performance-based standards for assessing the phlebotomy skills of healthcare workers. The common practice is for more advanced phlebotomists to observe a trainee over a designated period or number of procedures.[11] Thus, the competency levels of clinicians performing phlebotomy can vary widely.

Safety factors, procedural challenges, and lack of performance standards make phlebotomy a particularly good candidate for simulation-based training. To date, however, only 1 study has examined VR training for phlebotomy. Scerbo et al[18] compared the CathSim system with simulated limbs. They trained third-year medical students for up to 2 hours using one or the other method and assessed performance with a 28-item instrument. In addition, 4 system-generated performance metrics were recorded for the students who trained using CathSim. All the participants performed a pretest and posttest on the simulated arm.

Scerbo et al[18] found a significant improvement between the pretest and posttest scores only for the students who trained with the simulated arms. Moreover, the posttest scores of the simulated arm group were significantly higher than those of the CathSim group. Furthermore, although some of the system-recorded performance metrics showed a significant improvement across training sessions, the posttest scores did not reflect the benefits.

Scerbo et al[18] noted that the 2 training systems differed in the number of steps that could be addressed from all those needed to perform the procedure.[18] Consequently, the investigators reanalyzed their data for only those steps common to both procedures. This second analysis showed a pattern of results similar to that from the full procedure. Posttest scores for the simulated-limb group were statistically higher than for the CathSim group.

To gain a better understanding of why the simulated limbs resulted in better performance, Scerbo et al[18] performed a physical and functional analysis of each simulator system. These researchers found that the CathSim system does not faithfully represent the activities required to tie a tourniquet, prepare the site, stabilize the vein, and orient the needle properly for insertion. In addition, there are some design-oriented concerns. For instance, the CathSim trainer is designed to be operated by a seated user interacting with the computer, whereas phlebotomy is typically performed with the phlebotomist standing and leaning over the patient's arm. Also, because the CathSim system requires users to interact simultaneously with both the needle/hub assembly and the computer mouse, there is greater motor interference among the steps.

Scerbo et al[18] argued that the physical and functional differences between the 2 simulator systems could account for the observed differences in performance. They also noted, however, that because both groups were assessed on the simulated limbs, it could be argued that the students in the CathSim group were at a disadvantage because they were assessed using a system that differed from the one on which they trained.

• EXPERIMENT 1

One goal of the first experiment was to reexamine the CathSim and simulated limb methods for phlebotomy training. Toward this end, participants were trained using 1 of the 2 methods. Again, they were assessed with a pretest and posttest on the simulated limbs. This aspect of the study was retained because simulated limbs offer a safe and standardized platform for assessment. Although this approach enables comparisons of performance before and after training, a clearer comparison of the 2 methods necessitates that performance be evaluated with a "neutral" target task. Accordingly, performance was assessed using a transfer of training paradigm. At completion of the posttest, the participants were assigned to a clinic and assessed on their first 2 attempts to draw blood from genuine patients. This additional test was included for 2 reasons. First, if the differences observed by Scerbo et al[18] resulted from assessing CathSim trainees on a different simulation system (the simulated limbs), then a subsequent test on a neutral platform (ie, genuine patients) would eliminate the unfair disadvantage for the CathSim trainees. Thus, all trainees would be assessed on a platform that differed from what they used for training.

Second, and more important, because the ultimate goal of simulation-based training is the transfer of skills to the operational environment, the current paradigm allows healthcare professionals to determine the relative efficacy of both training systems for performing where it counts most—with genuine patients.

• METHODS

Participants

The study participants were 45 third-year medical students at Eastern Virginia Medical School who participated as part of their family clerkship rotation requirements. The mean age of participants was 26.48 ± 3.23 years. Some of the students had prior medical experience (9 had given intramuscular injections, 7 had given subcutaneous injections). Most of the students had no prior experience with medical or other simulators. However, 3 students reported cursory training with a mannequin arm and 7 reported experience in a driving or flight simulator.

Materials

A Life/Form simulated arm (NASCO, Inc., Fort Atkinson, Wis.) was used for training and for the pretest and posttest assessments (Figure 1). The simulated arm contains latex veins covered by vinyl skin. An IV bag containing artificial blood is hung approximately 2 feet above the arm and connected to the latex veins via tubing. Gravity draws the artificial blood into the arm's veins and simulates bleeding when the skin and vein are punctured. The simulated arm has several potential sites for phlebotomy. However, only the antecubital fossa was used in this study. Other materials also required for phlebotomy included gloves, tourniquets, alcohol swabs, gauze pads, 20-gauge needles, and Vacutainer (BD, Franklin Lakes, NJ) collection tubes. A biohazard sharps container also was available so that all needles could be discarded properly.

The CathSim VR system was used in this study (Figure 1). (Immersion Medical, Inc. has released an upgraded version of the CathSim system since completion of this study.) This system has a phlebotomy module with 6 case patients. Once a case is selected, an image of the patient's arm appears on the computer screen, and the system guides the participants through the steps of selecting an insertion site, palpating the site, and applying the tourniquet, all via the computer's mouse. Next, a magnified image of the insertion site is presented on the screen along with a virtual needle. The mouse is used to position the virtual needle for insertion.

After choosing the insertion site, participants apply traction to the simulated skin pad, fully retract the needle unit of the AccuTouch device, and then insert it into the virtual arm while monitoring their progress on the screen. Once the needle has accessed the vein, the mouse is used to click on icons representing the collection tubes. Participants attach a physical tube to the needle unit on the AccuTouch device. If vein access is successful, the virtual collection tube on the screen appears to fill with blood. Multiple tubes can be filled. After the last tube has been filled, the student uses the mouse to release the tourniquet and detach the tube from the AccuTouch device. The procedure is completed when the image on the computer screen displays the needle being deposited into a biohazard sharps container.

Performance Metrics

Four performance metrics from the CathSim system were used to evaluate training in this study. The first was a pain factor that produces a score from 1 (minimal pain) to 10 (maximum pain). Pain scores increase if needle penetration is too deep (ie, the needle passes through both vein walls), the needle angle is inappropriate, or the needle is moved after it is embedded in the skin. The second metric was hematoma status. Hematomas occur if the needle

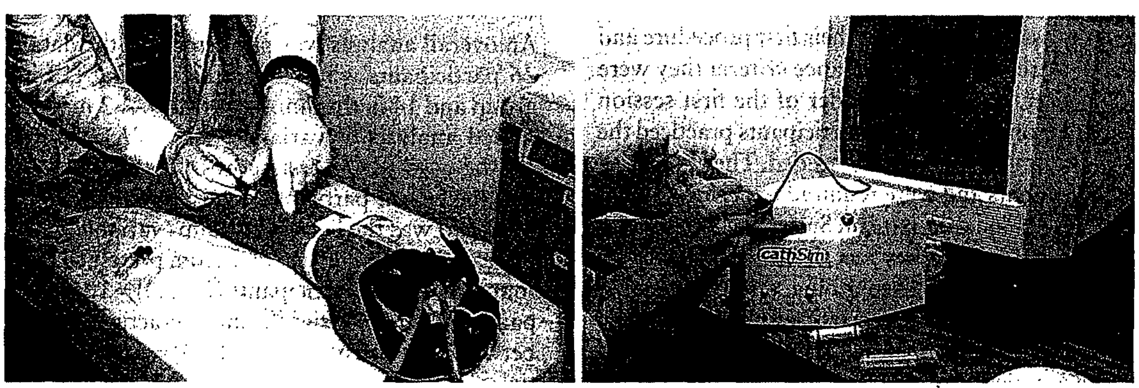

FIGURE 1.
Trainee performing a phlebotomy on the simulated arm (*left*) and the CathSim system (*right*).

scrapes the wall of the vein or passes through both vein walls. The third metric was the total amount of time the tourniquet was on the arm, and the fourth metric was the success (ie, if the student successfully completed the draw) or failure of the procedure.

Assessment

The checklist described by Scerbo et al[18] was used in this study to assess pretest, posttest, and field test performance. The checklist addresses 23 steps necessary for performing a complete phlebotomy procedure (eg, site preparation, needle insertion and withdrawal) and 3 steps concerning overall performance. Checklist scores can range from 0 to 88 points, with higher scores reflecting better performance.

Procedure

The participants completed a background questionnaire, including demographic information and prior experience with medical procedures and simulators. Then 15 participants were assigned to the VR (ie, CathSim), simulated arm (SimArm), and clinic group conditions. (Original plans called for assigning a group of students to a clinic for on-the-job training supervised by a phlebotomist. However, that phlebotomist left employment shortly after the study began. No data for those clinic-trained students could be retrieved, and the position went unfilled for much of the study. Thus, only data for the VR and SimArm groups are presented in this article.) All the participants were shown an introductory video that described the phlebotomy procedure. After the video, all the participants performed a phlebotomy pretest on the simulated arm.

All the participants were trained individually. The VR group was trained for two 1-hour sessions separated by 1 week. During the first 20 to 30 minutes of session 1, the participants were introduced to the CathSim system and instructed on how to use the AccuTouch device. The experimenters assisted them with their first procedure and informed them about the performance criteria they were required to meet. For the remainder of the first session and all of the second session, the participants practiced the procedure, with guidance given as needed. They practiced on all 6 case patients and were required to perform a successful phlebotomy on each patient. Specifically, they practiced on each patient until they met the following criteria: a pain factor of 3 or less, no hematoma, and a tourniquet time less than 90 seconds. The participants had to meet these criteria before they could progress to the next case patient. The 6 patients differed slightly, with some cases presenting a greater challenge than others (eg, smaller veins, less visible veins). The participants began training with an introductory patient, then progressed to the more difficult patients. Also, to maximize uniformity across training conditions, the participants were not allowed to use the side or transparent views.

Students in the SimArm group practiced phlebotomy on the arm and were trained in accordance with the items on the checklist. During the first 10 minutes of the first session, they were reintroduced to the equipment they needed for the phlebotomy and instructed in the steps necessary for performance of the complete procedure: assemble the needle unit, tie a tourniquet, palpate the vein, cleanse the site, insert the needle, depress and exchange the Vacutainer collection tubes, and withdraw the needle. For the remainder of the session, the participants practiced the procedure, and the experimenter provided them with verbal feedback regarding their performance. The first session ended when the student was able to perform a phlebotomy according to the criteria on the checklist in 2 consecutive attempts.

During the second session, the students were once again provided with verbal feedback regarding their performance until they could meet the criteria on 2 consecutive attempts. On average, the participants in this group completed their first session in 30 to 40 minutes and their second session in 5 to 15 minutes.

At the completion of training, all the students were given a posttest on the simulated arm, and their performance was assessed against the checklist. Next, the VR and simulated arm participants were assigned to a clinic to perform phlebotomy on actual patients under the supervision of a trained phlebotomist who was blind to the group assignments. The phlebotomist assessed the participant's performance on the first 2 phlebotomy attempts using the same checklist used for the pretest and posttest.

• RESULTS

Analyses for All Participants

An overall analysis was performed on the data from the 26 participants who completed training (12 in the VR group and 14 in the SimArm group). A 2 method × 2 test mixed analysis of variance (ANOVA) was conducted on the assessment test scores. Test (pretest, posttest) was the within-participants variable, and method (VR or SimArm) was the between-groups variable. A significant increase in assessment scores from pretest to posttest was found for all the participants ($F[1,24] = 106.34$; $P < .001$; partial $\eta^2 = .82$). A significant interaction also was found between test and method ($F[1,24] = 51.95$; $P < .001$; partial $\eta^2 = .68$).

The means for each group on each test are shown in the top half of Table 1. Tukey HSD post hoc analyses

TABLE 1

Means Assessment Scores and Standard Deviations for All Participants

	VR	SimArm	Mean
Full Procedure			
Pretest	64.08 (10.70)	57.93 (7.94)	60.77 (9.64)
Posttest	68.50 (8.02)	82.86 (3.21)	76.23 (9.32)
Common Steps			
Pretest	37.50 (7.63)	33.14 (5.96)	35.15 (7.00)
Posttest	41.50 (5.47)	49.86 (2.14)	46.00 (5.80)

VR, virtual reality.

demonstrated that the SimArm participants scored significantly lower than the VR participants on the pretest, putting the SimArm participants at a slight disadvantage initially. Both groups showed a significant improvement from pretest to posttest. However, the posttest scores of the SimArm participants were significantly higher than the posttest scores of the VR participants.

Analyses for Field Test Participants

A second analysis was performed on the data from only the 15 participants from the VR and SimArm groups who completed all phases of the study including the field test. In the field test phase, the participants attempted a phlebotomy with genuine patients and were assessed by a trained phlebotomist. The participants were allowed to perform the procedure up until the point the phlebotomist thought it necessary to intervene and take over. Thus, field test assessment scores reflect the cumulative point total until the phlebotomist had to intervene (if necessary).

It should be noted that only data from the initial attempt are reported. The phlebotomist who supervised the participants during the field test subsequently revealed that the performance of many participants was so poor that it was necessary to provide remedial training before allowing them to make another attempt. Consequently, data from the second attempt are contaminated with additional training outside of the experimental protocol, and therefore are not presented.

A 2 method × 3 test mixed ANOVA was conducted, with method as the between-groups variable and test as the within-participants variable. There were 8 participants in the VR group and 8 in the SimArm group. A significant main effect of test was found for VR and SimArm participants ($F[2,13] = 10.09$; $P < .01$; partial $\eta^2 = .44$). The main effect of test, however, was moderated by a significant interaction with method ($F[2,13] = 4.66$; $P < .05$; partial $\eta^2 = .26$).

Tukey HSD post hoc tests demonstrated that the field test scores for VR participants were significantly lower than their pretest or posttest scores, which did not differ from one another (Table 2). No significant differences were found among the SimArm pretest, posttest, and field test scores. However, post hoc tests did show that the SimArm participants scored significantly higher than the VR participants on the field test.

TABLE 2

Means and Standard Deviations for VR and SimArm Participants on All Assessment Phases

	VR	SimArm	Mean
Full Procedure			
Pretest	64.25 (10.07)	58.43 (8.87)	61.53 (9.66)
Posttest	70.13 (7.75)	84.29 (2.43)	76.73 (9.28)
Field test	26.25 (41.30)	64.00 (35.81)	43.87 (42.22)
Common Steps			
Pretest	38.00 (7.41)	31.71 (6.87)	35.07 (7.63)
Posttest	42.50 (5.63)	50.57 (1.90)	46.27 (5.89)
Field test	15 (22.27)	36.86 (17.92)	25.2 (22.65)

VR, virtual reality.

Analyses of Common Steps

As noted by Scerbo et al,[18] the number of steps from the phlebotomy procedure that can be trained using the CathSim and SimArm methods differ. Thus, an assessment of the 14 steps common to both methods described by Scerbo et al[18] also was conducted. The same 2 method × 2 test mixed ANOVA also was performed using the data from the 26 participants who completed training. A significant increase in scores from pretest to posttest on the common steps was found for all the participants ($F[1,24] = 81.86$; $P < .001$; partial $\hat{\eta}^2 = .77$). A significant interaction also was found between test scores and method ($F[1,24] = 30.84$; $P < .001$; partial $\hat{\eta}^2 = .56$).

The means for each group on each test are shown in Table 1. Tukey HSD post hoc analyses of the means reflected the same patterns observed for the full procedure: the SimArm participants scored significantly lower than the VR participants on the pretest. Both groups showed a significant improvement from pretest to posttest. However, the posttest scores of the SimArm participants were significantly higher than the posttest scores of the VR participants.

A 2 method × 3 test mixed ANOVA also was performed using the data from the 15 participants who completed the field test. A significant interaction was found between test and method ($F[2,13] = 4.47$; $P < .05$; partial $\hat{\eta}^2 = .26$). A Tukey HSD post hoc test showed that the SimArm participants scored significantly higher on the field test than the VR participants. No other comparisons between test and method reached significance.

CathSim METRICS

The performance metrics recorded for the students in the CathSim group during each training session are shown in Table 3. The means for each metric were determined by collapsing the data across cases and trials within cases. Although the trends for all the metrics suggest improvement from session 1 to session 2, only the decrease in hematomas reached statistical significance ($t[11] = 2.87$; $P < .05$).

TABLE 3

Performance Metrics for the CathSim System for Each Training Session Collapsed Across Trials and Cases

Metric	Session 1	Session 2
Mean no. of unsuccessful procedures	1.83 (2.82)	0.67 (1.23)
Mean no. of hematomas	3.25 (2.14)	1.33 (1.67)*
Mean tourniquet time (sec)	88.53 (35.34)	76.97 (9.72)
Mean pain score	4.15 (3.16)	3.19 (2.89)

Standard deviations in parentheses.
* $P < .05$.

• DISCUSSION

The findings from the current study show an advantage for the simulated limbs over the CathSim system. Although all the participants improved from pretest to posttest irrespective of training method, the posttest scores of those in the SimArm group were significantly higher than those who trained with the CathSim system. Because Scerbo et al[18] noted that each training method addresses a different number of steps than the complete procedure, a second analysis was performed on only those steps common to both methods. The findings were similar. Although all groups showed improvement from pretest to posttest, the group that trained with the simulated limbs achieved significantly higher posttest scores than the CathSim group even on the common steps. Collectively, these results support the earlier findings of Scerbo et al,[18] and suggest that the physical and functional differences between the 2 simulator systems may transcend the steps common to both systems and account for the observed training differences.

Although the findings from the current study replicate those of Scerbo et al,[18] it still could be argued that the participants who trained with the CathSim system were assessed on a target task that differed from the one on which they practiced. Thus, a second goal of the current study was to use a transfer of training approach and examine the performance of both groups on a neutral platform that differed from their training environment. Toward this end, all the participants were reexamined on their first attempt at phlebotomy with genuine patients.

The field test data with actual patients showed 2 important findings. First, the performance gains observed on the posttest were not sustained when participants had to perform an actual phlebotomy on a genuine patient. Training with either method did not transfer well to the operational environment.

Of course, a disadvantage of using real patients to evaluate training methods is the lack of methodologic control over patient characteristics. The students in this study were asked to perform a phlebotomy on the first patient who showed up at the clinic during their session. Although the clinic records demographic information concerning its patient population, these data were not collected in the current study. Thus, although it is possible that the students trained under each method may have seen patients with more (or fewer) challenging characteristics, one would expect individual patient characteristics to be distributed randomly across a group assignment.

Second, although all the students had difficulty with genuine patients, there was a clear difference between the 2 groups. Specifically, no statistical differences were found across tests for the SimArm group. Thus, there was no training advantage or disadvantage for these students when they performed their first phlebotomy on an actual patient. By contrast, there was a significant drop in performance on the field test for those who trained with the CathSim system relative to their pretest and posttest scores. Furthermore, their field test scores were significantly lower than those of the group that trained with the simulated limbs. A similar pattern of results also was observed when only the steps common to both methods were observed.

Although on the surface these results show that there are problems with the CathSim system for phlebotomy training, it is important to note that efforts were made to keep the training conditions consistent to maintain experimental rigor. Thus, all the participants were restricted to no more than 2 hours of practice. Unlike the simulated limbs, the CathSim system is composed of several computer devices, and trainees must spend a fair amount of time learning how to coordinate interactions among the components to perform the procedure. For some of the participants in the CathSim condition, much of the initial training session was dedicated to learning how to operate the system. Thus, it is possible that participants in this condition were not given sufficient time both to learn the simulator system and to practice the procedure itself. Also, although the CathSim system provides 2 auxiliary views (side and transparent views) to facilitate training, the participants were not allowed to access these views. Thus, the participants in the CathSim condition were unable to take advantage of visual aids that could facilitate training.

• EXPERIMENT 2

A second study was performed that removed the training restrictions imposed in experiment 1 to maintain consistency across conditions. The objective in experiment 2 was to provide trainees with an extended period to practice phlebotomy on the CathSim system. We expected that performance would improve as a result of continued practice. Furthermore, we hypothesized that if the poorer posttest scores of those trained with the CathSim system in experiment 1 were attributable to unfamiliarity with the simulator system, then providing additional practice time should eliminate that disadvantage. In addition, the 2 visual performance aids were studied to determine their effect on skill acquisition. We expected that the visual aids would have a positive effect on the rate of learning.

• METHODS

Participants

The participants in experiment 2 were 10 graduate students in a psychology program at Old Dominion University. They ranged in age from 22 to 32 years (mean, 25.8 ± 3.4 years). All the participants received monetary compensation for their participation. Only 2 of the participants reported prior experience in the medical field, with 1 indicating some experience with phlebotomy (ie, drawing blood from animals). No other students reported experience with phlebotomy or giving of injections. Seven of the students did report experience with either a flight or driving simulator, and all the students reported computer usage of 20 to 50 hours (mean, 33.3 ± 10.31 hours) per week.

Materials

The same simulated limbs and CathSim system used in experiment 1 also were used in experiment 2.

Procedure

All the participants watched the same instructional video about phlebotomy used in experiment 1, then performed a pretest on the simulated arm. Each participant then received 5 hours of individualized training over 2 separate sessions using all 6 case patients provided with the CathSim system. All the participants were required to meet the same performance criteria established in experiment 1 (ie, a pain factor of 3 or less, no hematoma, and a tourniquet time less than 90 seconds) for each case during their training sessions.

Once training was complete, all the participants performed a posttest on the simulated limb. Half of the participants, assigned at random, were allowed to use the 2 visual aids: a cutaway side view that showed the needle penetrating the arm and a transparency view of the underlying vascular system. They were permitted to access the visual aids as often as they wished. The remaining participants practiced without the visual aids.

Performance on the pretest and posttest was assessed with the same 28-item checklist used in experiment 1. Skill acquisition was measured by the time taken to reach the 90-sec criterion. This measure was chosen because 3 criteria (pain factor, presence of hematoma, and tourniquet time) had to be met before the participant could move on to another case.

• RESULTS

Pretest and Posttest

One individual did not complete the training, so the results are based on 9 participants. Initial analyses showed no effects of the visual aids. Thus, the data were collapsed across groups. Pretest and posttest scores were compared using a dependent t test. Performance improved significantly from pretest (mean = 48.56, SD = 10.24) to posttest (mean = 63.89, SD = 10.13; $t[8] < .01$).

Learning Curve

Each participant required a different number of attempts to reach the criterion on each case patient. The mean total times required to reach the criteria for all the cases were computed by collapsing the data across attempts and participants. The resultant means are shown in Figure 2. As can be seen in the figure, most of the performance gain was achieved within the first 6 or 7 trials, and there was little additional improvement beyond 15 cases. The abnormally long time for case 18 was attributable to a single student who struggled repeatedly with one of the more difficult cases. A line of best fit ($y = 510.92 \times -0.381$) also is shown in the figure with case 18 excluded from that data. The line represents a good fit with the data ($R^2 = .488$; $P < .001$).

Comparison Between Experiments 1 and 2

Another way to examine the effects of extended practice on the CathSim system is to compare the posttest scores from experiments 1 and 2. The participants in experiment 1 received up to 2 hours of training and achieved a mean posttest score of 68.50 ± 8.02. The participants in experiment 2 received 5 hours of training and achieved a mean posttest score of 63.89 ± 10.13. The results of an independent t test showed that the means did not differ significantly ($t[19] = -1.17$; $P > .05$).

• DISCUSSION

The primary goal of experiment 2 was to examine the role of extended training on the CathSim system. Overall, the participants showed improvement between the pretest and posttest, but the gains were not dramatic. The posttest scores were only 30% higher than the pretest scores after 5 hours of practice. Moreover, the mean posttest scores from experiment 2 were equivalent to the mean posttest scores of the CathSim participants observed in experiment 1. Thus, the results from experiment 2 suggest that giving trainees an additional 3 hours of practice beyond the 2 hours provided in experiment 1 is unlikely to produce any appreciable improvements in performance. The results regarding criterion time showed that performance became fairly stable after only a few cases (~45 minutes), but still remained variable across the entire training session. It is possible that much of this variability can be attributed to the different levels of difficulty associated with each unique case patient.

Another goal of experiment 2 was to examine how visual aids facilitate skill acquisition with a VR simulator for phlebotomy. The results showed no appreciable performance benefit from providing users with a cutaway side view or a transparent view of the underlying vascular system. The participants in both groups learned at the same rate and scored similarly on the posttest.

It should be noted that the participants in experiments 1 and 2 were drawn from different populations. Medical students were used in experiment 1, but a decision was made to use graduate students in experiment 2 because of the limited number of medical students available to participate in this study. We believe that the difference in subject populations is unlikely to account for the performance differences between the 2 experiments because the demographic characteristics of the medical and graduate students were similar, and because both sets of students had little or no prior experience with phlebotomy. Furthermore, because the focus of the study was aimed at motor skill performance, knowledge of medicine would not have been an advantage for the medical students.

It also could be argued that student nurses would have been a more suitable population. Again, participants who were naïve regarding phlebotomy were recruited so that the trainees could not rely on their previous or related experiences to accomplish the task. In this respect, one would expect all participants, regardless of career path, to be equally naïve. In addition, Scerbo et al[9] also conducted a comparison of the CathSim system and simulated limbs for IV cannulation. The participants in their study were students in a physician assistant program. Although this also is not a nursing population, it is a group likely to perform IV cannulation in their duties. Scerbo et al[9] found the same pattern of results in that earlier study as found in experiment 1 of the current study. The posttest scores of those trained with simulated limbs were significantly higher than those in the CathSim group. Thus, it is more likely that the pattern of results observed in each study is attributable to differences between the 2 training methods and not the populations from which the participants were drawn.

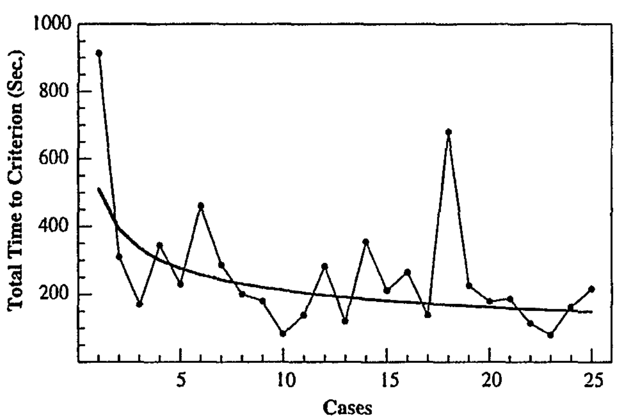

FIGURE 2.
Total time needed to reach criterion collapsed across participants. The heavy black line represents the line of best fit.

• GENERAL DISCUSSION

The goal of the reported experiments was to examine the efficacy of the CathSim system and simulated limbs for phlebotomy training. In a previous experiment, Scerbo et al[18] found that simulated arms resulted in greater performance improvements than the CathSim system. A similar pattern of results was observed in the current study. However, students trained under both methods in the current study were assessed for their ability to perform phlebotomy on genuine patients. The results showed that those trained on the CathSim system performed more poorly when they attempted an actual procedure. Furthermore, the results from the second study showed that extended training on the CathSim system and auxiliary visual aids are unlikely to change the pattern of results observed with genuine patients.

Scerbo et al[18] performed a functional and physical analysis of CathSim and simulated limb systems and argued that 2 important differences between the training systems could explain the poorer performance of the CathSim students. First, the CathSim system allows trainees to practice fewer steps than the full procedure includes. Second, the manner in which some steps are implemented in the VR system differs significantly from how those steps are performed in an actual procedure. For example, the CathSim system does not allow the user to choose where to place the tourniquet. Moreover, when the tourniquet is placed, it appears automatically tied in the proper location. Thus, trainees never learn how to place and tie an actual tourniquet. This particular design characteristic may account, in part, for the low field test scores observed in the first study. The students who could not properly place a tourniquet were not allowed to continue with the procedure.

It is important to note that neither system completely or faithfully represents the phlebotomy task as it is performed in practice. Therefore, it should not be surprising that the students in this study had some difficulty transferring the skills they acquired during training to an actual procedure with a genuine patient. For example, neither device allows trainees to practice palpation of the insertion site. Furthermore, the choice of insertion site poses no real challenge with either system. On the simulated arm, the veins protrude from the arm, making site selection obvious. Also, trainees cannot inspect the site for bleeding after removing the needle, as would be done with a genuine patient. On the CathSim system, the computer's mouse is used to select a site and allows palpation in only specific areas of the arm. Finally, neither system addresses the order in which collection tubes must be filled to minimize carryover contamination effects from additives in the tubes.[15]

Despite the limitations observed with the CathSim system, it does provide certain advantages. One of the valuable features is that the system records a set of the objective performance metrics that are not available or easily obtainable with simulated arms. For example, the CathSim system records an index of hand steadiness (ie, reflected in the pain measure). Also, the system can generate a hematoma on the basis of the user's performance, which is not observable with the simulated limbs. In fact, in the current study, the students did produce significantly fewer hematomas across training sessions.

There is one other important difference between simulated limbs and the CathSim system. Training with simulated limbs requires the use of expendable supplies (eg, needles, collection tubes, alcohol swabs). Thus, there are costs associated with simulated limbs every time the procedure is practiced. All "materials" used in the CathSim system are virtual, thus allowing an unlimited number of practice trials with no additional costs.

Overall, the CathSim system does provide some critical measures of performance that would be observed with actual patients, but not with the simulated arms. There are advantages and disadvantages to both the CathSim system and the simulated arms for phlebotomy training.

Phlebotomy requires knowledge of blood collection procedures as well as the skills needed to obtain a good sample for analysis. Although there are numerous training courses that address the procedures, standards regarding the performance aspects still are lacking.

In the current study, 2 simulator-based methods for training phlebotomy skills were examined. The results showed a clear advantage for simulated limbs over the VR-based CathSim system. The simulated limbs expose trainees to more steps of the procedure and allow them to practice in a manner more consistent with how the procedure actually is performed. These advantages became obvious when participants attempted to perform phlebotomy with a genuine patient. Thus, simulated limbs are likely to remain the method of choice for phlebotomy training.

As noted earlier, however, each simulator system does have its own strengths and weaknesses, and neither system faithfully represents all the steps needed to perform the procedure. Thus, the optimal training program may be one that supplements simulated limbs with a VR-based system.

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A Simulation-Based Training System for Surgical Wound Debridement

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Abstract. A simulation-based training system for surgical wound debridement was developed and comprises a multimedia introduction, a surgical simulator (tutorial component), and an assessment component. The simulator includes two PCs, a haptic device, and mirrored display. Debridement is performed on a virtual leg model with a shallow laceration wound superimposed. Trainees are instructed to remove debris with forceps, scrub with a brush, and rinse with saline solution to maintain sterility. Research and development issues currently under investigation include tissue deformation models using mass-spring system and finite element methods; tissue cutting using a high-resolution volumetric mesh and dynamic topology; and accurate collision detection, cutting, and soft-body haptic rendering for two devices within the same haptic space.

Keywords. Surgical debridement, wound debridement, training, virtual agent, multimedia, debris modeling, prototype, augmented reality.

Introduction

In 1999, The Institute of Medicine issued a report estimating that as many as 98,000 people die from errors in hospital settings each year [1]. Subsequently, the AMA's Accreditation Council for Graduate Medical Education limited the time that residents can be required to work to 80 hours a week. Although this action was intended to improve patient safety, it also reduced the number of patient-contact hours needed to train residents. Thus, medical educators are looking for alternative methods to provide residents with meaningful learning experiences. Many are turning to simulator-based training to meet that need [2, 3].

In many high risk domains (e.g., aviation, military training, nuclear process plant control, etc.), simulators are often used to allow trainees to acquire and practice skills in a safe and controlled environment [4]. One of the important benefits of this approach is that trainees can acquire much of the fundamental knowledge and skills needed to perform elementary activities largely on their own without the need for constant supervision by an instructor. Accordingly, that approach was adopted as the guiding principle behind the development of the surgical wound debridement simulator system.

1. Wound Debridement

Wound debridement refers to the process of removing necrotic, devitalized, or contaminated tissue and/or foreign material to promote healing [5]. In surgical debridement, a scalpel or scissors is used to cut away the necrotic tissue. Wound debridement is a minor surgical procedure, but one that is performed by surgeons, physicians assistants, surgical assistants, nurses, and military medics and corpsmen. At present, this procedure is typically learned with actual patients under the guidance of a more experienced physician.

2. The Simulation-Based Training System

A simulation-based virtual reality (VR) training system for surgical wound debridement was developed to provide trainees with the fundamental knowledge and skills to perform the procedure through self-instruction and practice, thereby eliminating the need for one-on-one instruction. The system comprises a multimedia introduction, a surgical simulator (tutorial component), and an assessment component.

2.1 Multimedia Training Component

The multimedia training component describes varieties of wound categories (e.g., burns, lacerations, etc.); methods of debridement (e.g., sharp, mechanical, etc.), and equipment/materials used in the procedure. This module provides the pedagogical context for skills training and assessment, linking together all of the required elements for mastering the procedure. Pedagogical material and methodologies have been researched (e.g., [5]) and the system design stems from training requirements and iterative development obtained through consultation with domain experts.

Modules are arranged in sequential order to support educational advancement of the novice; however, the navigational menu design permits all items to be accessible at any time thereby also supporting the experienced user. Further, freedom to run the multimedia component on a platform other than the one used for the skills training makes it possible to support multiple users simultaneously.

2.2 Virtual Agent

A software virtual agent is included and performs the role of an instructor by providing verbal guidance and assessment feedback (see Figure 1a). Designed to be comprehensive in order to reduce the need for a more senior instructor, the software addresses the patient's condition, initial description of the injury, and provides instruction on operation of the simulator. Specific instructions cover the removal of foreign objects with forceps, scrubbing with a brush, rinsing with saline solution, and the maintenance of sterility. The trainee is prompted to move on when the current stage is satisfactorily completed. The current software implementation for the agent uses Haptek®[1] and NeoSpeech[2].

2.3 The Simulator: General Description and Technical Implementation

A prototype of the wound debridement trainer has been developed using the Derivative, Inc., API[3], for fast initial testing of user and design requirements (see Figure 1b).

[1] Haptek®, *PeoplePutty, Haptek Player SDK, Haptek® Player* viewed 10-17-05, http://www.haptek.com
[2] NeoSpeech, *Kate,* viewed 10-17-05, http://www.nextup.com/neospeech.html
[3] Derivative Inc. *Touch Designer,* viewed 10-17-05, http://www.derivativeinc.com/

OpenHaptics™ Toolkit (SensAble, Inc.) interfaces with a Phantom® haptic device (Omni™ or Premium) for wound interaction while viewing it on a Reachin display device [4,5]. A parallel research effort with an open architecture uses OpenSceneGraph alongside an FEM physics approach for increased flexibility and realism in the training application (see Section 3.2).

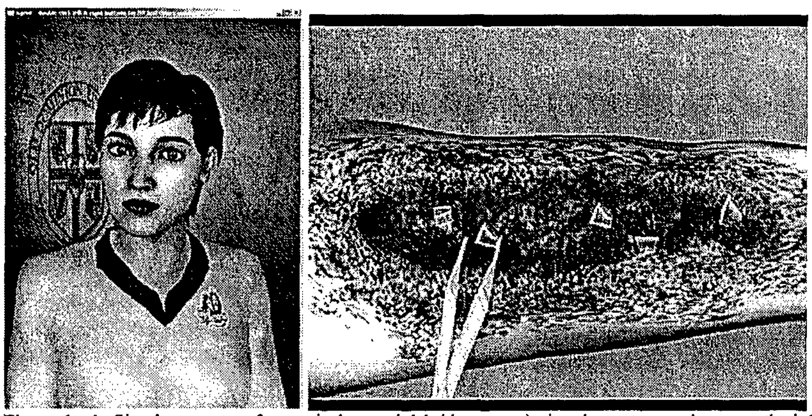

Figure 1a, b. Simulator system for surgical wound debridement: a) virtual agent tutor shown on the left and b) prototype system for removing glass shards from thigh laceration shown on the right.

2.3.1 The Anatomy and Wound

The simulator provides training on a shallow laceration wound to the thigh caused by a motorcycle accident. Our wound research focuses on the extremities and the leg model is derived from the National Library of Medicine's Visible Human Project [6]. Axial anatomical imagery is manually segmented, registered, and triangulated polygonal surface meshes of relevant objects are constructed. Subsequent to viewport culling, the skin mesh, as used in our prototype, is approximately 1000 polygons.

Foreign material embedded in the wound is modelled both geometrically and as surface texture. It is possible to render a high degree of dirt without an increase in computational expense as would be the case if debris implementation were pursued solely as geometry. Currently the majority of the debris (dust, dirt) is rendered as texture on the wound surface geometry while larger objects are polygonal meshes.

The simulation uses several textures for a range of the debridement processes (see Figure 2). Each polygon in the mesh is handled separately in terms of texture image while texture coordinates remain constant. The intersection between an instrument and surface polygon results in a substitute texture being called for that polygon.

Bleeding is implemented using a particle system. Particles are created only when instruments intersect with polygons within the wound area. Small amounts of gravity and randomness are added to particle motion. Upon collision with the wound surface, a particle's reflecting vector is reduced normal to the collision. These implementations contribute to a realistic rendering where particles slow down and approach the wound surface geometry over the duration of their lifespan.

[4] SensAble Technologies *OpenHaptics™ Toolkit, Phantom® Premium,, Omni™*, viewed 10-17-05, http://www.sensable.com

[5] Reachin Technologies *Reachin Display*, viewed 10-17-05, http://www.reachin.se/

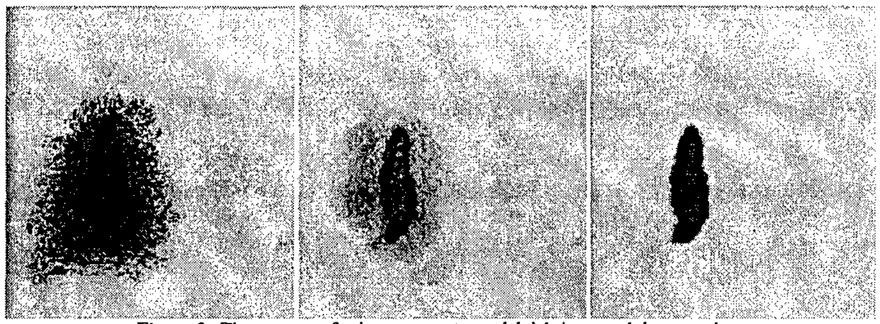

Figure 2. The concept of using textures to model debris around the wound.

2.3.2 Graphics and Haptics Simulation within the Prototype Application

A mass-spring simulation implemented within the prototype application and Derivative API drives graphics deformation. Approximately 200 nodes are deformed to restrict the simulation to those that fall inside the wound area (the remainder are fixed). All nodes have the same mass and drag and the spring is kept fairly stiff for stability.

A haptic model that does not update topological changes from the deforming mass spring model in Derivative has been implemented. Users do not readily perceive the limited synchronicity between the graphics and haptics implying an effective and economic implementation. The haptic rendering also supports grabbing points on both the deforming graphic and the haptic meshes (e.g., with forceps, see Figure 1b). Force is subsequently applied and the user feels tension through the haptic device. Releasing the tissue updates the graphical points back to their starting position. Both graphics and haptics applications of the simulator will run on a single laptop computer (i.e., with 3.2 GHz CPU; 1GB RAM; GeForceFX Go 5700). Running in parallel, the applications average 60Hz for graphics and 300Hz for haptics.

3. Ongoing Research and Development

3.1 Assessment

At present, assessment is limited to the amount of foreign material successfully removed from the wound and the time needed to perform the procedure. The next generation will include assessment modules for the didactic content addressing preoperative and postoperative care, performance-based feedback during the tutorial, summative feedback at the end of the tutorial, and assessment information for either the trainee or instructor. Performance-based assessment will target two types of errors. One set of errors is intended to be "recoverable". For example, removal of a very large shard of glass from the wound could cause a significant amount of bleeding. It would then be necessary for the trainee to stop the bleeding and proceed with the debridement. The second type of error is intended to be "unrecoverable". For instance, the trainee might damage a major blood vessel or nerve. At this point the simulation would terminate and feedback would be provided that describes the seriousness of the error, why it occurred, and how to avoid it in the future.

3.2 Development Platform

There are many fundamental challenges to developing a simulation system for an open procedure like surgical debridement. To address the issues in the current prototype using the Derivative API, a new solution employing more capable and flexible technologies is currently under research and development. The following briefly describes several major components under research and development:

- Object oriented software design and development are employed to ensure software quality, ease of component integration, future extension, and maintenance. Major classes of the simulator include tissue and instrument supporting the simulated objects and mass spring and finite element models underlying the physics-based models. Some auxiliary classes are also developed to facilitate computation, such as topology processing. In addition, the software components are not tied to a specific operating system specific and facilitate portability to other platforms.
- OpenSceneGraph, an open source high performance 3D graphics toolkit, is utilized for developing the visualization component of the debridement simulator. Utilizing scene graph technology and the latest OpenGL® 2.0 graphics, OpenSceneGraph has strength in performance, productivity, portability, and scalability. A variety of models are utilized for different computations. Volume mesh is used by tissue deformation and cutting simulation, while surface mesh used by irrigation simulation and collision detection. For computational efficiency, instruments are represented by a line segment(s) enclosing them for collision detection purposes.
- Removing necrotic or contaminated tissue with a scalpel or scissors is a critical procedure that differentiates between surgical debridement and other debridement approaches. Thus, simulation of tissue cutting in a surgical debridement simulator is essential. To effectively model and simulate the cutting procedure, a volume mesh is utilized to represent the wound region on the thigh. A surface mesh is extracted from the volume mesh to render the thigh graphically. Tissue cutting is simulated by deleting volume elements in contact with the cutting instruments, with color images from the visible human data set rendered as 3D textures.
- Mass-spring system and finite element method (FEM) approaches are implemented to simulate soft tissue deformation. Research is underway to build fast computational schemes to improve real-time performance for fast FEM computational methods, rapid neighborhood construction, and a hybrid structure of Mass-spring and FEM.
- XML, a simple and very flexible markup language, is selected as the file format to store the graphical and physical properties of the thigh model, including geometry, texture maps, topology, and FEM parameters. XML writer and reader programs have been developed to create and parse XML files.

The finite element code developed for the wound debridement application computes the 3D volumetric deformation of the leg model based on the displacement of a few surface nodes as determined by the collision detection module. The current model assumes all materials are either linear elastic or rigid. Rigid materials, (e.g., bones), can be represented by applying 0-displacement boundary conditions to an appropriate subset of the model's nodes. The stiffness of elastic tissues in the model can be varied according to segmented tissue type.

The finite element code was written specifically for the purpose of interactive simulation. It makes use of sparse matrix data structures and efficient LASPACK sparse matrix solution routines. Incremental updates to the stiffness matrix are made as the model mesh is cut during the simulation. The finite element code provides as output: (1) the displacement of every node in the model, and (2) the force vector in effect at every node. The force vector that is computed at the point of contact between a surgical instrument and the deformable model defines the force that should be haptically displayed to the user. Currently, the finite element code computes a deformation solution at a rate of 60-70 Hz for a model with 400 elements and 20-30 Hz for a model with 1100 elements which is sufficient for graphics. Further optimization of the code to improve efficiency and a parallel implementation is planned.

4. Conclusion

A simulator-based training system was developed for surgical wound debridement. The goal was to create a system that would allow health care providers to acquire the fundamental knowledge and skills to perform the procedure through self-instruction. The current system contains a multimedia component for didactic material, a tutorial, and a VR-based simulator with haptic feedback. Trainees can learn to clean to a wound and remove foreign objects. However, many technical challenges remain to improve the realism of the graphical and haptic displays. These include: 1) more realistic tissue deformation using mass-spring and finite element models, 2) better collision detection, 3) incorporating tissue cutting, and 4) adding two-handed haptics because debridement is typically performed using both hands. It is expected that solutions to these challenges will not only help to refine the physics-based models underlying the anatomy and physiology represented in the system, but will also expand the variety of wounds that can be included in the set of training cases.

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Simulation Advances in Medical Education and Training: Laparoscopic Skill Acquisition

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Abstract

The number of fatalities attributable to medical errors in the United States has recently come under intense scrutiny. In response to this problem, medical schools are seeking alternative methods to train their students. One of the methods currently being used to enhance medical training is simulation. In surgery, the most common type of simulators target laparscopic procedures and the Minimally Invasive Surgical Trainer Virtual Reality (MIST VR) is the most widely studied laparoscopic simulator. Despite its research exposure, however, few studies have demonstrated the transfer of skills learned on the MIST VR to procedures performed on genuine patients. Further, most of the research to date is not tied to any theories of learning. The purpose of the present paper is to describe current research on laparoscopic training with simulators and discuss the need for theories of learning and skill acquistion in future research.

Medically-Related Deaths and the Classical Model

Recent research reveals that patients incur an increased risk to their safety when they receive hospital care. In a report issued by the Institute of Medicine (IOM), it was estimated that between 44,000 and 98,000 deaths can be attributed to medical errors each year in U.S. hospitals (Kohn, Corrigan, & Donaldson 1999). Further, it was noted that patient care associated with surgery, accounted for 35-48% of all adverse events. Statistics such as these have helped to sharpen the focus on patient safety. However the estimate of deaths has encouraged other researchers to take a closer look at the context in which these deaths occur. Hayward and Hofer (2001) offered a more conservative estimate of deaths due to medical error. In their study, they assessed not only deaths due to medical error, but also the likelihood that the death could have been prevented with better care. Their assessment sampled deaths for a one year period in seven Veterans Affairs in Virginia hospitals. , The reviewers determined that out of 111 fatalities, death might have been prevented in 23% of cases, and was probably preventable in 6% of cases. The authors noted that these percentages are similar to those reported in other studies (e.g., Brennan, Leape, & Laird 1991; Hayward, McMahon, & Bernard 1993) which reviewed death rates due to medical error. More important, however, the reviewers judged that about one third of the patients would have survived for only another three months or so had they been given optimal care. These findings suggest, that the estimate of hospital-related death rates in the IOM report due to medical errors may have been inflated because the population upon which they were based is often older, terminally ill, and may also include do not resuscitate orders.

Other research, however, using different a methodology and definitions of errors, found that the earlier estimate of deaths reported by the IOM may have been too *conservative.* The HealthGrades report (2004) included Medicare data from all 50 states over a three-year period.

Patient safety incidents (e.g., failure to rescue, foreign bodies left during a procedure, infections due to medical care, etc.) were tallied for living and deceased individuals. The findings from the HealthGrades report suggested that nearly 195,000 deaths occur each year because of hospital related medical errors. Further, if patient death due to medical error was listed as a formal cause of death by the Centers for Disease Control and Prevention, it would rank number six among all leading causes. More important, the study also indicated that deaths due to medical error have shown no signs of decreasing from the rates first published in the IOM report.

Errors that compromise patient safety may be due, in part, to the classic teaching model in medicine. Training in the medical profession has typically followed an apprenticeship model, whereby students learn and train under the supervision of a more experienced professional (Kauffman, 2001). Unfortunately, this model may create inconsistent training and practice across students. Shimada et al. (1998) expressed several disadvantages associated with clinical training under the apprenticeship model: a) students typically will not encounter all possible pathologies during their time of training, which can hinder their ability to recognize and diagnose pathology they have never encountered before; b) there may be fewer opportunities for less experienced students to practice uncommon procedures when confronted with very sick patients; and c) there is a need for patient cooperation, and many patients may choose not to be cared for by student physicians.

Satava (2004) noted that surgical training has never faced a more challenging set of circumstances. Financial policies concerning reimbursement continue to draw down funds needed for training. Resident work hours have also been reduced in an attempt to standardize training. Others have also noted that reductions in training time as well as limited operating room exposure can produce students and residents who have deficient technical abilities

(Feldman, Sherman, & Fried, 2004). Kauffman (2001) also noted two other sources of problems in surgical education: 1) teachers have fewer hours to train residents, and 2) residents have fewer hours of patient contact. Twenty years ago, patients were typically admitted to the hospital for a period of one to two days, which allowed residents to spend many hours learning from each patient. Today, however, patients spend substantially less time in the hospital, which leads to a decrease in patient contact time for the resident. Fewer hours of patient contact, in turn, may ultimately result in missed learning opportunities for the resident.

Another problem with the reduction in resident hours concerns the opportunity to become technically competent on a wide range of procedures. Surgeons are expected to learn and master many different psychomotor skills despite the potential inconsistencies associated with their training, such as exposure to different types of surgery, patients, and different curriculum criteria. Hamdorf and Hall (2000) noted that surgical skills require three general stages for mastery. The first stage is associated with cognition and perceptual awareness; that is, an individual must understand the task and skills to be performed as well as the spatial relations and mechanical requirements involved. During the second stage, the newly acquired motor techniques are integrated with their application. In the third stage, the techniques are practiced, thereby permitting the development of new motor skills that can be performed more efficiently and with greater precision. Although Hamdorf and Hall were describing skill acquisition as it relates to surgery, an extensive literature on the nature of psychomotor skills in general does exist.

Skill Acquisition

Skills can be described as an individual's learned capability to perform specific acts (Farmer et al., 1999). Skills are acquired by making a permanent change in the way an act is performed through intentional or incidental learning. Psychomotor skills are coordinated muscular movements of the body that follow a motor schema. A motor schema has been described as a memory for motor skills that have been well learned and operate independently of perceptual feedback information (Schmidt, 1975). Psychomotor skills can be divided into fine and gross categories (Holding, 1987). Fine psychomotor skills are those that usually involve detailed manipulations of a specific part of the body (e.g., fingers, hands, etc.). Gross motor skills are those that involve whole-body movements.

In order for an individual to successfully acquire fine psychomotor skills they must practice. One of the most important issues concerns the amount of practice needed to learn a psychomotor skill. Crossman (1959) demonstrated that motor skill acquisition can be described with respect to performance speed and amount of practice. Performance speed and practice follow a log power function, such that initially, performance speed is quite slow when practicing the task. However, with more practice, performance speed increases. The increase in performance speed is thought to result from decreases in attentional resource demands that allow the skill to be performed in an automated fashion (Wickens & Hollands, 2000). However, performance speed does not increase linearly with extended practice. Instead, it increases at a decreasing rate and eventually, additional practice on the task will result in only minimal gains in performance speed.

Overlearning is another issue related to practice. Wickens and Hollands (2000) noted that overlearning occurs when an individual continues to practice after he or she has met the performance criterion. As noted previously, overlearning does not necessarily decrease the amount of time it takes to perform the task. However, overlearning does enable the individual to make the newly acquired skill more automatic. That is, the motor program developed through additional practice comes to require fewer cognitive resources. Wickens and Hollands (2000) suggested that for skills not practiced on a routine basis, overlearning will enhance the probability that the skills will be retained over time.

Another important aspect of practice concerns how sessions are structured. Specifically, schedules of practice can be either massed (performed all at one time) or distributed (performed in intervals over a period of time). Farmer et al. (1999) discussed the advantages and disadvantages associated with each schedule of practice. For psychomotor skill acquisition, training sessions that are massed rather than distributed, usually result in poorer skill acquisition (Schmidt & Lee, 2005). Also, performance assessed immediately after completion of training is poorer and more variable under massed practice (Lee & Genovese, 1988). Farmer et al. (1999) noted that the poorer performance associated with massed practice sessions is usually due to fatigue as well as decreases in motivation. However, if distributed practice sessions are employed, performance during and immediately following training is more consistent. When performance is assessed for skill retention both massed and distributed schedules of practice can produce both similar and dissimilar effects (Farmer et al. 1999; Holding, 1987). Discrepancies in the literature may be due to fatigue, retention intervals, durations of work/rest cycles, and the nature of the task. Schmidt and Lee (2005) suggest that the benefits of distributed over massed schedules of practice must be separated from the effects of fatigue present during training and assessment performed at a later time. Moreover, they note that much more is known about continuous as opposed to discrete tasks. In fact, they indicate that there may be benefits to massed practice schedules over distributed schedules for discrete tasks.

Training is also an important aspect of skill acquisition and concerns "how" skills are acquired. Training can be accomplished by practicing the skills on the whole task or part of the task. Often training on the whole task is not possible. Thus, part-task training incorporates a subset of the elements necessary to acquire the skills. Part-task training is usually accomplished by either segmenting the task (i.e., decomposing each phase of the task into subcomponents to be practiced), or fractionalizing (i.e., dividing the task into two or more components that are performed together; Wickens & Hollands, 2000). Part-task training has been found to be beneficial for serial tasks, but less so for continuous tasks especially where there are strong interdependencies among the parts (Schmidt & Lee, 2005).

Another type of practice that is crucial for successfully acquiring psychomotor skills is guided training. Wickens and Hollands (2000) noted that under a guided training paradigm, an individual's performance is monitored so that progress adheres to the task requirements. Errors in learning are corrected to ensure that they are not repeated. Guided training usually involves providing feedback to an individual about their training and practice performance in the form of knowledge of results. Providing knowledge of results can help individuals maintain motivation and enhance performance by continually reducing the error between current levels of performance and the criterion (Holding, 1987). Wickens and Hollands (2000) suggested that training performance is likely to benefit most when knowledge of results is provided immediately after a performance or session.

If the goal is efficient psychomotor skill acquisition and retention, then an understanding of the principles of overlearning, schedules, and training is necessary. That is, tasks that reinforce psychomotor skills should be overlearned through distributed practice sessions so that the individual does not become fatigued or unmotivated. Further, overlearning will enhance the probability of skill retention when performed at a later time. Also, part-task training should be conducted by decomposing or dividing the tasks so that each subcomponent reinforces the skill to be acquired. Finally, using guided training by providing knowledge of results will help to enhance training performance and initial skill performance.

Medical Simulators: Part of the Solution

Simulation technology has been proposed as a partial solution to help promote the acquisition and retention of surgical psychomotor skills (Kauffman, 2001; Macintyre & Munro, 1990). There are significant disadvantages associated with clinical surgical training today, as noted above. However, simulators could be used to help students acquire skills in a manner not possible during clinical training. Kauffman (2001) noted that surgical simulators provide students more time to practice newly acquired skills. Further, students can be required to reach a specific level of proficiency before being able to practice their skills on a patient. Simulators also allow students to make mistakes and learn from them without endangering patients. Perhaps the most important advantage of medical simulation technology is that it can help change the classic teaching model of "see one, do one, teach one", to a more structured training model of, "see one, practice many, do one, teach one" (Kauffman, 1999). Obviously, a new model that incorporates additional time for practice is advantageous not only to medical students and residents, but also to the patients.

Types of Medical Simulators

Medical simulators can be classified into three categories: mannequin, virtual reality (VR), and hybrid. Mannequin-based simulators are physical representations of the human body and its anatomy. One example of a mannequin-based simulator is the TraumaMan® system by Simulab, Inc (Figure 1). The TraumaMan® system is a realistic anatomical model of the neck, chest, and abdomen that has replaceable tissue and fluid components. The TraumaMan® system is used for Advance Trauma Life Support (ATLS®) training and allows students to perform procedures on a realistic representation of human anatomy. The main advantage of mannequin-based simulators is that students can practice with a simulator just as they would with a genuine patient. However, mannequin-based simulators do not provide objective performance assessment. Thus, an experienced physician must assess trainee performance, which can lead to subjective assessments.

Figure 1. Student performing a thorocostomy (chest tube insertion) on the TraumaMan® by Simulab, Inc.

Virtual reality simulators, by contrast, are based on computer simulation, as opposed to physical models. These types of simulators include visual, auditory, and haptic displays that enable individuals to see, hear, and feel the effects of their actions. Virtual reality simulators also allow students to interact with the simulator and receive objective feedback in real time (Satava, 2001). Thus, when students interact with the simulator, they can receive immediate feedback regarding their performance. Virtual reality simulators can be either whole-task or part-task trainers. An example of a whole-task VR simulator is the Endoscopy AccuTouch® simulator from Immersion Medical, Inc. (Figure 2). The Endoscopy AccuTouch® simulator has a colonoscopy module which simulates the entire procedure. The trainee manipulates a facsimile of a colonoscope while viewing images of the colon on the computer monitor. Haptic feedback is provided throughout the procedure and gives cues as to the difficulty of various maneuvers (e.g., when turns and loops of the colon must be navigated). The patient's voice also provides information regarding the quality of the student's performance. Training on the full procedure has advantages because it allows individuals to learn the proper sequence of steps and transitions between steps. However, when first learning to perform a complex procedure, it may be beneficial to learn individual parts of the task and then later recombine the parts in order to perform the full procedure.

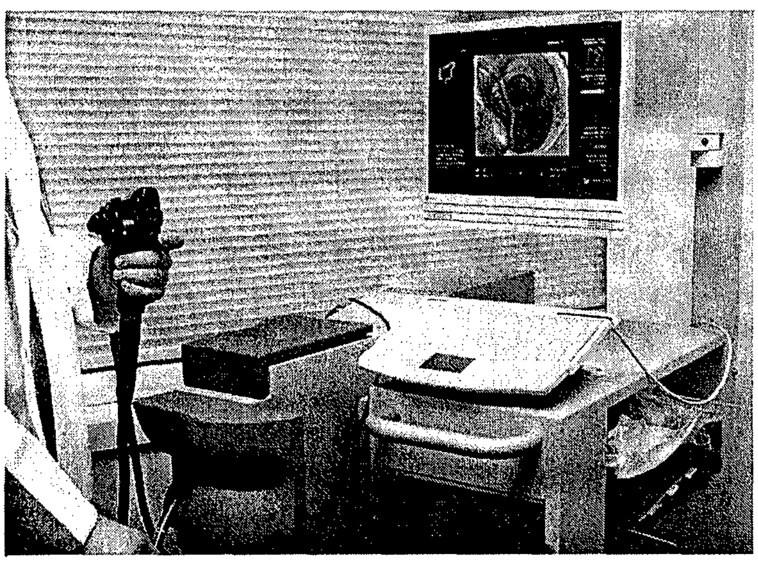

Figure 2. Virtual reality simulator for colonoscopy from Immersion Medical, Inc.

One VR simulator that allows the individual to practice parts of a task, rather than the whole task, is the MIST VR (system produced by Mentice AB, see Figure 3). The MIST VR is designed for laparoscopic surgery; however, it does not simulate any procedural aspect of laparoscopic surgery. Instead, it allows the trainee to practice the basic skills necessary to perform minimally invasive surgery in a variety of subtasks. For example, one MIST VR task requires students to touch simulated spheres with the tips of their laparoscopic instruments. The main advantage of learning and practicing skills on a part-task trainer is that the individual does not become overwhelmed by learning the full procedure all at once.

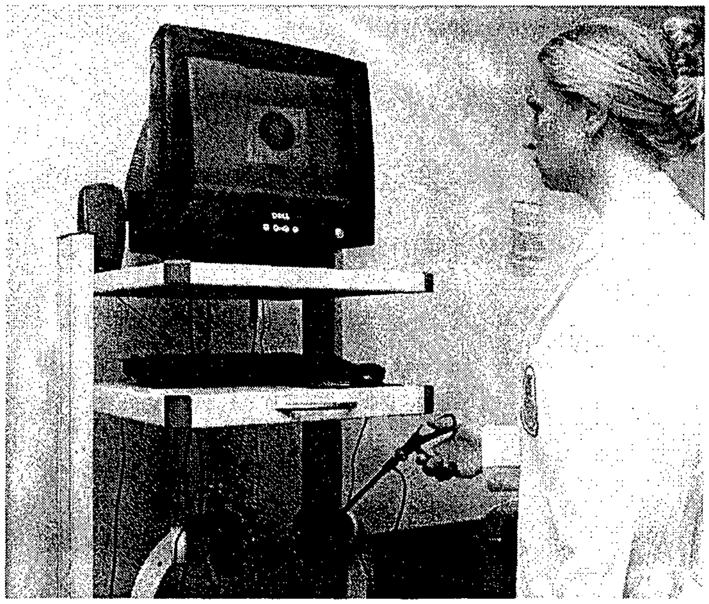

Figure 3. The MIST VR simulator for basic laparoscopic skills (by Mentice AB).

Hybrid simulators are those that incorporate aspects of VR computer-based systems into mannequin simulators (Satava, 2001). These simulators have certain advantages as well. Not only are individuals able to interact with a mannequin that represents typical human anatomy, but they can also receive some objective feedback regarding their performance because the simulator is built on a computer platform. For example, the UltraSim® system is a hybrid ultrasound training simulator that contains a mannequin abdomen, hand held ultrasound probe, and computer to display the images from the abdomen (Figure 4). As noted earlier, one of the disadvantages associated with mannequin-based simulators is that they often lack patient or case variety. Although this disadvantage is also true of the mannequin portion of hybrid simulators, the virtual components help to over come this limitation.

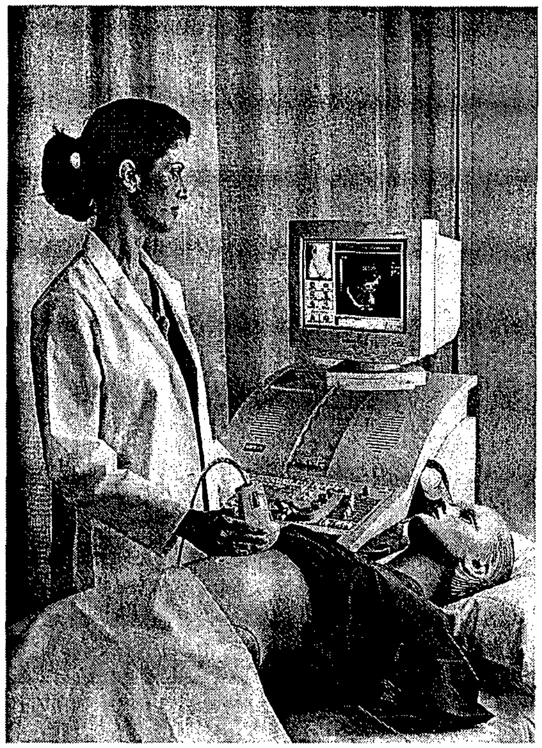

Figure 4. The UltraSim® hybrid ultrasound training simulator by MedSim, Inc. (photo provided courtesy of MedSim, Inc.)

All of the simulators described above allow students to practice in a safe environment. Thus, students are free to make errors and learn from their mistakes without putting patients at risk. Given the concerns regarding patient safety described above, the development and use of medical simulators may help improve the quality of healthcare and reduce the incidence of medical errors.

Laparoscopy and Simulation Technology

The majority of medical VR simulators available today target laparoscopic skill acquisition. Minimally invasive surgery, via laparoscopy, was quickly embraced during the late 1980s as a safer way to operate on patients. Laparoscopic surgery is performed using instruments and a miniature video camera that are inserted through small incisions in the body.

The images from the camera are displayed on a monitor and allow the surgeon to view his/her actions while performing procedures.

Laparoscopic procedures are more amenable to VR simulation for many reasons. For example, during laparoscopic procedures, surgeons can only manipulate patient anatomy indirectly with the instruments that pass through the incisions in the body. The indirect access to the patient's anatomy does not allow the surgeon to feel the haptic sensations associated with direct contact of the tissues and organs. In open surgery, although surgeons still manipulate the patient's anatomy with instruments (e.g., scalpel, forceps, etc.), they can also directly touch and feel the patient's tissues and organs.

As Biggs and Srinivasan (2002) have noted, the degree of difficulty involved in haptic VR simulation depends upon whether the object and user interaction is direct (i.e., with the fingers and hands) or accomplished with a tool (i.e., tip of a laparoscopic instrument). If the haptic simulation can be achieved with a tool, then the haptic interface design is less complex and easier for VR designers to simulate. The reduced complexity is due to point-based haptic interactions that occur when the end of a tool comes in contact with a specific point on an object. In virtual systems, when the end point of a simulated tool contacts a simulated object, collision detection and collision response rules are used to engage the force feedback system and constrain the user's movement (Biggs & Srinivasan, 2000). The collision algorithms are fairly easy to render in a point-based haptic system and therefore lend themselves to laparoscopic procedures because much of the activity occurs through single points of contact.

The visual representation of the surgeon's movements and manipulation of anatomy is another major issue concerning laparoscopic VR simulators. Designers must represent 3D anatomy and on a 2D display monitor. Although this is a challenge, it is not as difficult as attempting to realistically represent the anatomy in 3D. Thus, laparoscopic procedures are probably more accessible to designers of VR simulators.

It is indeed fortunate that there are fewer technical challenges simulating laparoscopic procedures because this type of surgery is more challenging for the surgeon. The skills required to perform laparoscopic surgery are very different from that of open surgery. Further, because laparoscopic surgery was quickly adopted, the difficulties associated with the procedures were not fully investigated. Deziel et al. (1993) surveyed U.S. hospitals on their major operative complication rates for laparoscopic cholecystectomy (i.e., gall bladder removal) and found that nearly 60 percent of reported injuries were to the patient's bile duct, the most common complication. The other most common injuries were to vascular and bowel tissue. Deziel et al. suggested that despite higher complication rates with laparoscopy, the procedure is generally safe. Moore and Bennett (1995) also assessed laparoscopic cholecystectomy complication rates and found that most complications result from relatively inexperienced surgeons (i.e., complications usually occur within the first thirty cases). Moore and Bennett performed a regression analysis on their data and noted that bile duct injuries could be expected to decrease from 1.7% for the first case to 0.17% after completion of 50 cases. Moore and Bennett also noted that the speed with which the procedure was implemented in the late 1980s, along with the absence of research on training, and risks and benefits to the patient, were likely contributors to the higher complication rates.

Although laparoscopic procedures seem to have higher complication rates for less experienced surgeons, it is still the preferred surgical method for many procedures. One reason for its wide acceptance rests with the benefits for the patient (Munz et al., 2004). The most important benefit is a lower risk of complications following surgery in patients who undergo laparoscopic procedures. Another advantage for patients is the cosmetic appeal of laparoscopy. Patients typically have less visible scarring. Patients also have a quicker recovery time after laparoscopic procedures. Although laparoscopic procedures and techniques have resulted in important benefits for the patients, surgeons face more challenges when performing laparoscopic surgery.

Gallagher and Smith (2003) have described some of the difficulties surgeons face with the minimally invasive technique. In particular, laparoscopy creates new perceptual, spatial, and psychomotor demands for the surgeon. Gallagher and Smith (2003) and Gallagher et al. (2003) point out that perceptually, the surgeon must translate information that is presented on a 2D monitor into a 3D mental model of the human anatomy. Others have also noted that the surgeon performing laparoscopy must compensate for navigating in a 3D environment with a 2D monitor by using depth cues other than stereopsis (Ahlberg et al., 2002).

The fulcrum effect is another perceptual problem that surgeons encounter during laparoscopic surgery. Because laparoscopic instruments pass through into small incisions in the body, the amount of space available to move the instruments is limited. Further, the instruments must be pivoted around the insertion point in the patient's body, thereby creating a fulcrum. When the instrument is moved in one direction, it appears as if it is moving in the opposite direction on the monitor. Thus, the fulcrum effect refers to the perceptual incongruency between the perceived physical movement and the representation of that movement on the display monitor. Gallagher et al. (2003) noted that the fulcrum effect creates psychomotor difficulties for laparoscopic surgeons. Further, the incongruence between the image seen on the monitor and the surgeon's mental model of what the anatomy should look like can also be a problem. For example, the patient's anatomy can look distorted depending upon where the laparoscope is located (i.e., if the laparoscope is too close or too far away from the anatomy).

Ergonomics is also an issue in laparoscopic surgery. Hanna et al. (1998) noted that there can be problems with the location of the display monitor. Often the monitor is placed to the side of the surgeon's field of view because laparoscopic surgery is performed in operating rooms that were traditionally built to accommodate open surgery and thus lack the space required for the laparoscopic equipment. Hanna et al. conducted a study in which endoscopic knot tying and overall knot quality in a box-trainer (see below) were assessed with different monitor positions. They found that when the monitor was placed slightly below the head and close to the surgeon's hands, knot-tying time decreased and overall quality of the knot increased. Hanna et al. concluded that this monitor position was associated with better surgical performance. However, they did not report the amount of prior endoscopic knot-tying experience their participants had. It is possible that their participants may have had extensive practice on a box trainer, which traditionally places the monitor close to the hands and directly in front of the head. In an actual operating room, positioning the monitor directly in front of the surgeon and closer to his/her hands may not be possible due to the need to access the patient in the case of an emergency.

To overcome some of the difficulties associated with laparoscopic procedures, surgeons have turned to a variety of training methods to facilitate skill acquisition outside the OR. The training methods are tied to two different classes of simulators: box trainers, which are similar to mannequin simulators, and VR-based systems.

Laparoscopic Box Trainers

Box trainers have been used to help surgeons acquire the skills necessary to perform laparoscopic surgery. They usually consist of a box-like structure with a camera and light source that displays the images inside the box trainer on a monitor (Figure 5). An opaque covering prohibits direct viewing inside the box, thus, allowing only the images on the monitor to be used as cues. Standard laparoscopic instruments are then used to manipulate various objects within the box trainer. The tasks typically associated with a box trainer include placing objects on a pegboard, cutting fabric, and applying clips. There is an assumption that the skills learned using the box trainer will transfer to an actual laparoscopic procedure. However, this assumption has not been extensively or objectively confirmed in the literature.

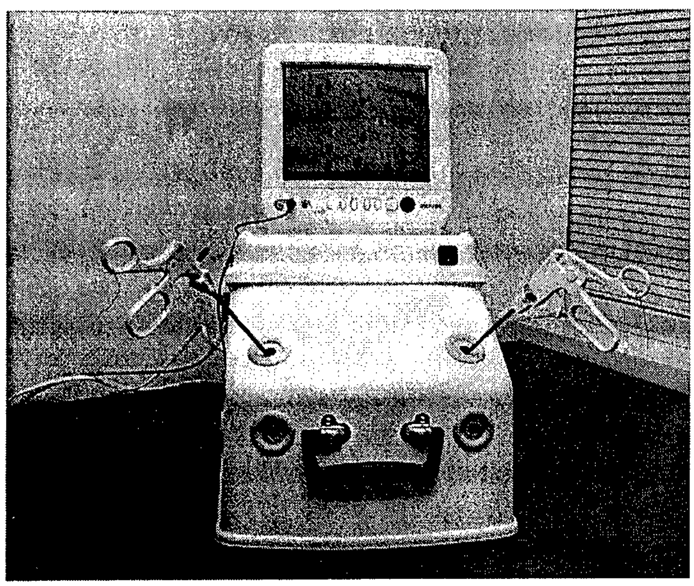

Figure 5. The laparoscopic box training system by 3-D Technical Services, Inc.

Two examples of research with box trainers suggest that evidence for the transfer of laparoscopic skills is lacking. Derossis et al. (1998) used a box trainer to develop objective measures of laparoscopic skills. They asked surgical residents to perform a series of laparoscopic box trainer tasks (e.g., peg board transfers, cutting, and suturing) and then assessed their performance speed and precision. Derossis et al. found that those who were further along in their residency, performed significantly better than newer residents. They suggested that box trainers can provide objective measures of laparoscopic skills because they can differentiate performance among years in residency and amount of practice. Another interesting finding from this study concerns performance on the individual tasks. When performance speed and precision of laparoscopic surgeons was compared to nonlaparoscopic surgeons, laparoscopic surgeons significantly outperformed nonlaparoscopic surgeons on only three of the seven box trainer tasks: pegboard patterns, pattern cutting, and intracorporeal knot tying. The tasks which did not produce a significant difference between the groups were clip application, placement of ligating tube, mesh placement over a defect, and extracorporeal knot tying. This finding suggests that the latter set of box trainer tasks may not have been difficult or unique enough to laparoscopy to distinguish between the groups. Also, because all participants were only assessed on a box trainer, it is not known whether these results would be replicated in real laparoscopic surgery.

One of the more challenging laparoscopic tasks is intracorporeal suturing, or the ability to tie knots within the patient's body. Korndorffer and his colleagues (in press) used a box training system to train residents on this skill. Importantly, the residents were required to perform the knot-tying task in a porcine laboratory (i.e., on a live pig) before and after training. The residents trained on the Storz Endoscopy videotraining system that included foam pads for suturing. Korndorffer et al. observed that the residents needed 151 minutes of practice on the box trainer, on average, to reach performance levels comparable to those of an expert group on that training system. Results from the porcine tests showed that the trainees achieved significant gains in performance from the pretest to posttest on several measures, but they did not achieve the same levels exhibited by the experts in the porcine lab. The authors concluded that the box training system does produce positive transfer to genuine operating procedures, but at a lower level than what would be expected from expert surgeons.

Macmillan and Cuschieri (1999) used a different box trainer known as the Advanced Dundee Endoscopic Psychomotor Tester (ADEPT) in an attempt to predict how well innate surgical abilities correlate with surgical performance. ADEPT is an advanced box trainer because it is computer based, thus allowing the software to dictate the training regimen and record performance indices. However, the tasks to be performed are similar to traditional box trainer tasks and primarily require object manipulation. Ten surgical residents were given approximately one hour of training on the ADEPT simulator. Expert surgeons then rated the clinical skills of the trainee surgeons. Macmillan and Cuschieri (1999) found a significant correlation ($r = .79$) between participant success rate on ADEPT and clinical skills assessed on actual laparoscopic surgery.

Box trainers, though still widely used, are now giving way to VR-based simulators. Box trainers are relatively static, in that only a small number of elements can be changed for further practice. Virtual reality simulators, however, allow for a more dynamic interaction (e.g., increased case variety, real-time interaction, etc.).

Virtual Reality Laparoscopic Trainers

Virtual reality trainers have an important advantage over box trainers because they allow a wider range of performance indices to be quantified and recorded. The Minimally Invasive Surgical Trainer (MIST VR) is the most widely used and researched VR trainer. It consists of a PC with a laparoscopic interface that can track and translate instrument movements into 3D graphics displayed on the monitor (Sutton et al., 1997). The MIST VR has five main components: tutorial, training, examination, analysis, and configuration. The training component consists of six different tasks including target placement, target diathermy, tool withdrawal and insertion.

MIST VR Learning Curves and Sensitivity

Because the MIST VR has been studied extensively, a number of performance criteria are available for review. Chaudhry et al. (1999) assessed the learning curves on six MIST VR tasks over 10 trials for 11 surgeons and 7 nonsurgeons (hospital staff). Their results showed that although the overall scores of experienced surgeons were significantly better on all tasks (demonstrating that the MIST VR has sensitivity), there were no significant differences in the learning curves or familiarization rates between the two groups. All participants took up to three sessions to familiarize themselves with the tasks and learn the processes, including how to correctly manipulate the instruments. However, another study of learning curves associated with MIST VR revealed significant differences in the familiarization curves for surgeons with different levels of laparoscopic experience (master, intermediate, and beginner). Grantcharov et al. (2003) assessed the surgeons on all six MIST VR tasks 10 separate times within a one-month period. They found that master surgeons had a steeper learning curve for the tasks than surgeons with less laparoscopic experience. The familiarization curves for master surgeons differed significantly from those of intermediate and beginner surgeons on several measures including time, errors, and unnecessary instrument movements. Intermediate surgeons were also found to have more rapid familiarization curves for the tasks than beginner surgeons. Brunner et al. (2004) studied skill acquisition with MIST VR over an extended period of time (i.e., approximately 7 hours). An analysis of the learning curves indicated that skills were acquired in successive stages and that even after 7 hours and 30 task repetitions, improvements in performance had still not reached their final plateau. Collectively, these studies with MIST VR demonstrate that the simulator is sensitive and can differentiate between individuals with different levels skill and surgical experience.

Overcoming the Fulcrum Effect

As noted above, the fulcrum effect refers to the incongruency between real and displayed movements that occur during laparoscopic surgery. Gallagher et al. (1999) assessed the degree to which MIST VR could help individuals overcome the fulcrum effect with participants who had no prior experience with endoscopy procedures. Half were trained on the MSIT VR and the other half served as the control group. After completing MSIT VR training, all participants were asked to perform a cutting task with a box trainer. Their results demonstrated that the individuals trained on MIST VR made significantly more correct incisions in a standard box training task when compared to the control group. Gallagher et al. (1999) suggested that the superior performance of the MIST VR trained group could be attributed to their being able to acclimate to the fulcrum effect more quickly. Jordan et al. (2000) also studied the fulcrum effect with the MIST VR and compared it to standard laparoscopic training conditions (i.e., with a box trainer). They assigned participants to one of three training conditions: 1) MIST VR, 2) a box trainer with randomly alternating normal and y-axis inverted views, and 3) a box trainer with normal laparoscopic views. Participants were given a pretest on a box trainer cutting task, six training tasks during one of the three conditions, and then a posttest on the same box trainer task. They found that participants trained on MIST VR made significantly more correct incisions on the posttest, followed by those in the randomly alternating condition, and then those in the normal laparoscopic condition. Jordan et al. (2000) suggested that training on MIST VR helped individuals acclimate to the fulcrum effect more quickly than training on a standard box trainer. However, the superior performance of those trained on MIST VR described in the studies above has only been demonstrated on box trainer tasks. Obviously, the critical test for MIST VR training requires that the skills learned in the simulator transfer to the operating room with real laparoscopic procedures performed on genuine patients.

Transfer of MIST VR Acquired Skill

To date, there have been only two attempts to validate transfer of MIST VR acquired skills to real laparoscopic procedures. In the first study, the goal was to determine whether skills acquired on MIST VR would transfer to a real laparoscopic procedure performed in a porcine laboratory. Alhberg et al. (2002) used fourth-year medical students who had no prior endoscopic experience. Half of their participants received two training sessions on MIST VR for a total of three hours, and the other half received no training. All participants then performed an appendectomy on a pig. The surgical sessions were recorded and scored by three observers for five relevant performance metrics (e.g., grasping bowel, cutting ligature, loop ligation, etc.). Alhberg et al. (2002) did not find any significant performance differences between the MIST VR and untrained groups. The authors suggested that absence of any performance benefit for MIST VR may have been due to the lack of haptic feedback. Thus, MIST VR may facilitate hand-eye coordination, but fails to provide the haptic sensations important for real laparoscopic procedures. Therefore, when MIST VR trained students had to perform the pig appendectomy, they may have been familiar with the visual issues associated with laparoscopic surgery, but had to acclimate to the haptic sensations associated with manipulating tissue.

Unlike Alhberg et al. (2002), Seymour and his colleagues (2002) attempted to determine whether MIST VR acquired skills would transfer to genuine laparoscopic procedures performed on human patients. Seymour et al. (2002) used surgical residents who were in their first to fourth year of training and assessed their fundamental abilities (i.e., visuospatial, perceptual, and psychomotor abilities). Half were assigned to MIST VR *plus* standard training and the other half to *only* standard training. The authors noted that the standard training was appropriate for their level of residency, but did not provide exact details regarding the nature of that training. The group that received training on MIST VR completed a single training session lasting one hour. Following training, all residents watched a video about laparoscopic cholecystectomy and then performed the procedure under the supervision of a surgeon. All of the procedures were recorded and assessed by surgeons who were blind to each participant's condition. Seymour et al. (2002) found that residents who trained on MIST VR and received standard laparoscopic training, completed the laparoscopic cholecystectomy in 29% less time than their counterparts in the standard only condition. Those trained on MIST VR also committed fewer errors during actual gall bladder removal than those in the standard only group. Seymour et al. argued that training on a VR simulator can produce transfer of laparoscopic skills to the operating room. However, it is important to remember that their VR group received standard training in addition to MIST VR training. Thus, one cannot determine the degree of improvement associated with MIST VR training relative to another group receiving another form of training for comparable duration.

Conclusion

The research regarding training on MIST VR demonstrates some benefits for laparoscopic skill acquisition. However, the extent of those benefits is still not known. To date, there have been no studies that suggest training solely on MIST VR will enable individuals to acquire necessary laparoscopic skills compared to other training devices (e.g., using a box trainer). The degree of skill transferability acquired with surgical simulators is just one problem medical educators must consider.

Another problem with incorporating simulators into medical school training or residency curricula is that many of the simulators have not achieved a sufficiently high degree of realism. Satava (1993) suggested that medical simulators must have adequate fidelity, objective images that behave according to their anatomical properties (e.g., tissue that is displaced properly when touched or grasped), an element of interactivity, and haptic qualities. The MIST VR, for example, is a part-task trainer using only abstract tasks. The MIST VR also lacks haptic force feedback, yet it is still the most widely researched surgical simulator on the market. Satava (2001) noted that designers of medical simulators must still address the tradeoff between visual fidelity and interactivity. That is, efforts to maximize visual fidelity are often achieved at the expense of interactivity and vice versa. However, Satava (2001) noted that the biggest challenge associated with training individuals on medical simulators concerns the optimal ways of incorporating them into a curriculum where they can be used for skills training and evaluation.

Another criticism of medical simulators is that they may dehumanize the healthcare profession, which seeks to care for individuals (Issenberg et al., 1999). Some critics fear that by focusing on computerized machines (i.e., simulators) for a portion of medical training, students may be missing the importance of personalized patient care. However, as Issenberg et al. (1999) suggest, patient care can still be learned at a later time, after students have been able to familiarize themselves with medical procedures and pathology. Thus, simulators in medical education must achieve a degree of realism that is currently lacking and their use needs to be balanced with real patient interactions.

Although many medical simulators are now being used in education and training, their efficacy must still be considered (Satava, 2001). For a simulator to be truly effective, it must exceed the benefits currently provided by standard methods of training. Therefore, educators must be aware of the limitations associated with using simulators to train students. Often using simulation as a training method enables individuals to acquire only some of the skills associated with a procedure or task. For example, when students train on MIST VR they are able to acquire the fundamental psychomotor skills associated with laparoscopic surgery. However, because MIST VR is only a part-task trainer, students must also familiarize themselves with relevant anatomy and the details of specific laparoscopic procedures. Educators must assess the benefits and limitations of simulators and make decisions regarding their appropriateness and place in the curriculum.

The decision to incorporate simulation training into a curriculum is not only dependent upon the potential training benefits, but also the financial costs involved. Satava (2001) noted the financial challenges associated with using simulation for training. For example, because VR simulators are built on a computer platform, the hardware and software required can be very expensive. Thus, the types of medical simulators that are currently available are somewhat simplistic and address procedures that are relatively easy to simulate. Satava (2001) suggests that three areas must be addressed for simulation to be a cost effective training method. First, simulators should be designed for many different types of surgical specialties. Second, they should accommodate individuals with different skill levels (i.e., students, residents, attendings, etc.). Third, simulators should not only be used for education and training, but also for planning complex surgical procedures. As Satava noted, the cost effectiveness of simulators in medical until costs decrease, simulation will likely be available for training on less complex procedures.

Further research is also needed regarding the ideal way to use simulators within the curriculum. Most of the research regarding simulation training is not theoretically driven. Theory of learning, training, and skill development are necessary to determine the effectiveness of simulation-based training. Many principles of skill acquisition have yet to be addressed in the research and development of simulators for medical training and education. Schedules of practice, guided training, overlearning, and types of trainers all need to be considered in future research to maximize the benefits of simulation-based training.

Learning and skill acquisition are issues that must be continually evaluated in simulation-based medical training. However, simulation holds a lot of promise for training future health care professionals. By conducting theory-driven research and following the principles of learning and skill acquisition, individuals in medicine may one day be able to acquire and practice the skills they need before ever touching a real patient.

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THE FUTURE OF MEDICAL TRAINING AND THE NEED FOR HUMAN FACTORS

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Within the last five years, several events have taken place that will have a profound effect on the practice of medicine and patient safety. First, medical virtual reality simulators have been developed for training minimally invasive and other forms of surgical procedures. Second, evidence is beginning to show that surgeons who train with this technology are more skillful when they operate on genuine patients. Third, several regulatory agencies will soon begin to require this technology for training and certification. At present, most medical virtual reality simulators have been developed with little or no human factors involvement, but the need for human factors knowledge and expertise is paramount. In this paper, I describe what I perceive to be the top 10 areas where human factors professionals can contribute to the evolution and adoption of this new technology.

INTRODUCTION

The use of computer-based simulators for training has a long history within the human factors profession. Research addressing flight, ATC, driving, power plant, and command and control simulators is so common within the pages of our literature that we almost take this technology for granted. However, there is still one high-risk profession in which simulation-based technology has been conspicuously absent – *medicine.*

Although medical simulation devices have been around since the 1940s, most of them have been little more than physical models with very limited functionality. That began to change, however, in the early 1990s as a result of three critical developments (Scerbo, 2005). First, the Visible Human project sponsored by the National Library of Medicine produced virtual representations of a patient's anatomy and systems (Satava, 2001). Second, a new procedure was introduced for performing cholecystectomy (i.e., gall bladder removal) by which the surgeon makes small incisions in the abdomen, inserts a small video camera and two surgical instruments, and performs the operation from outside the body. By the end of the decade, this minimally invasive (or laparoscopic) process became the standard for a growing number of surgical procedures. Third, haptic force feedback rendering systems that enable users to touch and manipulate objects in virtual space were developed and refined. Collectively, these events made it feasible to develop a virtual reality (VR) surgical simulator by using facsimiles of laparoscopic instruments interfaced with force feedback systems and visual graphics to permit interaction with virtual organs.

In 2002, Seymour at al. published the results of the first double-blind experiment comparing training via the traditional apprenticeship approach to surgery and training with a VR simulator. The simulator they studied was the MIST® VR system which uses abstract representations of laparoscopic tasks to train the fundamental psychomotor skills needed to perform the procedures. Their results showed that residents who trained on the simulator needed 30% less time to perform a genuine procedure than those trained according to the traditional method. Moreover, those who trained on the VR system were less likely to injure the gall bladder, burn nontarget tissue, or have the attending surgeon step in and take over.

More recently, Gallagher and Cates (2004a) reported on their experience with a different surgical procedure for patients who have plaque build-up in the carotid artery. Because the risk of stroke is extremely high for patients with this condition, a new procedure was developed in which a wire stent is placed in the carotid artery to reduce the possibility of an embolism and improve blood flow. The procedure is both complicated and risky. In essence, it requires the physician to insert various catheters into the body and manipulate them to reach the carotid artery, deploy a catch basket, break up the plaque, place the stent, and then remove the basket along with the loosened plaque. Until recently, there were very few physicians who could perform the procedure and further, it was not reimbursable through insurance companies.

In 2000, researchers at the Center for Integration of Medicine and Innovative Technology began work on what would become the VIST® Vascular Interventional System for Training. This VR simulator uses physical models of the catheters and the vascular system to generate graphical images that can reproduce the appearance and physiological dynamics depicted on the cardiologist's X-Ray display. The simulator also records a variety of performance metrics (e.g., completion time, accuracy, use of contrasting agent, etc.) that can be used to assess skill acquisition.

In March 2004, Gallagher and Cates (2004b) met with the US Food and Drug Administration to present evidence for the efficacy of VR-based simulation for skills training and assessment. The following month, the FDA voted to approve the carotid stent procedure accompanied by simulation-based training. As Scerbo (2005) noted, physicians wishing to perform the procedure would have to meet a set of training criteria on the simulator established by a normative group of physicians who have extensive experience with the procedure. After they demonstrated competency on the simulator, they would be allowed to perform the procedure on patients. A formal experimental trial comparing VR-trained and non-VR-trained physicians on the procedure is currently underway.

This action taken by the FDA is an historical event of unimaginable proportions. It is the first time in the history of medicine that performance-based competency measures will determine who can and cannot perform a medical procedure. It is also the first time the FDA has approved a device along with a requirement that dictates how physicians must treat their patients. Consequently, the governing boards of several medical specialties (e.g., American College of Surgeons) are now giving serious consideration to simulation-based training and competency assessment in their curricula (Healy, 2002).

Gallagher and his colleagues (2005) argue that medical VR simulators are creating a paradigmatic shift in how medicine will be taught and practiced in the future. Although it is exciting to see these changes taking place in medicine, it is also sobering to realize that all of this has been accomplished with little or no human factors involvement. There were no human factors designers on the development teams for either of the two simulator systems responsible for these events, (i.e., MIST® VR and VIST® VR).

Clearly, the knowledge and experience human factors professionals have acquired with simulation-based technology across numerous domains suggest that our profession has much to offer for those working in the medical profession. In the remainder of the paper, I describe what I consider to be the 10 most important areas where human factors can and should contribute to the evolution of medical and surgical simulation technology.

TOP 10 AREAS FOR HUMAN FACTORS CONTRIBUTIONS

1) Training paradigms

Recently, the American Medical Association's Accreditation Council for Graduate Medical Education, the organization that accredits teaching hospitals in the U.S., established an 80-hour/week limit on the number of hours medical residents can work (AMA, 2003). These new restrictions represent about a 10% - 30% *decrease* in the typical working hours of residents and medical school faculty members are greatly concerned about their ability to provide adequate training within this restricted time frame.

VR simulators may provide a partial solution to this problem because they allow trainees to learn procedures largely on their own. However, designers of medical simulators and curricula alike are now investigating methods to optimize training. Human factors researchers can offer guidance on principles of knowledge and skill acquisition that address task sequencing, part and whole task training, and hierarchical and integrative approaches (Proctor & Dutta, 1995). Also, we understand how to assess transfer of training and conduct task analyses to identify procedural components that promote the development of automatic skills and more efficient performance (Schneider, 1985).

2) Simulator fidelity

A major issue facing developers of medical VR systems concerns simulator fidelity. Designers continue to debate over how much fidelity is necessary. Human factors researchers have a history of studying simulator fidelity issues (Hays & Singer, 1989). We understand that simulator fidelity differs along physical and functional dimensions. Further, the degree of fidelity should follow from an analysis of training requirements. In addition, the costs associated with building and training in a high fidelity simulator must be weighed against the degree of transfer from the simulated to operational environment. Further, many high fidelity simulators may have negligible performance benefits over more modest systems (Lintern, 1991). Clearly, we can offer much guidance on nature of simulator fidelity as it relates to medical procedures.

3) Virtual environments (VEs)

Human factors researchers have extensive experience with VEs (Stanney, 2002). Recently, Scerbo et al. (2005) used a VE to examine emergency surgical procedures under hazardous conditions. They argued that VEs can be a valuable tool for medical training because they provide a rich context in which to examine performance. The benefits of this approach are numerous. First, VEs provide a safe environment for training medical personnel under a variety of stressful conditions. Second, VEs extend the range of applications for current medical simulators. Thus, a VR medical simulator can be embedded in a VE to examine contextual factors on performance. Most important, VEs allow one to examine performance without putting any patients at risk. In this regard, they offer a laboratory in which to study new training techniques.

4) Team training

Many medical VR simulators address surgical procedures. Although these simulators are typically designed to train individual skills, surgical procedures are actually performed in a team context that includes the surgeon, anesthesiologist, surgical and anesthetic nurses, possibly trainees (e.g., residents, medical students, etc.), and, of course, the patient. Many human factors specialists have experience with training paradigms that address both individuals and teams (Swezey & Salas, 1992). Further, principles of crew resource management that have been effective in the aviation community are now being applied to medical teams (Gaba, 1994; Helmreich & Schaefer, 1994); however, the emphasis thus far has been aimed primarily at anesthesiologists. This team perspective has not been wholly embraced by those who study VR-based simulators. Thus, there is a need to expand the study of medical team performance to include a wider range of simulators and address the unique needs of each team member.

5) Errors

In the recent Institute of Medicine report, *To Err is Human* (Kohn, Corrigan, M., & Donaldson, 1999), medical errors were estimated to contribute to as many as 98,000 deaths annually in U.S. hospitals. The report has had a significant impact in the medical profession as health care providers and the institutions that train them attempt to understand and address this problem. Although medical simulators are being promoted as a partial solution to reducing medical errors, it is not clear that developers are creating simulators from a fundamental understanding of human error.

The study of human error is a cornerstone of human factors. Models of human error, in general, have been offered by Reason (1990), Moray and Senders (1991), and Wickens (1992). Moreover, Bogner (1994; 2004) and others have been studying human error in medicine for over a decade. Further, human factors professionals are also knowledgeable about techniques for investigating human error and accidents (Strauch, 2002; Wiegmann, & Shappell, 2003). Clearly, human factors has much to offer in the area of medical error.

6) Workload, stress, and fatigue

Surgeons, and particularly residents, are required to work very long hours, under moderate to severe levels of sleep deprivation, simultaneously manage multiple patient cases that vary in condition and severity, work in teams whose members change on a continual basis, while literally holding the lives of their patients in their hands. In fact, surgery is *rarely* practiced in a low workload environment free from stress and fatigue. However, there has been little systematic research on the effects of workload, stress, and fatigue on surgical performance because efforts to study these factors may exacerbate their effects and put patients at greater risk.

Medical simulators offer a reasonable compromise. They provide an opportunity to manipulate and study workload, stress and fatigue in a safe, controlled environment. Human factors researchers have a long history of studying workload, stress, and fatigue as well as designing countermeasures to their deleterious effects (e.g., Hancock & Desmond, 2001) and could provide invaluable help addressing these issues in surgery.

7) Haptic and multimodal perception

At present, the models underlying the haptic feedback systems in most medical VR simulators are still crude. The ability to faithfully reproduce the response of soft tissue continues to present a significant design challenge. Moreover, some developers and even physicians have questioned the need for high fidelity haptics or any haptics at all (Montgomery, 2005). There are many researchers within our profession who understand haptic perception and the psychophysical methods for comparing and equating real and virtual objects in haptic space (Dow, Thomas, & Johnson, 1999; Biggs, & Srinivasan, 2002). We can help develop haptic response systems that feel natural. Further, other human factors researchers study multimodal perception and understand the challenges associated with designing multimodal VR systems that include visual, auditory, and haptic displays (Nelson & Bolia, 2002).

8) Cognitive engineering

Most current medical VR systems focus on the psychomotor skills needed to perform specific procedures. Although the early years of a physician's residency are aimed at developing these skills, in later years physicians spend more of their time addressing the cognitive skills required for diagnoses, decision-making, problem-solving, and management. Thus, there is need to include these aspects of a physician's job in future simulators (Jarrell, 2005). Again, many human factors researchers and designers have extensive experience in cognitive task analysis, cognitive engineering, intelligent interface design, and automated systems. The designers of medical VR systems will need to draw upon this knowledge in order to create the next generation of simulators that benefit more advanced residents or practicing physicians.

9) Cost justification

Human factors professionals have long understood the economic benefits that come from well-designed products (Alexander, 1994). Hendrick (1996) described numerous examples of ergonomic solutions that paid big dividends in cost reductions or increased sales. Others have described methods for using cost-benefit analysis to show the value of human factors contributions within the product development life cycle (see Bias & Mayhew, 1994). Those who work more closely with simulation-based training systems have described methods for determining the cost effectiveness of such systems (Farmer, van Rooij, Riemersma, Jorna, & Moraal, 1999).

The medical simulation community still has not given much consideration to the economic impact of their systems. Although Satava (2001) has discussed the expenses associated with developing medical simulators, few have attempted to measure the cost savings. Many practitioners within the human factors community recognize that calculating the added value of ergonomic solutions is not only a necessary component of feasibility studies for individual projects, but important for the discipline as a whole. The medical simulation community would be well served to follow the ground work laid by human factors professionals where cost justification is concerned.

10) Validity, control, and experimental design

There is great interest among the developers and users of medical VR simulators to show that they are valid and that training on a simulator transfers to procedures performed on genuine patients. Unfortunately, much of the research conducted to support these efforts suffers from a variety of methodological weaknesses. The research literature is often plagued with simplistic or even incorrect notions of construct, internal, and external validity. For instance, it is not uncommon for investigators to claim they have established construct validity without ever mentioning the underlying construct. Some of research also suffers from inadequate controls or specification of control procedures. Often, good experimental control is exercised, but for the least likely threats to validity, while the most serious threats go uncontrolled.

Most human factors specialists have strong methodological and quantitative skills and can design experiments that minimize threats to internal validity while maximizing opportunities for external validity. More important, human factors researchers often design studies in which sources of variance can be identified and the mechanisms underlying results obviated.

CONCLUSION

Obviously, there are other human factors issues that could be added to this list. But, there are also technological challenges that are equally significant. Some of these include better physical models of tissues and organs, more extensive representation of disease and pathology, establishment of interoperability standards among systems, and how best to integrate simulators into current medical curricula.

Clearly, medical VR simulators have arrived and are already having a profound impact on the way medicine is being taught. For the first time in the history of medicine, they offer the opportunity for the objective assessment of performance with standardized metrics in a safe and controlled manner. They will increase skill proficiency and reduce the performance variance and errors of those who practice medicine and ultimately, will provide new and verifiable ways to improve patient safety. Gallagher (2004) has suggested that in evolutionary terms, current VR simulators in medicine are on a par with the Link flight simulator introduced in the 1930s. We in the human factors community recognize the innumerable and significant contributions we have made to the evolution of aviation in the areas of design, training, and safety in large part due to simulation technology. Perhaps, 70 years from now we will be able to look back on our role in medicine and healthcare and recognize the innumerable and significant contributions we made through our involvement in the evolution of medical simulators.

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UNDERSTANDING THE NATURE OF SURGICAL EXCELLENCE USING A COMPETENCY MODELING APPROACH

by

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ABSTRACT

UNDERSTANDING THE NATURE OF SURGICAL EXCELLENCE USING A COMPETENCY MODELING APPROACH

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Currently, a thorough description of the knowledge, skills, abilities, and other personal characteristics (KSAOs) that distinguish an exceptional surgeon does not exist. This knowledge is pertinent to the development of selection, training, and performance assessment methods that can be used to develop high performing surgeons. Expert surgeons from around the country were recruited to participate in an interview to discuss the KSAOs (i.e., the competencies) needed to be exceptional in the field. A smaller number of novice surgeons were also interviewed. The expert interview data were distilled into a competency model that consists of ten competencies and patterns within the data that distinguished between the expert and novice results were examined. Results revealed ten competencies essential for distinguishing between outstanding and typical and surgeons: Dedication to Patient Care, Integrity, Tireless Work Ethic, Preparedness, Intellectual Giftedness and Curiosity, Humility, Compassion, Devotion to Field, Rapid Decision Making, and Passion for Teaching. These results suggest that surgical training would benefit from focusing on the development and enhancement of character-based competencies. Once validated, Industrial-Organizational psychologists can use the present model to assist surgeons in creating instruments that measure and track residents' acquisition of these competencies.

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INTRODUCTION

During the Annual Meeting of the Society of University Surgeons in 2003, Dr. William Silen of Harvard Medical School delivered the keynote address in which he described the current state of surgical education. Silen argued that a major change was needed in surgical residency programs. In this address, he shared the following statement made by a surgical resident from a reputable medical school:

> I believe the apprenticeship model, so successful in the mid portion of the 20th century, is now dead and has taken the spirit out of the work of medicine. There are too many sick patients to be cared for by too few people...Time spent practicing, teaching, thinking are considered luxuries, taken with the knowledge that each minute will subtract from time [treating patients] or from time sleeping. (p. 399)

Others have recently expressed similar attitudes regarding this shift in surgical education. For example, Gawande (2001) stated that residency programs must acknowledge that although the method of learning-by-doing (i.e., on-the-job training) worked for decades, its flaws are increasingly evident. Silen and Gawande represent a growing contingent of educators who are endorsing a major modification to surgical training.

Such remarks also indicate that many surgical programs have reached a crossroads. The Halstedian method, the reigning teaching strategy for the past century, consists of a "see one, do one, teach one" approach to surgical training. In other words, the Halstedian-based system to training surgical residents mirrors a traditional apprenticeship model. This method was a logical approach to surgery when there was no viable alternative to learning directly with patients. The consensus in surgical education is that the Halstedian method is now insufficient given the changing competencies required for surgeons (Fabri, 2003; Hall, 2004; Haluck & Krummel, 2000). The concern over this teaching method is so widespread that formalized training programs of basic surgical skills have been established in many countries, including the United Kingdom and Australia (Davies & Hamdorf, 2003). A good example of such a skills training facility is The Centre for Medical and Surgical Skills (CTEC) in Perth, Western Australia, a state-of-the-art training center consisting of a medical and surgical workshop, a high-fidelity simulated anesthesia mannequin, and a virtual hospital that contains an operating theater, emergency department, and intensive care unit.

Because few surgical programs are equipped with such technically advanced training centers, most education continues to occur in the operating room (OR). From an educational standpoint, the OR is a poor classroom for learning important surgical skills. It is an uncomfortable, stressful, and even hostile environment; thus, learning potential and the ability for a surgeon to concentrate are often compromised (Haluck & Krummel, 2000). Although many residency programs need to improve aspects of their current curricula, it is of even greater importance to determine whether these programs are producing *competent* surgeons. To do so, the surgical community must first reach a consensus regarding the definition of a competent surgeon. Currently, surgical competency is an elusive concept that even the American Board of Surgery is grappling to define (Scott et al., 2000). However, this Board does suggest that multiple assessment instruments be used to evaluate competency. This recommendation implies that surgical competency is multidimensional in nature and therefore, assessing only medical knowledge or technical skill does not provide a complete picture of a surgeon's proficiency.

Of equal significance to the concept of surgical competency is the role of assessment. It is important to investigate whether educators can adequately assess the levels of competency that surgical residents achieve throughout their training. The identification of poor performers is important because these individuals require additional training or, in extreme cases, dismissal from the surgical program altogether. Unfortunately, existing assessment methods are often criticized as subjective, inconsistent, and too general to discriminate among trainees (Cheung & Yau, 2002; Gibbons, Baker, & Skinner, 1986; Paisley, Baldwin, & Paterson-Brown, 2001).

Assessing Surgical Performance

Little has been written about characteristics that distinguish a typical surgeon from an exceptional one. However, all surgeons, even the exceptional ones, begin their training in medical school. Upon graduating from college, aspiring physicians must first attend medical school, where they acquire a broad education in medicine typically within a four-year program. The first two years are taught largely via classroom lectures, laboratories, and demonstrations. The object of these two years is to provide students with a foundation in medical-related sciences. During the third and fourth years, students complete various medical rotations in some of the main specialties of medicine such as obstetrics/gynecology, family medicine, psychiatry, and general surgery. Once the four years are completed, students receive their medical degrees and are then matched to residency programs within their chosen specialty. These doctors are now referred to as residents. In essence, residency is a time when surgeons are expected to sharpen their skills and further their medical knowledge. The first year of residency is known as the internship, although the internship can be as long as three years in certain institutions (Ludmerer, 1999). Once residency is concluded, the formal portion of a surgeon's medical education is considered to be complete. But the question remains, how good is a surgeon at what he or she does?

Until recently, surgical performance was defined by the raw number of medical procedures performed and patients examined (Haluck & Krummel, 2000). Due to a recent shift in educational standards and tremendous advances in medical technology (e.g., medical simulators), this approach is becoming obsolete. Rather than defining level of performance by a set number of procedures, many surgical programs are turning to predetermined educational goals and objectives for assessment purposes (Romanchuk, 2004).

The need to operationalize surgical performance is widespread. In fact, there has been extensive public interest and scrutiny in defining levels of surgical performance (Satava, Gallagher, & Pellegrini, 2003). The media, patient groups, governmental agencies, and insurance companies are a few of the many parties involved in this debate (Singh, Smeeton, & O'Brien, 2003). Most medical professionals believe that a surgeon's level of performance can be determined by considering an amalgam of several skills and abilities including, clinical skills, technical ability, academic potential, administrative skills, good judgment, and the ability to maintain strong relationships with patients and other health care professionals (Cuschieri, Francis, Crosby, & Hanna, 2001). Patil, Cheng, and Wong (2003) agree that a high performing surgeon must have strong clinical skills, a compassionate and professional attitude, and effective communication skills, but they also state that a high performing surgeon must possess the ability to think and work in highly stressful situations.

Hall, Ellis, and Hamdorf (2002) acknowledge that although technical ability is crucial, a high performing surgeon must also be a capable decision maker. It has been estimated that a surgical procedure requires approximately 75 percent cognitive skills and 25 percent technical skills (Satava et al., 2003; Spencer, 1978). Surgical performance, by its very nature, is complex because it requires good manual dexterity, a blend of high stakes decision making, and critical thinking in complex situations often with relatively uncommon procedures (Hall, 2004; Higgins et al., 2004; Spanknebel et al., 2004). There have been many attempts to define surgical competency, each with its own merits and weaknesses.

Historical Attempts to Assess Surgical Performance

Mortality Rates

One fairly straightforward approach to determining the quality of a surgeon's level of performance is simply, the death of a patient (e.g., Margulies et al., 2001; Singh, Smeeton, & O'Brien, 2003). Mortality rates allow hospital administrators and patients to determine the quality of surgical care they are likely to receive. In a recent study aimed at identifying under-performing surgeons, Singh et al. (2003) provided an example of operationalizing surgical performance. They used a mortality rate of four percent over a 30-day period following a radical cystectomy procedure for bladder cancer. Acceptable surgical performance was defined as a mortality rate of four percent and under-performance was defined as a mortality rate of eight percent or greater.

Although mortality rates are clinically relevant and certainly important to patient groups and insurance companies, there are problems inherent with this approach. For instance, very large sample sizes are needed which often create logistical problems in medical research. Furthermore, since surgery is a team effort, a surgeon is rarely the sole person responsible for the death of a patient. If a surgical team fails to communicate or provide proper monitoring and feedback during a procedure, it may not be possible to place blame on any particular individual. As such, defining surgical performance through mortality statistics may be viewed as both a contaminated and deficient measure of performance. It may be contaminated because the surgeon may not necessarily be responsible for problems that arose at the team level. Mortality rates may also be deficient because they do not provide any evaluative information regarding other important characteristics of job performance, such as interpersonal interactions with patients and their family members.

Patient Satisfaction

The quality of a surgeon's performance is not only tied to patient survival, but also the attitudes and reactions held by their patients. Although medical practitioners are evaluated by their superiors, many hospitals and clinics now include their patients in the evaluation process. Over the past 25 years, patients' opinions have become a serious concern in the medical and nursing literature (Sitzia & Wood, 1997). For example, patient satisfaction with physicians' interpersonal skills has been shown to be related to long-term psychological adjustment. Mager and Andrykowski (2002) interviewed 60 women diagnosed with local or regional breast cancer to examine the relationship between breast cancer survivors' experiences during their diagnostic consultation and their subsequent psychological adjustment. One interesting finding was that the best predictor of long-term patient depression, stress, and anxiety was not perceptions of physician competence, but patients' perceptions of a physician's interpersonal skills. Thus, patients may require more than technical expertise from their physicians; patients typically expect to be treated with sensitivity and respect.

Assuming that patients are well-informed and well-intentioned, the information gathered from patient satisfaction questionnaires can be extremely useful. On the other hand, some physicians are suspicious of patient satisfaction data. They believe that these data may unduly threaten the status and livelihood of medical practitioners, as well as threaten the professional standards of the medical community as a whole (Armstrong, 1991). Although such physicians may assume that many patients are dissatisfied with their medical care, in practice the opposite is usually true (Sitzia & Wood, 1997). Since these fears are likely to be unfounded, patient satisfaction information could be an important and worthwhile component of surgical excellence.

To date, there are many more studies involving patient satisfaction with non-surgical physicians than there are with surgeons. However, at the University of Toronto, MacRae, Cohen, Regehr, Reznick, and Burstein (1997) developed a six-station, three-hour, standardized-patient-based evaluation system. MacRae et al. called this system the Patient Assessment and Management Examination (PAME). They used it to assess 18 senior general surgery residents. Although the sample size was small, their results suggested that the PAME is a reliable and useful tool for assessing the attitudes of surgical patients. However, it must also be acknowledged that most patients have limited insight into an operative procedure. Typically, patients are able to judge only interpersonal interactions with the surgeon as well as the final outcome of a procedure. While patient input provides an important measure of a surgeon's performance, patients are not capable of providing a complete evaluation of surgical ability.

Suturing Skill

Another approach that has been used to define surgical performance is the assessment of suturing skills. Those who use suturing as a measure of surgical performance seem drawn to its objectivity. In these studies, a standardized battery of knot-tying and suturing stations may be used to assess performance (Bann, Khan, Datta, & Dazi, 2004). Although suturing is not the only skill necessary for technical performance, it is a fundamental aspect of surgery. Seki (1987, 1988) conducted several studies dealing with the suturing techniques among surgeons. His work demonstrated that surgeons may overestimate their accuracy of suturing and cause tissue damage by wavering the needle without realizing it. Furthermore, Seki's research demonstrated that less experienced surgeons benefited more from training than more experienced ones. Khan, Bann, Darzi, and Butler (2003) asked a group of 43 plastic surgeons and 46 general surgeons to suture a wound made in a latex pad using interrupted sutures. They were videotaped performing the procedure while their movements were monitored using an electromagnetic tracking system. All videotapes were assessed via the Objective Structured Assessment of Technical Skills (OSATS), which is an operation-specific checklist that is frequently used to assess surgical skills among residents in teaching hospitals (Faulkner, Regehr, Martin, & Reznick, 1996; Hernandez et al., 2004; Reznick, Regehr, MacRae, Martin, & McCulloch, 1997). This assessment method allows trainees to be scored objectively by their peers or superiors (for further description of the OSATS, see the following section, "Technical Skill"). Khan et al. found that, when suturing, plastic surgeons were significantly more efficient with their time than general surgeons. They also found that senior surgeons performed better than their juniors, regardless of surgical specialty.

Collectively, these studies suggest that suturing skill may be useful as a measure of surgical performance for two reasons. First, suturing assessment may be a sensitive measure because it has been shown to discriminate among surgeons from different specialties and with different levels of experience. Second, suturing may provide an index of one's overall level of technical competence.

Technical Skill

Psychomotor abilities and technical skills have been an important part of selection and assessment research for the past 80 years (Ackerman, Cianciolo, & Bowen, 1999). Technical skills have played a role in predicting individual differences in various skilled professions. However, the convention in Industrial-Organizational psychology is to lump technical skills into a "noncognitive skills and abilities" category (Schmidt, Ones, & Hunter, 1992). Other terms that fall under the "noncognitive" umbrella are psychomotor and perceptual ability. Although general cognitive ability is considered to be the strongest predictor of job performance across a wide range of jobs, noncognitive abilities may improve the overall predictive validity of cognitive ability measures (e.g., Schmidt & Hunter, 1998, McHenry, Hough, Toquam, Hanson, & Ashworth, 1990).

Approximately twenty years ago, the United States Army began a seven-year research program to improve the selection and classification of entry-level military members. This effort, known as Project A, was one of the few examples of empirical research in which the role of noncognitive abilities in selection was examined (McHenry, et al., 1990). Results suggested that while cognitive ability was the best predictor of job performance across nine different military occupations, adding specific ability tests increased the validity beyond what was predicted by cognitive ability alone (McHenry et al., 1990). Johnston and Catano (2002) also examined the predictive and incremental validity of noncognitive abilities. They administered tests of manual dexterity, finger dexterity, and motor coordination to 209 Canadian Forces trainees in technical and mechanical occupations. The results indicated that only manual dexterity predicted training performance. Further, although the addition of the three psychomotor tests increased validity beyond using only cognitive measures, only manual dexterity significantly contributed to the regression model.

Logic suggests that technical skill is related to surgical performance. However, until the past decade, the formal assessment of surgeons' technical skills was often accomplished via only a single item on summary achievement indicators, such as in-training reports (Winckel, Reznick, Cohen, & Taylor, 1994). Until the OSATS was introduced into the surgical community, the assessment of technical skills was much less sophisticated than the assessment of clinical skills, cognitive ability, and medical knowledge. The OSATS is comprised of six separate tasks that a trainee must perform within 90 minutes. These tasks include excision of a skin lesion, insertion of a T-tube, abdominal wall closure, control of major bleeding, stapled bowel anastomosis, and sutured bowel anastomosis (Faulkner, Regehr, Martin, & Reznick, 1996). Using a task-specific checklist and a global rating scale, the examiner is able to assess the trainee's performance.

Technical skill may also be assessed more generally using human cadavers, animal models, and living patients. There are obvious ethical constraints to using living patients since safety must always precede training opportunities. These constraints may also hinder the assessment process, particularly when an examiner must step in to assist a trainee if something goes wrong during the procedure. Such external help or guidance would bias the evaluation process. Cadavers therefore alleviate some of the ethical concerns and problems related to assessment. However, since tissue supply is limited in cadavers and tissue properties are different from those of live patients, the use of cadavers also presents problems (Khan, Bann, Darzi, & Butler, 2003). Furthermore, human cadavers may place trainees at risk because it is possible to transfer disease from cadavers to humans.

Recently, surgical educators have taken advantage of computer-enhanced technology to train residents to perform specific procedures, as well as to improve their overall technical skills. Several virtual reality (VR) simulators that address endoscopy and laparoscopy are now available to train instrument manipulation and advanced procedures (Patil, Cheng, & Wong, 2003). As surgery becomes less invasive, the range of skills required to manage surgical issues is increasing. Compared to traditional open procedurs, minimally invasive surgery (MIS) involves smaller incisions and less extensive manipulation of the tissues surrounding the target structure (Guyer, Foley, Phillips, & Ball, 2003). Further, patients who undergo minimally invasive procedures typically experience less pain, a smoother recovery, and an improved cosmetic outcome (Cooley, 1998).

Researchers acknowledge that training and assessment of the skills needed for MIS differ somewhat from the skills needed for conventional surgical procedures (e.g., Seymour et al., 2002). The Minimally Invasive Surgical Trainer-Virtual Reality (MIST®-VR) has become one of the most popular trainers and assessment systems of the technical skills needed to perform MIS (Jordan, Gallagher, McGuigan, McGlade, & McClure, 2000). This PC-based system, which contains two laparoscopic instruments and a diathermy pedal, has six tasks of increasing difficulty. The tasks use abstract graphics that simulate the manipulations required during laparoscopic cholecystectomy (Grantcharov, Bardram, Funch-Jensen, & Rosenberg, 2001). The MIST®-VR system records number of errors, economy of movement for each hand (actual path length/ideal path length), and time information. This scoring system permits measurement of skills relevant to laparoscopic surgery. Moreover, research has shown that individuals trained on the MIST®-VR demonstrate significantly better technical performance than those surgeons trained using traditional methods (Seymour et al., 2002).

As with any assessment method, one must consider its advantages and disadvantages. One obvious benefit of defining surgical ability by technical skills is its intuitive appeal. Instrument handling and the ability to demonstrate respect for tissue are necessary prerequisites for any surgical procedure. However, the question then begs, is a surgeon truly exceptional if he or she is technically proficient but has poor interpersonal and communication skills and is lacking in overall professionalism? Although technical skill is important and clearly necessary to perform surgical procedures, it does not provide information about other aspects of surgery that are relevant to patient care. Thus, for the present study, it is anticipated that technical skill will not emerge as a competency that distinguishes typical from exceptional surgeons.

Critical Thinking

Surgery consists of activities that are highly complex and risky. In fact, much medical decision making is based on insufficient information (Satish et al., 2001). As such, a surgeon often needs to make life or death decisions during specialized, intricate, and sometimes, relatively uncommon procedures (Spanknebel, Shoup, Temple, Coit, Brennan, & Jaques, 2004). The majority of surgical research focuses on thought processes involving major decisions such as deciding whether to operate, determining diagnoses, and deciding the level of risk to which a patient can be exposed by operating (Birkmeyer & Birkmeyer, 1996). With the advent of MIS, surgeons must now make important mid-surgery decisions such as whether to convert from a minimally invasive procedure to an open-incision procedure (Dominguez, 2001).

To be a high performing surgeon, it is likely that one needs to possess a combination of technical skills and higher-order cognitive processes, such as critical thinking and independent thought. Although surgeons must be intellectually prepared to handle a wide array of contingencies, many training programs are not designed to produce surgeons who think critically, learn independently, and generate new ideas (Ludmerer, 1999). Curricula are often typified by rote memorization, lectures, and other rigid processes. In addition, the Halstedian method is essentially a behavioral approach to instruction, as observed behavior rather than internal processes is emphasized (Hall, Ellis, & Hamdorf, 2002). Given that the Halstedian method is becoming obsolete, the role of critical thinking is taking a more prominent role in surgical programs.

Critical thinking is especially necessary when dealing with complex medical cases and individualized treatment plans. Satish et al. (2001) also believe that high performing surgeons require more than strong technical skills. They contend that these surgeons should have the capacity to respond appropriately to multiple, simultaneous symptoms and medical events that can potentially compromise a patient's safety. Educating surgeons about diseases and medication is fairly straightforward information that can be translated through training, lectures, and medical textbooks. However, as Satish et al. (2001) emphasize, it is the *integration* of that information toward individualized treatment plans and the response to unpredictable changes in the patient's status that are much more difficult to convey through traditional skill training. Therefore, these researchers used an alternative assessment method to measure critical thinking, as well as other skills needed for integrative surgical decision making (e.g., flexibility, crisis management). This method, known as the Strategic Management Simulation (SMS), uses different medical scenarios to measure critical thinking and to identify where an individual needs improvement. Satish and his colleagues used the SMS to predict surgical residents' higher cognitive function (e.g., critical thinking). Their SMS results were very similar to ratings provided by surgical faculty who had known the residents for a minimum of two years.

Given how important it is for surgeons to be able to critically assess complex medical cases and procedures, it is anticipated that critically thinking will emerge as a competency in the present study.

The Need for Clear Standards of Surgical Performance

The previous section described the difficulties researchers face when trying to evaluate a surgeon's performance. Nonetheless, it is becoming more important for surgeons to demonstrate that they can perform according to professional standards.

Recertification and Professional Development

Professional organizations commonly endorse certification and recertification/revalidation programs for various surgical specialties. Such bodies prescribe high standards and requirements for both board certification and recertification. For instance, before the American Board of Colon and Rectal Surgery (ABCRS) permits a surgeon to apply for recertification, he or she is required to: submit a practice review of consecutive operative cases for the preceding year and acquire 100 approved hours of postgraduate medical education in surgical or colorectal surgery in the two years prior to application. The purpose of these boards is to ensure that surgeons maintain acceptable qualifications of practice in their surgical specialty, as well as maintain commitment to ongoing education and evaluation of performance in practice (Patil, Cheng, & Wong, 2003).

Although continuous medical education (CME) and recertification appear to be universal endeavors for most surgical specialties, ongoing professional development opportunities for those practicing general surgery is less straightforward. Since general surgery is heterogeneous in nature, it is much more difficult to create surgical competence assessment sections that are broad enough to encompass the spectrum of surgical circumstances (Patil et al., 2003). As such, a major challenge facing the surgical profession is to develop and validate measures that assess a representative sample of general surgeries. Moreover, the profession needs to create requirements that are broad enough to allow general surgeons to qualify for recertification. Having discussed recertification, the resident work hour mandate is another important issue facing surgeons today.

Resident Work Hour Mandate

Whether a resident chooses general surgery or some surgical specialty, he or she is now subject to limits in working hours and training time. The Accreditation Council for Graduate Medical Education (ACGME), which is the umbrella organization for all residency review committees in medicine, promulgated this decision in 2002. As of July 1, 2003, residents in all specialties are required to adhere to an 80-hour work week (http://www.acgme.org/acWebsite/newsRoom/newsRm_dutyHours.asp). This mandate was due, in large part, to the Institute of Medicine's (IOM) report, *To Err is Human: Building a Safer Health System,* which focused on the relationship between work hours and medical error (Kohn, Corrigan, & Donaldson, 1999). This report revealed that medical error was responsible for 98,000 deaths and over 1 million injuries every year in the United States alone (Chen et al., 2003). Although many individuals outside the medical field have criticized the long hours traditionally required by surgical programs in the past (e.g., Botta, 2003), there are some surgeons who oppose the control that external bodies have recently had over their field. There is a growing fear that the ACGME mandate will result in unprepared surgeons and thus, an overall decline in patient care (Komenaka, 2003). Furthermore, the 80-hour restriction impacts continuity in care since residents may not be able to see the patients on whom they operated the previous day.

Although it is not yet known whether the 80-hour restriction will be beneficial or detrimental to surgeons and their patients, it is clear that this mandate demonstrates the need for clearly articulated standards of surgical performance. The Society of University Surgeons (SUS) released a statement about the resident work hour issue, stating that specific hours for surgery residents cannot be arbitrarily defined. The SUS statement suggests that constrained work hours "do not prepare residents for the real world of surgical practice" (Cole, Bertagnolli, & Nussbaum, 2002). Some surgeons also fear that the mandate will affect the quality of future surgeons. For instance, Komenaka (2003) is concerned that a very different type of medical student will now be attracted to the surgical professional. He argues that students who choose "lifestyle specialties" (e.g., dermatology, emergency medicine, anesthesia, etc.) may now be attracted to surgical programs because time commitments and training obligations are less burdensome under the new mandate. According to Komenaka, individuals who are attracted to lifestyle specialties have a work ethic and value system that are a poor match for surgery. If this is indeed the case, the development of standards of competence is more imperative now than before the introduction of the 80-hour limit. In fact, residency programs may find it necessary to devote more attention to the *selection* of surgical residents, particularly if greater numbers of medical students decide to apply to surgery programs.

Selection instruments should be able to exclude applicants who lack not only the potential to master the important technical and interpersonal skills needed in surgery, but also identify those applicants lacking the personal characteristics and values that many senior surgeons want their successors to possess. To rely on these methods for important selection and promotion decisions, it is essential that they are subjected to well-established principles of validation.

This work hour mandate places considerable demands on surgical residency programs. Program directors are forced to work within the constraints of an 80-hour week and still produce high performing surgeons. In addition, educators must ensure their residents have the skills required to perform the latest surgical techniques.

New Technologies and Skill Sets

As with the introduction of any new technology, the adoption of MIS required new training procedures. By the late 1990s, many authors had discussed the need for objective assessment and feedback parameters in MIS (Sokollik, Gross, & Buess, 2004). Although MIS was a revolutionary advancement within the surgical community, the training it requires has been a burden for most surgical programs. Specifically, MIS requires many new skills that are less relevant to conventional open procedures including keen psychomotor skills, interpreting the three-dimensional operating field from a two-dimensional monitor, and adapting to reduced tactile/haptic feedback (Hanna et al., 1996). Furthermore, performing advanced MIS procedures typically requires surgeons to undergo an additional one to two years of postresidency training (Gallagher, Ritter, & Satava, 2003). Since MIS is the gold standard for an increasing number of surgeries today (e.g., cholecystectomy, antireflux surgery), most expert practitioners agree that education and training should be intensified to ensure optimal quality of treatment (Grantcharov, Bardram, Funch-Jensen, & Rosenberg, 2003).

Surgical educators typically acknowledge that the complexity associated with MIS must be handled cautiously. The acquisition of these new skills poses a serious challenge to conventional systems of surgical training. Accordingly, the establishment of clear standards of surgical performance in MIS will not be easy. However, since MIS is associated with significantly higher complication rates (Deziel et al., 1993), particularly during a surgeon's early use of these procedures (Moore & Bennett, 1995), it is imperative that education and training in laparoscopic skills play an important role in surgical programs. Similarly, expert surgeons need to be able to clearly define what makes a surgeon skilled in MIS. Once surgeons agree upon such a definition, assessment and feedback should become a regular component of their training in laparoscopic skills.

The section described above illustrates some of the difficulties researchers face in trying to define and assess a surgeon's level of performance. It is anticipated that the expert participants in the present study will mention these themes when discussing the qualities that impact surgical excellence.

Competency Modeling: A New Approach to Determining Levels of Surgical Performance

What are Competencies?

During the past twenty years, economic, demographic, and technological changes have had a powerful influence on modern organizations. These changes have posed a major challenge for organizations to remain competitive within local and global markets. Due to heavy competition, many organizations have focused on developing and maximizing the talent of their human resources. Previously, the success of many organizations was defined by monetary capital and hard assets (McLagan, 1997). Today, employees' knowledge, skills, abilities, and other personal characteristics (KSAOs) are considered to be an important yardstick for measuring an organization's success.

In order to become a high performing organization, it is imperative that high performing people are identified, selected, and ultimately retained (Rodriguez, Patel, Bright, Gregory, & Gowing, 2002). Over the past three decades, many human resource specialists have begun to rely on competency models to select high performers. Although there have been many attempts to describe competency, one widely accepted definition is "an underlying characteristic of a person which results in effective and/or superior performance on the job" (Klemp, 1980, p. 21). As such, competencies are also referred to as "superior-performer differentiators" (McLagan, 1997) or "success factors" (Mirabile, 1997). Unlike a list of tasks found in a typical job description, a competency model describes the talents and skills a person must have to be successful in an organization (Rodriguez, Patel, Bright, Gregory, & Gowing, 2002).

Competency modeling is a systematic process of determining the combination of KSAOs needed to perform at a high level in an organization (Harris, 1998; Lucia & Lepsinger, 1999). Therefore, a competency model is a general description of the qualities that top-level employees possess. Competency models may differ in format (e.g., verbal or graphical) as a function of the data collection method and customer requirements. Competency models can be used for selection, training and development, performance evaluation, promotion decisions, leadership development, and succession planning (Lucia & Lepsinger, 1999). Moreover, competencies help to ensure that employees and managers alike share a common view of what it takes to be successful in an organization.

The development of a competency model is a complicated procedure, particularly if a job involves higher-level cognitive processes, such as problem-solving and strategic thinking. Those KSAOs that are concrete are much easier to identify, describe, and measure than those that are abstract. For example, although it may be straightforward to develop a typing test that measures psychomotor ability, it is much more complicated to measure hypothetical constructs such as creativity. Further, characteristics such as aptitudes and personality traits are typically more difficult to measure than knowledge, skills, and abilities because there is less agreement on definitions of these terms, which in turn, complicates efforts at validation. Competency modeling can be helpful for identifying and defining these abstract personal characteristics. It can also be used to classify personal characteristics that are more trainable and those that are innate.

There are several reasons why competency models are becoming increasingly popular. For instance, competency models improve the ability of selection committees to identify applicants who possess critical KSAOs. Competency models can be used to improve the interview process by ensuring that all persons involved in making selection decisions are using the same criteria. In addition, competency models provide an alternative to strong reliance on "gut instincts" or initial impressions gained from employment interviews, which have historically proven to be a weak predictor of job success (Latham & Wexley, 1981). They also increase the likelihood that individuals selected for a job will succeed. Furthermore, competency models can minimize investment in employees who fail to reach certain levels of performance (Lucia & Lepsinger, 1999). Because it can be extremely costly to recruit, hire, and train an employee such as a surgical resident, competency models can help to optimize the process of selecting the best candidates.

The ACGME Competencies

Over the past decade, medical schools and residency programs have undergone many changes. For instance, the Balanced Budget Act of 1997 mandated that medical schools revise their curricula (Langdale, Schaad, Wipf, Marshall, & Scott, 2003). In 1999, the same year that the IOM released its report, *To Err is Human* (Kohn, Corrigan, & Donaldson, 1999), the ACGME took radical steps to define competencies in resident education. By July 1, 2001, the ACGME mandated that all U.S. residency programs implement a curriculum and evaluation program based on the six core competencies. The ACGME gave residency programs a ten-year timeline to implement the new competencies into their curriculum and use them to guide educational goals, objectives, and evaluation instruments (http://www.acgme.org/outcome/). The American Board of Surgery also adopted the same six competencies for ongoing assessment of surgeons (Dunnington & Williams, 2003). The six ACGME core competency requirements are shown in Table 1 along with their definitions and behavioral examples.

Table 1

ACGME Competencies and Definitions

Competency	Definition
Patient Care	Patient care that is compassionate, appropriate, and effective for the treatment of health problems and the promotion of health. Examples: • Able to develop and execute patient care plans appropriate for the resident's level • Performs procedures safely and proficiently • Demonstrates proficiency of sterile technique
Medical Knowledge	Medical knowledge about established and evolved biomedical, clinical, and cognate (e.g., epidemiological and social-behavioral) sciences and the application of this knowledge to patient care. Examples: • Critically evaluates and demonstrates knowledge of pertinent scientific information • Uses clinical data in operative decision-making and patient management • Demonstrates appropriate basic and clinical science knowledge (specifically relating to anatomy, pathophysiology, fluids and electrolytes, and pharmacology)
Practice-Based Learning and Improvement	Practice-based learning and improvement that involves investigation and evaluation of their own patient care, appraisal, and assimilation of scientific evidence, and improvement of patient care. Examples: • Critiques personal practice outcomes • Integrates scientific evidence when diagnosing and developing treatment plans • Effectively uses information technology to manage information

Table 1- Continued

Competency	Definition
Interpersonal and Communication Skills	Interpersonal and communication skills that result in effective information exchange and collaboration with patients, their families, and other healthcare professionals. Examples: • Communicates effectively with other healthcare professionals • Counsels and educates patients and families • Demonstrates caring behavior toward patients and families
Professionalism	Professionalism as manifested through a commitment to carrying out professional responsibilities, adherence to ethical principles, and sensitivity to a diverse population. Examples: • Demonstrates a commitment to continuity of patient care • Demonstrates sensitivity to age, gender, and culture of patients and other health care professionals • Integrates constructive feedback
System-Based Learning	System-based practice as manifested by actions that demonstrate an awareness of and response to the larger context and system of health care and effectively call on system resources to provide optimal care. Examples: • Practices high quality, cost-effective patient care • Demonstrates an understanding of the role of different specialties and other health care professionals in overall patient management • Able to access and mobilize outside resources

Assessing Competencies in Medicine and Surgery

The term "competency" is defined differently in psychology than in most other fields. In medicine, competency is typically synonymous with the terms, "ability" or "skill." Langdale and his colleagues (2003) defined competency in medicine as "having sufficient experience to allow the independent completion of the task with minimal or no supervision" (p. 40). Further, in medicine, competency is generally measured through volume performance and patient outcome, while surgery may also use performance measures such decision time and reaction time (Trunkey & Botney, 2001).

Psychologists, in contrast, define competencies as KSAOs that distinguish exceptional from average performers (Lucia & Lepsinger, 1999; McClelland, 1973, Schippmann, et al., 2000; Spencer, McClelland, & Spencer, 1994). In the context of surgery, a competency based on the psychological definition would be a skill or attribute that differentiates an exceptional surgeon from a typical surgeon. Although the medical and psychological definitions of competency differ slightly, it is a difference worth noting. In medicine, all residents are expected to acquire minimum standards of performance in each of the six ACGME designated competencies throughout their training. Competencies, as described in I-O psychology, are the KSAOs that are largely associated with outstanding performers. Thus, they describe characteristics that are beyond the basic minimum standards expected of residents by the end of their training. In fact, these qualities may not begin to manifest until a surgeon is already established in his or her career. Therefore, there may be some overlap between the results of the present study and the ACGME competencies, but it is likely that additional KSAOs will be identified that are unique to only exceptional surgeons.

Leadership

Although no one denies that the ACGME core competencies are a fundamental part of surgical education and training, several surgical educators have also begun to express the need to incorporate basic leadership training in both the undergraduate and graduate educational curricula (Craven, 2002; Itani, Liscum, & Brunicardi, 2004; Schwartz, 1998). According to Muller (1984), leadership training has historically occurred on an informal basis during random opportunities or via observation during surgical training. Today, a greater number of surgical programs are changing their curricula to bolster the development of leadership skills to a more prominent level (Bowen, 1998; Sims & Darcy, 1997).

This curricular modification is imperative because many surgical residents do not feel confident or competent in their leadership skills. Itani et al. (2004) administered a survey to 43 general surgery residents and asked them to rank 18 leadership characteristics in terms of importance and then rate their own levels of confidence and competency in the same leadership areas. Although nearly all (92%) of the residents rated the leadership characteristics as either “somewhat” or “very important” to their careers, more than half of the respondents rated themselves as either “minimally” or “not competent” in 10 of the 18 leadership areas. Over 75% of the residents indicated that they were least competent in conflict resolution, practice management, and leadership theory.

The type of leadership required in surgery may be different from that of many other disciplines. In teaching hospitals, in particular, a strict formal division of labor exists with the attending surgeon at the top of the hierarchy, followed by a chief resident, surgical interns, senior medical students, and finally, junior medical students. Since the attending surgeon is ultimately responsible for everything that occurs in his or her surgical service, he or she is viewed as a leader. The rank of an attending surgeon grants almost total power and authority to address issues that arise within his or her service. Furthermore, an attending also holds the power to make or break careers (Bosk, 2003).

Despite the strict hierarchy that exists in surgery, particularly in teaching hospitals, actual surgical procedures require teamwork. Because the practice of surgery is team-oriented, some surgical programs are introducing collaborative leadership training (e.g., Awad, Hayley, Fagan, Berger, & Brunicardi, 2004). The outcome of any surgical procedure is contingent on the entire medical team; therefore, it is imperative that surgeons not only know how to collaborate with others, but also how to *lead* a surgical team (Gawande, 2001). According to Awad and his colleagues, collaborative leadership training should focus on teaching effective communication, alignment of the team toward providing good patient care, and integrity. If a team leader has integrity, he or she will hold the entire team to high personal and professional standards. Integrity will also help to create an atmosphere of trust among team members.

Some fields of medicine, including cardiac surgery and anesthesia, have adopted a specific type of team training known as, crew resource management (CRM), to enhance both communication and patient safety (Helmreich & Davies, 1997; Howard, Gaba, Fish, Yang, & Sarnquist, 1992). Crew resource management was originally developed in the aviation community to increase safety practices and reduce errors and accidents among cockpit teams (Salas, Burke, Bowers, & Wilson, 2001). One conclusion of the IOM report (1999), *To Err is Human,* was that CRM had the potential to improve patient safety and reduce medical errors. Thus, medical educators were urged to translate and apply the concepts of CRM within their domain.

Although leadership and teamwork skills are not explicitly listed in the ACGME core competencies, an increasing number of surgical educators realize that they want to produce surgeons who are knowledgeable, able to communicate effectively, and demonstrate integrity and professionalism. These qualities are strongly related to being an excellent leader in a high performing team (Larson & LaFasto, 1989).

Intelligence

Although most, if not all of the ACGME competencies require a surgeon to be intelligent, we do not know if exceptional surgeons are more intelligent than the typical surgeon. In other words, would a competency model of an exceptional surgeon deem intelligence to be a factor that distinguishes different levels of surgical performance?

The study of intelligence has played an important role in psychology for over a century. The first article on intelligence, "'General Intelligence,' Objectively Determined and Measured" was written by Spearman in 1904. Since the appearance of this article, several major theories of intelligence have emerged, some more controversial than others. For example, Jensen (1979) maintained the existence of a single, general factor in human intelligence. This factor was called *g*, or general mental ability. Jensen believed that *g* was identified through the factor analysis of correlations among several different intelligence tests. Gardner (1983), on the other hand, argued that there are seven different types of intelligences: interpersonal, intrapersonal, linguistic, logical-mathematical, musical, spatial, and bodily-kinesthetic. In an effort to incorporate several existing theories of intelligence, Sternberg (1985) developed the triarchic theory of human intelligence. According to Sternberg (1988), intelligence can be thought of as "the purposive adaptation to, selection of, and shaping of real-world environments relevant to one's life and abilities" (1988, p. 65). Sternberg argues that traditional conceptions of intelligence are too narrow and that an expanded view of the construct is necessary. Accordingly, Sternberg developed a theory that divides intelligence into three different, yet interrelated parts.

Analytical Intelligence

Analytical intelligence was the first module described by Sternberg and arguably the most thoroughly developed (Tigner & Tigner, 2000). It is often measured through academic problem solving, analogies, and reading comprehension exercises. Sternberg (1985) believes that analytical intelligence is based on a combination of metacomponents, performance components, and knowledge acquisition components of intelligence. Metacomponents include planning, monitoring, and evaluating skills that aid in problem solving. Sternberg considers metacomponents to be the higher-order executive processes of human intelligence. Metacomponents are viewed as the foundation of mental self-management. They allow an individual to decide what cognitive action to take and which components are necessary to perform. Performance components are the basic operations required to execute any cognitive action. It would be nearly impossible to list and describe all performance components (Sternberg, 1988). However, some examples include encoding and maintaining information in short-term memory, discovering relationships between objects or events, performing mental calculations, applying knowledge to real world problems, and critiquing ideas and products. Finally, knowledge acquisition components are processes used to gain and store new knowledge (e.g., the way in which individuals learn new words and concepts).

An individual with high analytical intelligence typically performs well in traditional educational settings (Tigner & Tigner, 2000). Since standard intelligence tests (e.g., the Scholastic Aptitude Test or SAT) were specifically developed to predict academic performance, it is logical that analytical intelligence is most similar to the type of intelligence measured in academic settings. Individuals with high analytical intelligence are likely to be good academic test-takers and thus, viewed as "smart." They also tend to be good critical thinkers.

Creative Intelligence

Sternberg (e.g., 1985, 1988) also noted that although many individuals appear to be gifted in traditional analytical and memory skills, they are not necessarily adept at creating their own ideas. Likewise, there are many individuals who excel at developing new and imaginative ideas, but do not score well on standard intelligence tests. It would therefore seem that creativity extends beyond traditional intelligence. Thus, the second facet of intelligence is creative intelligence or the experiential facet of intelligence. According to Sternberg (1985), creativity involves insight, synthesis, and the ability to react to novel situations and stimuli. Creative behavior is demonstrated when a person must deal with a relatively novel task or situation, or when a task becomes automatized. The triarchic theory dictates that performance on novel tasks is an excellent measure of intelligence because it assesses an individual's ability to apply existing knowledge to new problems. For instance, when individuals first arrive in a foreign country, they must rely on their intelligence to adjust to the demands of a new culture. However, the less attention required to process novel conditions, the more that remains to automatize actions. Likewise, the more efficiently an individual can automatize performance, the more attention he or she will have for dealing with novel situations and tasks (Sternberg, 1988). Sternberg provides an excellent example of the relationship between coping with novelty and automatization of information processing. Returning to the example of traveling to a foreign country, the less attention an individual devotes to adjusting to the new currency, the more attention he or she will have to enjoy shopping.

Individuals high in creative intelligence excel at discovering, creating, and inventing ideas and products (Sternberg, Castejón, Prieto, Hautamäki, & Grigorenko, 2001). One must note that creativity is context-specific; thus, what is creative in one context may not be creative in another (Sternberg & Lubart, 1995). Sternberg believes that it is essential to view creativity as a property of an individual as he or she interacts with one or more systems (Sternberg, 2001). For instance, in the 1950s, certain New York abstract expressionist artists such as Jackson Pollock or Willem de Kooning were the first to produce drip style paintings. At the time, this style was considered to be innovative because it represented a major change in the art world. By contrast, if someone were to produce a drip painting today, it would not be considered creative because this style is no longer original. In essence, Sternberg believes that highly creative behavior is "crowd defying." In other words, creative individuals are often underappreciated or even attacked for their way of thinking. If the public eventually decides to accept these novel ideas, crowd-defying creativity actually may propel a field in an entirely new direction (Sternberg & Lubart, 1995).

Practical Intelligence

Sternberg (1985) was not the first author to discuss practical intelligence. Neisser (1976) distinguished academic intelligence from intelligent performance in natural settings. The former term is comparable to Sternberg's analytical intelligence while the latter is equivalent to his concept of practical intelligence. For both Sternberg and Neisser, traditional intelligence is insufficient for successful performance in real-world situations because it does not address the ability to learn information and then *apply* it correctly. Practical intelligence or the contextual aspect of intelligence, also refers to the ability to grasp, understand, and deal with everyday tasks, particularly in regard to one's short-term and long-term goals (Sternberg, 1988). More commonly, practical intelligence is conceived of as "street smarts" or intelligence that functions in the real world. Traditional, academic intelligence is only a subset of the abilities needed to determine how a person performs in real-life contexts.

Unlike the other two aspects of intelligence, practical intelligence includes attitudes and emotions that may be associated with real-world intelligence. For example, although the decision to purchase a house is partly an intellectual decision, this decision also has a strong emotional component for most people. Another novel aspect of practical intelligence is that it is very individualistic, particularly in comparison to analytical intelligence. Practical intelligence allows people to take the knowledge they have gained throughout their many life experiences and generalize that knowledge to other contexts they encounter. It is also distinctive in that what is relevant and useful for one person's life may be totally irrelevant for another individual (Tigner & Tigner, 2000). Consequently, practical intelligence is difficult to assess through traditional intelligence tests and shows little or no correlation with analytical or creative intelligence (Sternberg, 1988).

A Competency Model for Exceptional Surgeons

The ACGME core competencies have served to either enhance or develop new curricula for surgical programs (Dunnington & Williams, 2003). Generally, these competencies have not been used to create new selection systems or evaluation plans. In fact, there is no standardized approach to selecting prospective surgeons. Rather, residency directors use a variety of criteria in their selection decisions. According to Berner, Brooks, and Erdmann (1993), the majority of surgical residency programs rely on face-to-face, unstructured interviews, academic transcripts, and scores on the National Board of Medical Examiners (NBME) Part I and Part II examinations. Although most selection committees are currently interested in academic indicators and interview performance, it is important to note that interviews have a long and tainted history from the I-O psychology perspective. Interviews suffer from low reliability (Judge, Higgins, & Cable, 2000). Interviews are also time and labor intensive (Cascio, 1998), prone to interview bias (e.g., Cash, Gillen, & Burns, 1977; Beehr & Gilmore, 1982), and require extensive training with active practice and feedback (Latham & Wexley, 1981). Individuals who conduct interviews should not only be aware of the potential problems inherent in the interview process, but also the best methods for enhancing validity and legal defensibility.

In many organizations outside of medicine, standardized psychological tests have been used for decades to improve their selection systems. In surgery programs within the U.S., the use of psychometrics to enhance the selection process is just beginning to gain popularity. International surgical programs, however, appear to be slightly ahead of the U.S. in using this approach. For instance, in 1983, the Association of Surgeons in The Netherlands integrated psychometric testing in their training process. The Royal College of Surgeons is also considering a similar approach (Gilligan, Treasure, & Watts, 1996). However, the main problem of identifying the competencies of an excellent surgeon remains and until this problem is resolved, the selection of outstanding surgeons will be greatly hindered (Wanzel, Ward, & Reznick, 2002).

A competency model for surgeons could be used by selection committees to more effectively screen for surgical acumen. Further, the competency model would also be useful in identifying those candidates who are ill-suited for surgical residency. In addition, a competency model can be used to improve training. In other words, the same set of competencies that are used for selecting high-quality candidates can also be used to guide surgical training and education. The use of a competency model as the foundation for a training program can ensure that training is based on the main KSAOs that constitute exceptional performance rather than passing fads that training practitioners choose to adopt (Lucia & Lepsinger, 1999). Additionally, competency models can serve to make training comprehensive, standardized, and directly linked to performance evaluations.

Finally, the use of a competency model in surgery can help to develop leadership programs. Few surgical residents are equipped with the skills and the know-how to become strong leaders. A competency model can be used to develop the content for leadership training, which would set expectations for residents in their roles as leaders and help them identify their own developmental goals (Lucia & Lepsinger, 1999).

Objectives of the Present Study

The primary goal of the present study was to develop an understanding of the nature of surgical excellence by means of the competency modeling approach. In the first part of the procedure, outstanding surgeons representing various specialties were interviewed to determine the specific competencies needed to be considered exceptional. In addition to outstanding surgeons, residents from various surgical specialties were interviewed. When developing a competency model, it is common practice to compare the interview results of exceptional performers to those of more typical performers. Since it would be difficult to identify surgeons who would identify themselves as "average," an alternative approach was used targeting less experienced surgeons. Furthermore, most competency assessment practitioners interview a greater number of exceptional performers than average performers. McClelland (1998), one of the earliest developers of competency modeling, recommends interviewing exceptional and average performers in a ratio of 3:2. He believes that there are more ways to be exceptional than there are to be typical. This ratio was also used in the present study.

The purpose of collecting data from the surgical residents was to determine how less experienced surgeons describe successful job performance. Therefore, another goal of the present study was to identify patterns within the data that distinguish between exceptional and novice surgeons. It was anticipated that although some degree of overlap would be found among the competencies provided by each group of surgeons, on the whole they would look quite different. Since the exceptional group of surgeons would have many more professional experiences to draw upon, they were expected to have a better grasp of those KSAOs needed to become truly exceptional in any field of surgery.

Predictions of the Present Study

ACGME Competencies

It was also anticipated that the exceptional surgeons would mention the importance of ACGME core competencies in surgical training; however, not all six were expected to be included in the final competency model. Since all surgical residents are expected to meet the minimum standards of performance described by the ACGME core competencies, it is unlikely they would differentiate between typical surgeons and those who are truly exceptional.

Leadership Skills

Although leadership skills are not explicitly listed in the ACGME core competencies, an increasing number of surgical educators recognize the importance of producing surgeons who are knowledgeable, able to communicate effectively, and demonstrate integrity and professionalism. As stated earlier, an increasing number of surgical programs are changing their curricula to address leadership skills (Bowen, 1998; Sims & Darcy, 1997). Therefore, it was anticipated that leadership skills would be a factor that distinguishes an exceptional surgeon from an average one.

Intelligence

Intuitively, one might surmise that an exceptional surgeon would also be highly intelligent. Although it is possible that the experts would view intelligence as an important factor for average and exceptional surgeons alike, it was anticipated that their descriptions of an outstanding surgeon would include all three forms of intelligence as described by Sternberg (1985).

Critical Thinking Skills and Decision Making Ability

Given that an important part of a surgeon's job is to make complicated, real-time decisions, exceptional surgeons must be able to rapidly evaluate multiple course of treatment. They must be able to quickly integrate information regarding medication, diseases, and changes in a patient's status. Therefore, it was anticipated that critical thinking and decision making ability would be included in the competency model of an exceptional surgeon.

Technical Skill

Historically, technical skill has been closely linked to surgical excellence. With the advent of MIS procedures, technical skill may become a more critical component of success in the field. Accordingly, it was predicted that the experts would include technical skill in the competency model.

Interpersonal Skills

Finally, patients' opinions have become a concern for the medical professional. As stated earlier, patient satisfaction questionnaires are becoming more common in the assessment of medical practitioners. It was therefore anticipated that the experts in the present study would indicate that surgeons' attitudes and sensitivity toward their patients, as well as the quality of their interpersonal skills, would be directly related to surgical excellence.

METHOD

Participants

The participants were forty surgeons from different geographical regions in the United States. Participants were divided into two separate groups. The first group consisted of exceptional surgeons. These surgeons were well-known and well-respected in their fields. All were board-certified and fellows of the American College of Surgeons (ACS). Since it is difficult to determine a list of objective criteria for surgical excellence, subject matter experts identified surgeons to be recruited for the present study. An experienced trauma surgeon and three of his colleagues developed a list that included a cross section of surgeons representing different surgical specialties. The second group of participants consisted of surgical residents from various specialties. Since these surgeons were in the initial stages of their career, they were considered novices. Due to their lack of experience, the second group was neither board-certified nor fellows of the ACS.

Expert participants included one female and 25 males with 13 to 44 years (M = 29.0) of surgical experience. The expert sample represented seven surgical subspecialties: cardiac/thoracic (N = 5), critical care (N = 3), gastro-intestinal (N = 2), general surgery (N = 8), head and neck (N = 1), surgical oncology (N = 5), and urology (N = 2). Novice participants included seven males and seven females with one to five years of surgical experience: PGY-1 (N = 2), PGY-2 (N = 2), PGY-3 (N = 2), PGY-4 (N = 4), PGY-5 (N = 4). The novice sample included five surgical subspecialties: general surgery (N = 10), orthopedic (N = 1), otolaryngology (N = 1), gynecological oncology (N = 1), and urology (N = 1).

Procedure

Once participants in both groups were identified, they were sent a formal letter via e-mail that explained the study and requested their participation (See Appendix A). Participants who agreed to be interviewed were sent the questions several days before the interview was scheduled so they could start thinking about their responses. A structured, one-on-one interview was used with all participants. Interviews were approximately forty minutes in length, or longer if the surgeon's schedule permitted. All participants granted permission to have the interview session tape recorded. Since the terminology surrounding a surgeon's job is highly technical, the interviews were tape recorded to ensure the accuracy and completeness of their comments (Lucia & Lepsinger, 1999). Detailed hand-written notes were taken throughout each interview as well.

All participants were told that their responses would be kept confidential and anonymous. They were instructed to refrain from mentioning other surgeons or healthcare professionals by name during the interview. Participants were assured that their names would not be linked to any comments included in the written report from the present study. The present study received approval from the Institutional Review Boards of Eastern Virginia Medical School and Old Dominion University.

Instruments

A structured interview was developed for the current study in consultation with I-O psychologists who have extensive experience developing competency models, as well as existing literature. The interview began with a brief introductory session explaining the purpose of the project and its potential impact. Participants were told why they were selected to participate and the expected duration of the interview. They were then given an opportunity to ask questions. All individuals were thanked for their participation both at the start and conclusion of the interview. Participants in both groups received the same structured interview. The actual interview consisted of seven main questions. The list of questions in the order presented were as follows:

1. Think of some of the finest surgeons you have ever known. What personality traits do you believe contributed to this person's success?
2. Once again, think of a surgeon that you respect and admire. What values or attitudes contributed to this person's success as a surgeon?
3. Think of the finest surgeon you have ever known. Now describe in detail one incident that reflects the personality, values, or skills that contribute to their excellence.
4. Think of a surgeon with whom you would never want to work. Now describe in detail one incident that reflects the personality, values, or lack of skills that contributed to their poor performance as a surgeon.
5. Think of some of the finest surgeons that you know. What characteristics or attributes do you share with these surgeons? What characteristics or attributes, if any, set you apart from these exceptional surgeons?
6. Describe a critical or significant experience that represents what you do well as a surgeon (i.e., an experience that made you proud). What about this experience makes you feel particularly effective?
7. Finally, please describe the job of a surgeon in the future (e.g., in the year 2015). What knowledge, skills, or other attributes will a surgeon in the future need to be exceptional?

For each question, participants were probed for additional information. Depending on the situation, probes included:

- What was the first thing you (or the surgeon in question) did?
- What were you (or the surgeon in question) trying to accomplish?
- What were you (or the surgeon in question) thinking at that point?
- Tell me more about that.
- Can you think of a specific example of that?
- Is there anything else you would like to add about what you (or the surgeon in question) did in that situation?

All interviews were transcribed. The transcriptions allowed for careful analysis of interview content for patterns within the data.

Analyses

The data for the exceptional surgeons and the surgical residents were handled differently. The analysis of the exceptional surgeons' data is described first. A common approach for analyzing the comments derived from competency interviews is known as the critical incident technique (CIT; Flanagan, 1954). Although this technique was developed half a century ago, it continues to be used in both practical and research settings today (Aamodt, Keller, Crawford, & Kimbrough, 1981; Stitt-Gohdes, Lambrecht, & Redmann, 2000). Bailey and Merritt (1995) argue that this method is optimal for rendering holistic and professionally-oriented descriptions of a job. Analyses were performed using an approach based on the critical incident technique (CIT). On the basis of a thorough literature review, previous medical research, and the analysis of the transcripts, the responses to each question were reduced to behavioral or critical incidents. Flanagan (1954) referred to this phase as incident segmentation.

In the second phase, the critical incidents obtained from the exceptional surgeons were sorted into categories (i.e., competencies). For each competency, definitions based on the critical events were developed. After the definitions were considered complete, they were submitted to a group of five experienced surgeons to be confirmed or modified. These surgeons were also well-known and well-respected in their respective specialties. This group of subject matter experts was responsible only for revising the competency definitions.

Next, a second I-O psychologist with experience in competency modeling and qualitative analysis sorted the critical incidents into their appropriate categories. His results were compared to the categories formed in Phase two. In the final phase, the importance of each category was estimated. Using the process described by Aamodt and his colleagues (1981), the number of critical incidents in each category retained after the final phase was summed. The number of critical incidents in each category was provided in an effort to establish relative importance of each competency.

In addition to describing the characteristics of outstanding surgeons, the interview data were also used to describe the characteristics of poor surgeons, as well as requirements for exceptional surgeons in the future. The same process of analysis used for the expert comments was applied to these categories of comments.

Interview Data from the Surgical Resident Group

A second goal of the present study was to identify patterns within the data that distinguish exceptional from novice surgeons. Once again, the critical incidents obtained from the residents were independently sorted into categories (i.e., competencies). Additionally, relative importance ratings were determined by summing the critical incidents within each competency. Once the categories were considered complete, they were not presented to another group of experienced surgeons for further consideration. The objective of analyzing the surgical resident data was to compare and contrast the resultant model with the one derived from the exceptional surgeons. Therefore, the interview content from the residents did not impact the final competency model of an exceptional surgeon. Rather, similarities and discrepancies between both groups of surgeons are described and explored below.

RESULTS

Main Analysis

Two sets of interviews were performed: the main analysis centered on the expert comments and the secondary analysis addressed the resident comments. The results of the main analysis will be described first. The expert comment analysis is divided into three sections. The first section consists of the characteristics of an exceptional surgeon (i.e., the competencies). The second section consists of the characteristics of a poor surgeon and the final section consists of the characteristics of the exceptional surgeon of the future.

Characteristics of an Exceptional Surgeon

The comment analysis of the characteristics of an exceptional surgeon consisted of 298 individual comments made by 26 expert surgeons. Each comment was placed into 17 themes. However, an *a priori* decision was made to include only themes that contained comments from a minimum of eight participants. Any theme containing comments from fewer than eight participants was not considered to be characteristic of the participant pool since it represented less than one-third of the total number of participants (See Appendix B for the residual comments). This criterion yielded ten competencies based on 237 comments. The most frequently noted competency had 39 comments and the least frequently noted competency had 15 comments.

Inter-rater Agreement

Two I-O psychologists with experience in competency modeling and qualitative analysis independently sorted the 237 comments into the ten competencies. Cohen's kappa (Cohen, 1960) was used to provide a measure of inter-rater agreement between the two judges. The value of kappa for this data set was 0.85, with a standard error of .03. Many researchers, including Landis and Koch (1977), believe that a kappa value of .61-.80 indicates "substantial agreement" and a value of .81-1.00 indicates "almost perfect agreement." Therefore, in the present study, it can be said with confidence that the two raters had extremely high agreement on their sortings.

The Ten Competencies

The following section contains a description of the ten competencies, along with the total number of individual comments comprising each competency. Definitions were created for each competency and these are shown in Table 2. Immediately following the table, a more thorough description of each competency is provided.

Table 2

Ten Competencies of an Exceptional Surgeon

Competency	# of Comments	Definition
Dedication to Patient Care	39	Consistently and passionately regarding the patient as the most important part of any professional transaction. Maintaining the patient as the primary focus while simultaneously holding one's personal needs, ego, and obligations as secondary. Answering all of a patient's questions and concerns while always communicating that everything possible will be done to ensure a positive outcome.
Integrity	33	Honestly recognizing one's strengths and weaknesses as a surgeon. Admitting when one is wrong and publicly accepting responsibility for mistakes. Agreeing to perform operations only after the complete consideration of a patient's full medical profile.

Table 2- Continued

Competency	# of Comments	Definition
Tireless Work Ethic	29	Displaying a high level of energy and drive when dealing with patients, residents, and other healthcare professionals. Willing and eager to work long hours to ensure excellence in one's career.
Preparedness	27	Delivering patient care in a thoughtful, precise, and deliberate manner. Consistently anticipating complications before entering the OR and having multiple contingencies covered. Conducting every operation in a structured and orderly way as to not confuse team members.
Intellectual Giftedness and Curiosity	23	Displaying an ability to process an enormous amount of medical information and grasp new concepts very quickly. Maintaining an insatiable curiosity about the field through the conduct of research and the development of new and improved surgical methods and procedures. Tackling medical issues in an innovative and creative manner.
Humility	21	Displaying respect for others regardless of their rank within the hospital setting. Maintaining a modest demeanor when interacting with patients and other healthcare professionals.
Compassion	19	Adopting a humanistic approach to treating patients, responding in a caring and empathetic manner to their suffering. Maintaining a gentle and patient attitude with co-workers and other healthcare professional, including nurses, residents and medical students.
Devotion to Field	16	Demonstrating an intense devotion to the field of surgery disproportionate to other surgeons. Viewing surgery not as a job but as a calling.

Table 2- Continued

Competency	# of Comments	Definition
Rapid Decision Making	15	Demonstrating the capacity to quickly analyze the risks and benefits of multiple courses of treatment and to choose the most appropriate and expeditious path to a positive patient outcome. Making swift yet informed decisions under intense pressure and with less than optimum data available.
Passion for Teaching	15	Maintaining the utmost dedication to the education of patients, the community or other health professionals, as well residents, both in and out of the classroom. Disregarding any time limit when training others. Demonstrating an intense responsibility and passion for creating the next generation of highly qualified surgeons.

Competency #1: Dedication to Patient Care

Twenty-two expert participants defined the exceptional surgeon as one who is totally dedicated to patient care. In fact, 39 comments related to the dedication to patient care were provided by the participants. An essential aspect of this competency is the ability and willingness to treat the patient with the utmost importance and urgency. Consequently, the needs of a surgeon, including any personal obligations, are viewed as secondary to those of the patient. One particularly relevant example given by a participant was that of an accomplished surgeon who was called into a hospital to operate on a patient who required emergency surgery. This surgeon performed a successful surgery which ultimately saved the patient's life. The poignant part of the story is that the surgeon's father had just died, although no one in the hospital knew about the tragedy at the time. Even after receiving horrendous personal news, the surgeon refused to abandon his patient.

Several participants also commented that their dedication to patient care helped them work through the fatigue of lengthy operations. A sense of duty to patients often compels a surgeon to spend ample time with a patient and family members prior to surgery to ensure that all questions and concerns regarding the disease and procedure are addressed. Postoperatively, this same sense of duty brings a surgeon to a patient's bedside and drives him or her to follow the recovery meticulously. Furthermore, dedication to patient care often compels a surgeon to be willing to hold the hand of a patient who is very upset. In fact, a few participants admitted to crying with several of their patients during these highly emotional times.

Another experience that several experts seemed to share was a long-standing relationship with a few of their patients who had extremely critical diseases or injuries. Some participants revealed that they still receive Christmas cards from patients that they operated on five, ten, or even fifteen years ago. Many of these patients acknowledge that they would not be alive if it were not for the valiant efforts of their surgeons. Moreover, surgeons felt honored that they continued to remain in their patients' thoughts and prayers so many years later. A handful of participants admitted becoming attached to patients and that these patients continued to be a part of their lives years after the surgery. One participant recently wrote a letter of recommendation for a former patient who decided to apply to law school. Another participant shared a story of a surgeon who developed such a strong rapport with a patient that he found employment for his former patient in the hospital in which he worked. These stories exemplify the unique bond that sometimes exists between an exceptional surgeon devoted to patient care and his or her patient.

Dedication to patient care extends from the initial meeting with the patient through the surgery and post-operative visits, and in certain cases, it may last for years into the future via annual cards or visits. Although it is impossible to expect a surgeon to maintain a close relationship with all patients, the exceptional surgeon consistently provides comfort when delivering bad news and sits down with a patient and his or her family to answer all of their questions and quell their fears. It is this type of surgeon who does everything in his or her power to ensure the well-being of a patient.

It was also frequently noted that the exceptional surgeon is forced to make many personal sacrifices, including missing important family events. However, none of the expert participants lamented the fact that they sometimes miss these occasions. There appeared to be an unspoken understanding that personal sacrifices are a natural consequence of being in such a demanding, patient-driven profession. In fact, nearly every participant spoke about the profession with passion and enthusiasm.

Competency #2: Integrity

Nineteen expert participants indicated that integrity was an essential characteristic of the exceptional surgeon. A total of 33 comments were offered concerning the importance of integrity for surgery. Specifically, integrity involves the recognition of one's strengths and weaknesses as a surgeon. It also includes the willingness to admit when one is wrong and the public acceptance of responsibility for mistakes made either in or out of the OR. In addition, integrity helps guide a surgeon's decision making when considering whether to operate on a patient. Clearly, if a surgeon performs an operation that is not needed, his or her integrity would be called into question.

Not every surgeon has the ability or the inclination to communicate honestly and directly. According to the experts, an exceptional surgeon communicates with everyone in an honest and straightforward manner, including patients, family members, colleagues, residents, and students. A surgeon with integrity can be trusted to inform patients of his or her limitations and not provide them with false hope or misinformation about their prognosis. Likewise, if a surgeon has limited experience with a particular procedure, it is expected that he or she will provide the patient with an honest representation of his or her skills and experience. A surgeon with integrity will be candid with the patient about whether he or she can help.

Exceptional surgeons have a clear understanding of right and wrong and a set of ethical principles that guide them in their practice. Many of the expert participants believed strongly that a surgeon should not perform a surgery unless the patient's full medical profile had been carefully considered. Certain patients are not good candidates for surgery. Therefore, if a procedure will put a patient at considerable risk, a surgeon may have to refuse to perform it. One participant commented that he must occasionally refuse older patients because he feels it is not in their best interest to have surgery. He offers them alternatives to surgery instead.

Additionally, a surgeon with integrity will be straightforward with patients and their family members, as well as colleagues when mistakes are made. Several participants described similar accounts of surgeons who accepted the blame for mistakes that occurred in the OR, even when other surgeons were directly responsible. For example, one participant recalled a time in his training when an attending surgeon assumed full responsibility for a complication caused by his resident. Furthermore, surgeons with integrity do not allow mistakes to be minimized or ignored. Rather, they take responsibility for them and candidly explain the nature of the mistake or complication to patients, family members, and to colleagues at morbidity and mortality meetings.

Competency #3: Tireless Work Ethic

Sixteen participants indicated that an exceptional surgeon has a tireless work ethic. In fact, 29 comments were offered regarding this competency. For a surgeon, a tireless work ethic includes limitless energy when dealing with patients, family members, residents, and colleagues. Underlying this competency is a passion for surgery that drives an individual to work through the exhaustion inherent in a surgeon's schedule. Exceptional surgeons will persist and push through procedure after procedure due to their passion for hard work and excellence.

Several experts argued that a tireless work ethic is not limited to the early years of practice. Rather, it is a goal-oriented behavior pattern that continues throughout a surgeon's career. Surgeons with a tireless work ethic are self-motivated and have an intense desire to succeed. However, success is not necessarily a byproduct of hard work but a *process* of achievement. Exceptional surgeons derive enormous satisfaction in the process of performing surgery. They also find excitement in rising to a challenge, such as successfully completing a complicated or life-threatening surgery. Moreover, the exceptional surgeon is one who successfully engenders the same enthusiasm and drive for hard work in others, including residents and colleagues.

Finally, a strong work ethic paired with high energy often results in a tenacious, persistent surgeon. Five participants remarked that surgeons with a tireless work ethic are often difficult to pull off task. These individuals rarely let themselves give up when dealing with a problem. They will devote extremely long hours to find solutions to problems. Several participants also indicated that an unresolved problem will keep them up at night. These surgeons are committed to working any time of day to tackle a problem.

Competency #4: Preparedness

Fourteen participants viewed preparedness as a central competency for surgeons. Twenty-seven participant comments indicated that preparedness distinguishes the exceptional from the typical surgeon. In the context of surgery, preparedness refers to how a surgeon approaches his or her cases. The prepared surgeon acts thoughtfully and precisely so that complications are anticipated prior to surgery and contingencies have been considered should any complication arise.

Furthermore, a prepared surgeon conducts every operation in a structured manner so that residents and other team members can easily anticipate and assist with each step of the procedure. An organized and structured style of work also decreases the chances that a surgeon will panic or lose focus should unexpected problems arise. Although complications do occur even with the most prepared surgeons, several participants commented that truly prepared surgeons rarely find themselves in major trouble and they tend to have the best outcomes with their patients.

In addition to performing well-planned and well-executed surgeries, the prepared surgeon also pays great attention to detail. The ability to attend to small details enables a surgeon to identify minor problems and prevent them from quickly spiraling into major problems or complications. Moreover, prepared surgeons are often viewed by others as compulsive, thorough, and orderly. One expert participant even described himself as a "control freak." Although individuals who are compulsive and controlling may be viewed somewhat negatively in other professions, these characteristics appear to be strongly linked to success in surgery.

Competency #5: Intellectual Giftedness and Curiosity

Ten participants indicated that a combination of intellectual giftedness and intellectual curiosity distinguishes expert from average surgeons. Twenty-three comments addressed intellectual giftedness and curiosity. Surgeons with this competency have the ability to process an enormous amount of medical information and grasp new concepts very quickly. They are also extremely active in research and often in the development of improved surgical procedures. Involvement in these activities demonstrates curiosity and an ability to advance the field through innovative thinking.

Not only do exceptional surgeons have an extensive medical knowledge base, they can process the information that they need very quickly. They also know where to find the information they need in a pinch. When new concepts or surgical methods arise, these surgeons are likely to master them rapidly. One reason why they may grasp new concepts quickly is that their intellectual giftedness and curiosity compels them to participate in research. Several participants indicated that it is in the exceptional surgeon's nature to ask questions about the field and to strive toward moving the field forward through the development of innovative procedures. Finally, while some surgeons may be reluctant to tackle critical medical issues, exceptional surgeons tend to derive enormous satisfaction from handling a crisis. Rather than be held back by fear of failure, an intellectually gifted/curious surgeon welcomes a challenge.

Competency #6: Humility

The next highest-ranking competency was humility, which was endorsed by eight participants. A total of 21 comments related to humility were provided by the participants. Humility reflects how surgeons relate to other professionals who are lower in rank (e.g., nurses, residents), as well as how they interact with patients and their family members. Humility is a characteristic often lacking in the stereotypical version of a surgeon. Nonetheless, a surgeon with humility allows patients to feel comfortable enough to ask questions and voice concerns. It also enables healthcare professionals who work alongside the surgeon to feel respected and valued for their contribution to patient care.

Surgeons with humility demonstrate modesty when dealing with patients and colleagues yet they retain their self-confidence. Remaining humble is often easier said than done for surgeons given that they are the team leaders in the OR. Although surgeons are generally revered by the public, exceptional surgeons do not act as if they are above others. The exceptional surgeon is humble rather than arrogant and confident rather than cocky.

Another aspect of humility concerns the display of respect for other healthcare professionals, regardless of their rank in the hospital or academic institution. In other words, surgeons with humility do not talk down to nurses or technicians, nor do they patronize those who are beginning their training. Several participants stressed that exceptional surgeons are respectful in all of their professional encounters. When surgeons fail to treat others with respect, they are essentially devaluing their contributions to patient care. An exceptional surgeon acknowledges the teamwork inherent in surgery and the value in each part played by every team member.

Competency #7: Compassion

Eleven participants indicated that compassion also distinguishes expert from average surgeons. Nineteen expert comments addressed this competency. Compassionate surgeons display a caring attitude toward co-workers and residents. These surgeons are genuinely sympathetic toward patients who are suffering. They also display empathy with residents who may be struggling to perform a procedure. Compassionate surgeons avoid turning surgery into a purely technical feat. Rather, they interact with their patients, residents, and colleagues with kindness and patience.

Surgeons with compassion give other individuals, including patients and residents, sufficient time to talk. Compassionate surgeons never rush patients out of their office, particularly when they have to deliver bad news. They take the time to listen to their patients' problems. Occasionally, these surgeons form bonds with their patients, especially those with chronic conditions. One participant noted that he has actually attended several of his patients' funeral services. Another participant spoke of his mentor who was extremely compassionate. Not only was he kind toward his patients, but he was described as a father figure with the residents. His residents knew they could call him at any time. In fact, he even responded to a late night phone call to bail a resident out of a jail. Not every surgeon has the personality to be overtly compassionate, but exceptional surgeons tend to exhibit a uniquely sympathetic attitude toward others.

Competency #8: Devotion to the Field

Eight expert participants indicated that a strong devotion to the field was an important component of an exceptional surgeon. A total of 16 comments comprised this competency. In describing exceptional surgeons, some of the words the participants used were "passionate, "single-minded", and "fanatical." These descriptions suggest that many exceptional surgeons display an intense dedication to their field above and beyond that of other surgeons. Colleagues and co-workers of exceptional surgeons recognize the passion they hold for surgery. It is something they typically wear on their sleeves.

One participant described this extreme form of commitment as "living and breathing surgery." Another participant stated that this type of surgeon "gives his life and soul to the field." These individuals tend to put in more time on the job than other surgeons. In fact, to these select few, surgery is much more than a job, it is a calling. Surgeons who are truly devoted to the field are not in the profession for money. Rather, they are in it for the love of helping and healing others. These surgeons never watch the clock or espouse a work shift mentality. In this vein, one participant compared himself to an artist because, as he stated, "an artist never watches the clock; he leaves the studio only when he feels he is finished." Likewise, devoted surgeons remain on the job until they feel confident that their work is truly completed.

Competency #9: Rapid Decision Making

Although rapid decision making received only 15 comments from experts, ten participants felt compelled to describe it as an important characteristic that distinguishes the exceptional surgeon. There are two important aspects of this competency. First, the exceptional surgeon often possesses the ability to swiftly analyze the risks and benefits of multiple courses of treatment and choose the most appropriate and expeditious path to a positive outcome. Second, these surgeons are frequently able to make informed decisions under highly stressful situations with incomplete data.

Rapid decision making reflects the ability to improvise and think quickly on one's feet. Several participants indicated that surgeons with rapid decision making ability can very quickly size up a disease and the potential complications associated with it. These individuals rarely hesitate or second-guess themselves. They are able to remain calm so they can concentrate fully on the proper course of action. One particular participant described rapid decision making as the ability to "maneuver through mine fields." These exceptional surgeons know best how to handle the most dangerous and complicated of situations.

Competency # 10: Passion for Teaching

The final competency gleaned from the expert comments was a passion for teaching. Twelve participants offered 15 comments indicating that a passion for teaching distinguishes expert from average surgeons. Exceptional surgeons display a profound love for education and a tremendous dedication to their medical students and residents both in and out of the classroom and the OR. One participant recalled a former teacher who would hold discussions about cases with his residents for hours, even late in the evening, despite the fact that his family was waiting for him at home. Another surgeon also reminisced fondly about a former teacher, who had an incredibly hectic schedule, but still spent hours talking to him about cases. This special type of surgeon takes surgical education very seriously.

Several participants noted that surgeons with a passion for teaching are also devoted to the development of their mentees. They enjoy helping residents, fellows, and even junior faculty members in their professional development. In fact, they often do whatever is in their power to facilitate the success of others. For this type of surgeon, there is a thrill in motivating someone else to achieve. The passionate educator often maintains a sense of responsibility, and certainly an enthusiasm, for creating the next generation of highly qualified surgeons.

Characteristics of a Poor Surgeon

The comment analysis of the characteristics of a poor surgeon consisted of 62 individual comments made by the expert surgeons. Each comment was placed into five overall themes. However, the fifth theme consisted of only five comments; therefore, it was not considered to be representative of the participant pool. The following section describes the four predominant characteristics of a poor surgeon. The most frequently noted characteristic consisted of 18 comments and the least frequently noted characteristic consisted of 10 comments. Furthermore, there were five comments that did not relate to any of the established themes and thus were not included in the analysis (See Appendix B).

Characteristic #1: Dishonesty

A total of 18 comments revealed that dishonesty was the primary characteristic of a poor surgeon. Dishonesty can manifest itself in several ways. Individuals may falsify records or data, submit dual publications, or perform surgeries that are ethically questionable. A dishonest surgeon may also fail to take ownership of his or her mistakes. Seven participants commented that dishonest surgeons often refuse to take responsibility for poor patient outcomes. One participant discussed an incident involving a technically weak surgeon who had a poor patient outcome. This surgeon blamed the nurses for the outcome and responded very poorly to the suggestion that the patient should go back into the OR. Dishonest surgeons tend to lie about their patients' complications and display an unwillingness to accept responsibility for their errors.

In an academic setting, a dishonest surgeon may falsify data or alter the results of a research study. One participant recalled a junior surgeon in his lab who misrepresented the data he collected. As a result, the participant could never trust the junior surgeon again. Another participant discussed the case of an academic surgeon who submitted the same abstract to two different conferences. In both of these cases, the surgeons' dishonest actions seriously damaged their reputations.

Five participants described dishonest surgeons as those who either perform procedures on patients who do not need them, or perform procedures for which they are unqualified. The participants offered several reasons why a surgeon might perform an unnecessary surgery. Some surgeons are driven by greed and may perform unnecessary surgeries for their own financial gain. Other surgeons attempt to establish themselves as experts by conducting surgeries that are extremely complicated but may not be in the best interest of the patients. These surgeons may become fanatical about performing as many surgeries as possible so that they will receive additional referrals from other physicians. For example, one participant described a surgeon with whom she worked. This surgeon was gifted technically, but almost amoral in practice and became consumed with doing as many cases as he could and getting as many referrals as possible. Furthermore, he demonstrated minimal concern for his patients once they were out of surgery. This surgeon exemplifies the prototypical dishonest surgeon whose need for recognition, success, or money overshadows his dedication to patient care.

Characteristic #2: Apathy Toward Patient Care

Thirteen individual comments indicated that apathy toward patient care is characteristic of a poor surgeon. Surgeons with this characteristic exhibit a lack of caring and commitment toward their patients. Two participants stated that these surgeons also display little enthusiasm and energy when dealing with patients and their family members.

Several participants shared stories of surgeons who fit this mold. One extreme example involved a cardiac surgeon who delegated too much responsibility to the nurses and junior surgeons. The surgeon actually left in the middle of a procedure, instructing the junior surgeon to handle it. Tragically, the patient died during the procedure. When the junior surgeon called the senior surgeon to inform him that the family was inquiring about what went wrong, he refused to return to the hospital to talk to the family. This surgeon demonstrated complete apathy toward his patients.

Another participant provided a more typical example of a surgeon who scheduled patients around his golf games. He also had very limited office hours and refused to extend them for any reason. His schedule, whether it involved golf or other personal matters, consistently took priority over his professional commitments. Both of these examples describe surgeons who are not committed to their patients and do not have their patients' best interests in mind.

Characteristic #3: Aggressive Behavior

Twelve comments indicated that poor surgeons often bully other people and behave aggressively, particularly in the OR. The recipients are typically residents and nurses, but they can be anyone working alongside surgeons in the OR. All 12 comments described intimidating surgeons who often resorted to yelling, using profanity, and publicly berating or demeaning co-workers. One participant recalled an episode in which a surgeon actually became violent in the OR. When this individual was training a junior surgeon, he punched his subordinate for making a mistake during the procedure. Not only did the senior surgeon overreact, but he behaved in an inappropriate and abusive manner.

Two participants discussed former teachers who commonly used public humiliation as a teaching strategy. One of these teachers would frequently mock residents who were beginning their training, particularly if he thought they had talent. Rather than encourage the residents to succeed, this surgeon would try to undermine their confidence by ridiculing them as they worked on cases. As the participant stated, this surgeon was "trying to keep the residents in their place."

Characteristic #4: Lack of Preparation and Focus

The final characteristic of a poor surgeon is a lack of preparation and focus, particularly in the OR. Ten comments indicated that a disorganized OR is a sure sign of an unprepared and unfocused surgeon. Although such surgeons may feel prepared to perform a particular surgery because they have done many similar procedures in the past, they often overlook how much prep work is involved. They rarely read relevant articles or books that would help them better prepare for major surgeries or deal with unanticipated complications.

Two participants remarked that unprepared surgeons are often hesitant and self-doubting. They are indecisive when important decisions need to be made (e.g., "Should I replace or repair the valve?"). According to the participants, unprepared surgeons are frequently "treading water" in that they waste valuable time debating their next move. Their operations tend to take longer than those of surgeons who are prepared. Moreover, these surgeons never seem to salvage a marginal patient. Although they may do well on cases without complications and patients who are relatively healthy, their outcomes tend to be less favorable with more vulnerable patients.

Finally, surgeons who lack preparation and focus may not attend to smaller, technical details, such as blood loss. They may have to rely on their team members to keep them abreast of subtle changes. These surgeons may also omit important tests that should be run prior to sending a patient for surgery. In addition, they may not consider the full array of risk factors that are involved in each individual case. When a surgeon overlooks important factors prior to surgery, disastrous outcomes may result. For instance, one participant described a surgeon who had a young patient bleed to death immediately following a splenectomy procedure (i.e., removal of the spleen) because the surgeon did not realize she was on a blood thinner. This tragedy could have been avoided if the surgeon had reviewed his patient's medication record prior to performing surgery.

Characteristics of an Exceptional Surgeon of the Future

The analysis for an exceptional surgeon of the future consisted of 101 comments. Participants were asked to discuss the "knowledge, skills, and other characteristics" necessary for a surgeon to be exceptional in the year 2015. Four themes emerged. The most frequently noted theme included 30 comments and the least frequently noted theme included 8 comments. Six other themes will not be discussed because they consisted of five or fewer comments. Further, there were seven comments that did not relate to any of the established themes and thus were not included in the analysis (See Appendix B).

Theme #1: Willingness to Adopt New Technologies and Skill Sets

Nearly every generation of surgeons is faced with the task of mastering new technology. For instance, during World War II, surgeons were forced to learn new technologies to deal with the vast number of casualties including the use of prosthetics, bone fusion, and the use of antibiotics. In the coming decade, surgeons will also need to embrace new forms of technology. It is likely that skills and expertise not traditionally associated with surgery, such as radiology, ultrasound, and cathlabs, will become an important part of the surgeon's arsenal.

Thirty expert comments revealed that surgeons of the future will need to adopt various technologies and learn new skill sets to be considered exceptional. Ten participants stated that future surgeons will need to embrace MIS procedures and five experts indicated that robotics and computer-assisted surgeries will play a significant role throughout the next decade. Regardless of the specific type of technology, it will be important for surgeons to develop skills that they might not have learned during residency. In fact, it is possible that surgeons will need to train themselves on new technology several times throughout their careers. They must also be able to discern which technologies are most beneficial to their patients. In addition, exceptional surgeons in the future will need to be able to use new technology that can reduce the complexity of procedures. For example, surgeons may need to master technology that provides more accurate prognoses and staging of various types of cancer.

Surgery has become less "hands-on" as lasers, robot assistants, and laparoscopic instruments reduce or eliminate direct contact with patients. Such new technologies will allow for improved treatment, diagnostic, and screening processes. Experts believe that this "non-touch" trend will continue over the next ten years. One participant speculated that future surgeons will be able to assess many patients without having to leave their homes. For instance, they will be able to access and read X-rays from their home e-mail accounts. Indeed, many technological challenges lie ahead for future surgeons.

Theme #2: Primary Qualities Remain Unchanged

Seventeen individual comments conveyed the notion that the primary characteristics of an exceptional surgeon in the future will remain the same as they are today. The participants did not expect the overall profile of an exceptional surgeon to be dramatically different because they believe that a surgeon's main responsibility will still be dedication to patient care. Although the field is expected to undergo technological changes, thirteen participants indicated that those changes should not impact the qualities of an exceptional surgeon.

The participants who believed that the characteristics of outstanding surgeons will be the same in the future as they are today, were also the same surgeons who held dedication to patient care as the most important competency. These surgeons seemed to believe that the interpersonal relationships surgeons have with their patients and the caring nature with which they treat patients are the defining characteristics of an excellent surgeon and these should not change over time.

Theme #3: Adjustment to the 80-Hour Work Week

The issue of the 80-hour work week restriction for residents is currently a hot topic and according to 11 participants, it will continue to remain a challenge for future surgeons. The participants believe that a cultural shift is starting to take place among younger surgeons and will persist throughout the next decade. Specifically, they are concerned that young surgeons are adopting a work shift mentality. One participant referred to this new breed of surgeons as “clock-watchers.” Many participants were disturbed by this new mindset because surgeons have traditionally taken pride in their work schedules which are not dictated by set time frames. One participant noted that many residents now view surgery as a job instead of a calling and have come to expect limited hours and more personal freedom than older surgeons.

According to the participants, the adjustment to the 80-hour work week is also creating surgeons who adopt different values. There is a danger in the near future that surgeons will no longer feel the same sense of responsibility to patients as their predecessors. They will become accustomed to handing patients off to whomever is working the next shift. Three different surgeons may take care of a patient in the future as opposed to the traditional paradigm in which a single surgeon closely monitors a patient’s entire stay in the hospital. As one participant commented, such disruption to the continuity of care may ultimately be detrimental to patients if a surgeon does not fully describe a patient’s condition and status to the subsequent physicians in charge.

Furthermore, poor continuity of care may result in poorer communication between surgeons and patients. The future surgeon will need to have strong communication skills with patients, physicians, and other healthcare professionals to offset the challenges posed by the new 80-hour work week.

Theme #4: Surgeons Will Become Highly Specialized

Eight expert comments revealed that there will be fewer general and community surgeons and many more specialized surgeons over the next ten years. These participants indicated that surgeons will begin gravitating toward more specific specialties. One participant commented that every surgeon will need to make a decision about performing a combination of traditional and minimally invasive procedures or severely limiting their practice and becoming proceduralists. These experts believed that most surgeons will choose the latter option. In other words, future surgeons will become highly skilled at performing a smaller number of related surgeries rather than compiling a broad repertoire of different procedures. Unfortunately, patients will be the ones to suffer in the end, particularly those who live far from a city. Over the next decade or so, it is likely that patients will need to travel considerable distances for surgery.

Three participants also indicated that many future surgeons are likely to go to great lengths to minimize the stress associated with their practice. They will work to maintain more control over their lifestyles. Once surgeons become accustomed to working only 80 hours per week during their residency, they will also come to expect more free time for their families and personal obligations during their practice. The experts speculated that future surgeons will lean more toward surgical specialties that afford the opportunity to limit their work hours while maximizing their earning potential.

The exceptional surgeons of the future will resist the urge to pursue careers of convenience. Rather, they will maintain professional integrity by keeping the best interests of their patients in mind while working as many hours as necessary to ensure optimal patient care.

Secondary Analysis

A second set of interviews was performed with novice surgeons (i.e., surgical residents). The novice comment analysis is divided into the same three sections used for the experts. The first section consists of the characteristics of an exceptional surgeon (i.e., the competencies). The second section consists of the characteristics of a poor surgeon and the final section consists of the characteristics of the exceptional surgeon of the future.

Characteristics of an Exceptional Surgeon

The second comment analysis consisted of 150 individual comments made by 14 novice surgeons. Each comment was placed into nine overall themes. However, an *a priori* decision was made to include only themes that contained comments from a minimum of five participants. Any theme containing fewer than five comments was not considered to be characteristic of the participant pool because it represented less than one-third of the total number of participants (See Appendix C for the residual comments). This guideline yielded nine competencies of an exceptional surgeon based on 98 comments. The most frequently noted competency had 19 comments and the least frequently noted competency had 8 comments.

Inter-rater Agreement

The same raters who independently sorted the expert comments also sorted the novice comments. The Cohen's (1960) kappa value for this data set was 0.85 with a standard error of .04 and was the same kappa coefficient found for the expert comments. Again, this is a very high level of inter-rater agreement.

Table 3

Nine Competencies of an Exceptional Surgeon from the Novice Surgeon's Perspective

Competency	# of Comments	Definition
Ability to Communicate in Nontechnical Terminology	19	Demonstrating the ability to express complex medical information into simple and straightforward language that patients can understand. Avoiding medical jargon when educating patients about diseases or when discussing treatment plans.
Excellent Bedside Manner	17	Maintaining an attitude of sincere concern and support of a patient's psychological state. Demonstrating regard for the patient-physician interaction by taking the time to address a patient's concerns and questions and treating them with compassion and respect.
Tireless Work Ethic	10	Displaying a high level of energy and drive when dealing with patients, residents, and other healthcare professionals. Willing and eager to work long hours to ensure excellence in one's career.
Preparedness	10	Delivering patient care in a thoughtful, precise, and deliberate manner. Consistently anticipating complications before entering the OR and having multiple contingencies covered. Conducting every operation in a structured and orderly way as not to confuse team members.

Table 3- Continued

Competency	# of Comments	Definition
Rapid Decision Making	9	Demonstrating the capacity to quickly analyze the risks and benefits of multiple courses of treatment and to choose the most appropriate and expeditious path to a positive patient outcome. Making swift yet informed decisions under intense pressure and with less than optimal data available.
Positive Interactions with Staff	9	Displaying the ability to develop a strong rapport with all staff members. Demonstrating respect and gratitude for their contribution to patient care.
Sociability	8	Demonstrating a pleasant disposition and a good sense of humor when interacting with patients and hospital employees. Interacting with others in a friendly and outgoing manner.
Maintaining Composure	8	Remaining calm and focused under highly stressful situations. Displaying the ability to restore order in the OR during moments of chaos or confusion.
Putting Patients First	8	Displaying total commitment to patient care. Consistently willing to place the needs of patients above personal needs and family obligations.

Three competencies emerged on the list for both experts and novices: Tireless Work Ethic, Preparedness and Rapid Decision Making. It was decided to use the same definitions for both sets of competencies since the actual comments from the expert and novice participants were very similar in content.

Competency #1: Ability to Communicate in Nontechnical Terminology

Nine novice participants defined the exceptional surgeon as one who has the ability to communicate with patients in nontechnical terminology. Nineteen comments reflected the importance of a surgeon's ability to distill complicated medical concepts into language that can be understood by a layperson. This competency also describes a surgeon's ability to consider a patient's education and socioeconomic status when communicating so that he or she neither confuses nor belittles the patient. In general, the residents believed that exceptional surgeons are adept at avoiding medical jargon and minimizing the use of overly technical language when talking to patients and family members about courses of treatment or when educating them about their illnesses. Exceptional surgeons are effective communicators who can easily adjust their style of communication to match the level of their audience.

Competency #2: Excellent Bedside Manner

Ten novice participants indicated that exceptional surgeons, by definition, have an excellent bedside manner. Seventeen comments echoed the notion that exceptional surgeons are genuinely concerned about the effects of illness and surgery on a patient's psychological well-being. These surgeons have been described as caring, compassionate, and empathetic individuals who are always willing to take the time needed to address their patients' questions and concerns. One resident discussed an exceptional surgeon who had an amazing presence and ability to make genuine connections with his patients and put them at ease. According to these novices, exceptional surgeons are committed to supporting both the physical and psychological health of their patients.

Competency #3: Tireless Work Ethic

Seven novices indicated that a tireless work ethic was an essential component of an exceptional surgeon. Ten comments indicated that exceptional surgeons are hard-working professionals with an untiring dedication to the job and their patients. According to the residents, these surgeons make themselves available to patients, residents, and other healthcare professionals at any time. They possess the physical stamina and energy necessary to sustain both their dedication to the job and their indefatigable work schedule over the course of their careers.

Competency #4: Preparedness

Six residents stated that preparedness was a distinguishing characteristic of exceptional surgeons. Ten comments reflected the idea that exceptional surgeons practice medicine in a very precise and deliberate manner, anticipating potential complications before they enter the OR and leaving little to chance. They perform surgeries in a structured way so that residents and other surgical team members can anticipate each step and do not become confused. Exceptional, prepared surgeons also maintain the ability to focus in critical situations. As one resident remarked that highly prepared surgeons can disconnect from their emotions when serious complications arise in the OR and get their patients out of trouble.

Competency #5: Rapid Decision Making

Five novice surgeons offered nine comments regarding the ability of exceptional surgeons to make rapid decisions. An outstanding surgeon can analyze the risks and benefits of multiple courses of treatment in a swift fashion. Additionally, they can quickly choose the best path to a positive outcome even under highly stressful conditions. Exceptional surgeons are decisive and adaptive individuals who are able to make effective decisions, often with less than optimal data.

Competency #6: Positive Interactions with Staff

Seven novices suggested that exceptional surgeons treat staff members well. Nine comments reflected the notion that exceptional surgeons have respect for and demonstrate general goodwill to the other healthcare professionals with whom they work, including residents, nurses, and technicians. Rather than demean or overlook their contribution to patient care, exceptional surgeons often display gratitude for the efforts of all healthcare workers. Consequently, these surgeons tend to develop a good rapport with most of the staff members they encounter.

Competency #7: Sociability

Six novice surgeons believed that sociability was an important characteristic of an exceptional surgeon. Eight comments indicated that exceptional surgeons are often sociable individuals who maintain a pleasant disposition when interacting with co-workers, patients, and family members. These participants viewed an exceptional surgeon as having a friendly and outgoing personality, as well as a great sense of humor. Such surgeons are charismatic individuals who get along very well with most people.

Competency #8: Maintaining Composure

Five novice surgeons provided eight comments on the ability of exceptional surgeons to maintain composure under highly stressful circumstances. Moreover, these participants noted that such surgeons can be relied on to restore order during stressful or chaotic times, such as when a patient's bleeding needs to be controlled. Three of the five novices used the word "levelheaded" to describe composed surgeons. Further, a composed surgeon appears unflustered and maintains his or her position as the revered team leader, even when other people in the OR are in a state of panic.

Competency #9: Putting Patients First

Five novices stated that exceptional surgeons consistently put their patients before all other obligations. Eight comments indicated that exceptional surgeons are willing to place the needs of their patients before their own personal needs or even those of their family. These participants described exceptional surgeons as selfless and completely focused on the patients. As a result, such surgeons may miss important personal events, such as an anniversary dinner or their child's soccer match. Thus, exceptional surgeons accept and acknowledge that their patients' well-being must take precedence over everything else.

Characteristics of a Poor Surgeon

The analysis for a poor surgeon consisted of 28 comments made by 14 novice surgeons. Each comment was placed into six overall themes. However, three of these themes were endorsed by only two novices; therefore, they were not considered to be representative of the participant pool and they were excluded from the analysis. The most frequently noted characteristic consisted of seven comments and the least frequently noted characteristic consisted of four comments. Moreover, there were six comments that did not relate to any of the established themes and thus were not included in the analysis (See Appendix C).

Characteristic #1: Lack of Concern for Others' Feelings

Seven comments made by four novice participants indicated that poor surgeons show a lack of concern for their patients' feelings, as well as the feelings of other people with whom they work. These surgeons convey little appreciation for their patients' suffering. Consequently, patients often view them as rude and disrespectful. One novice described an incident in which a surgeon made a patient cry after telling him that his kidneys were going to lose their ability to function because he was "fat." He then informed the patient that he was "going to die." The surgeon immediately left the room, leaving the patient alone to cry. He appeared to have no concern over how his statement affected his patient or the manner in which he delivered the bad news. Surgeons who share this characteristic may also disparage other healthcare professionals by speaking to them with sarcasm or disrespect. Still other surgeons behave unprofessionally by voicing contempt for the opinions or ideas of other physicians. In each case, these were considered to be examples of poor surgeons who did not display the ability to treat patients and co-workers with dignity and consideration.

Characteristic #2: Apathy toward Patient Care

Five comments made by five different novice participants indicated that apathy toward patient care is another characteristic of poor surgeons. For instance, these surgeons often refuse to return to the hospital to assist a patient once they are home. They are unwilling to shift their schedules to accommodate their patients or if they do, they are often resentful of patients impeding on their personal time. If a patient develops sudden complications, these surgeons are more likely to delay surgery until the following day when they are on schedule. Furthermore, two of the five participants believed that surgeons who are apathetic toward patients may make decisions to operate without considering their patients' level of comfort or prospect for survival. Particularly with older patients, poor surgeons may perform surgeries that are not in the best interest of their patients and rob them of dying with dignity. The novices believe it is important to inform patients when the risks of surgery outweigh the likelihood of a good recovery. Thus, poor surgeons make decisions to operate without weighing the risks of surgery against the benefits.

Characteristic #3: Aggressive Behavior

Four comments offered by four residents indicated that they believe poor surgeons tend to exhibit aggressive behavior. Such surgeons are known to yell at nurses, technicians, and other staff members, particularly in the OR. They may also throw instruments and other objects when they become frustrated during surgery. In essence, these surgeons are quick to lose their temper and displace their aggression onto other personnel who may be doing their best to assist them. Accordingly, surgeons who demonstrate aggressive behavior often have very tense ORs, exacerbating the levels of stress among other team members worried about making mistakes. The other team members realize how easy it is to trigger surgeons who are prone to aggression, especially during challenging procedures or when complications suddenly arise.

Characteristics of an Exceptional Surgeon of the Future

The analysis of characteristics of an exceptional surgeon of the future consisted of 44 comments. Novice participants were also asked to discuss the "knowledge, skills, and other characteristics" necessary for a surgeon to be exceptional in the year 2015. Only two of the seven themes that emerged from the interviews were endorsed by over one third of the participants. However, three other themes were endorsed by three (21%) participants. Therefore, the two highest-ranking themes will be described in detail below and the three themes that did not quite reach criteria for inclusion will be discussed briefly. The most frequently noted theme consisted of 16 comments made by 10 novices. The next highest theme consisted of four comments made by four novices. There were six comments that did not relate to any of the established themes and thus were not included in the analysis (See Appendix C).

Theme #1: Willingness to Integrate New Technologies into One's Surgical Practice

Ten residents indicated that exceptional surgeons in the future will need to embrace new technologies and procedures and integrate them into their practice. The novices specifically mentioned minimally invasive procedures and robotics. Exceptional surgeons will need to go beyond keeping up with the literature; they will need to incorporate the latest research into their practice. They may also need to take continuing education courses and practice their new skills in a laboratory setting or with medical simulators before they perform these procedures on their patients.

Exceptional surgeons will need to be highly self-motivated to stay abreast of the latest technology. They must be open to learning long after they leave their residency programs. According to the novice surgeons, open surgical procedures will become rarer in the future. Conditions that typically require surgery, such as breast or ovarian cancer, will be performed through MIS. Therefore, exceptional surgeons of the future must be well-versed in these new methods.

Theme #2: Primary Qualities Remain Unchanged

Four comments made by the novices indicated that the main qualities of an exceptional surgeon of the future will be the same as they are for surgeons today. Although the majority of participants commented that technological advances will bring about massive changes to the field, they did not believe that technology will alter the characteristics of a truly competent surgeon. The novice surgeons believe that an exceptional surgeon in 2015 will still need to possess competencies including an Excellent Bedside Manner, Rapid Decision Making, a Tireless Work Ethic, Preparedness, and the ability to Maintain Composure. The challenge, as they see it, will be to reach this level of excellence and sustain it over the course of one's career.

Other Relevant Themes

The following three themes did not reach criteria for inclusion, but they were endorsed by over 20 percent of the participants. The first theme concerned strong computer management skills. At a minimum, exceptional surgeons must be fluent with the Internet and personal computers. They should also be able to retrieve electronic medical records and be comfortable using wireless devices, such as a Personal Digital Assistant (PDA) to keep track of their appointments.

The second theme focused on strong interpersonal skills. These skills will not only foster improved communication between surgeons and patients, but better communication among surgeons themselves. Exceptional surgeons will be expected to speak clearly and compassionately with their patients. According to one participant, many past behaviors, such as yelling and throwing instruments, will no longer be accepted of surgeons in the future. The novices also stated that surgeons will be required to communicate more readily with other surgeons, particularly when they must hand off cases due to vacation plans or conference schedules. There will also be an expectation for surgeons to address patients and other physicians with respect and benevolence.

Finally, exceptional surgeons of the future may also be expected to successfully manage an interdisciplinary surgical team. Three residents indicated that surgeons will be responsible for coordinating an increasingly complex team of people, including members of the critical care service, nurse practitioners, physician assistants, and surgical assistants. Therefore, good surgeons must be able to facilitate interactions among workers while minimizing breakdowns in communication. The participants also stated that exceptional surgeons must embrace diversity in future teams and incorporate both traditional and non-traditional perspectives and talents.

Comparison between Competencies Identified by Experts and Novices

One objective of the competency analyses was to identify trends or patterns that might exist between the experts and novices. In the following section, similarities and differences between both competency lists are addressed.

Similarities between Expert and Novice Competency Results

Several similarities existed between the results of the expert and novice interviews. For instance, a similar number of competencies were identified for both groups and three specific competencies were mentioned by both groups. These competencies were Rapid Decision Making, Preparedness, and Tireless Work Ethic.

Experts and novices agreed that exceptional surgeons are skilled decision makers that do not waver under stress. Both groups also held similar views regarding the importance of anticipating complications and setting up contingency plans before entering the OR. Furthermore, expert and novice participants agreed that exceptional surgeons are unstinting individuals who work through the exhaustion of the job and maintain high levels of energy and productivity throughout their careers.

The experts identified Dedication to Patient Care as the highest-ranking competency of an exceptional surgeon. This competency was similar to the novice's lowest-ranking competency, Putting Patients First. However, the emphasis within each competency differed slightly for both groups. The novice comments focused more on the personal and familial sacrifices that exceptional surgeons make for their patients. By contrast, experts focused more on the welfare of their patients. In general, both expert and novice comments indicated that exceptional surgeons view the well-being of their patients as a critical component of their practice.

On the surface it appears that the experts identified several personality-related competencies, such as Humility and Compassion that the novices did not mention. It can be argued, however, that there is some overlap between Compassion and Excellent Bedside Manner reported by the novices. There is also overlap between the expert competency, Humility, and the novice competency, Positive Interactions with Staff. One important aspect of Humility concerns respect for healthcare professionals regardless of their rank or title. Although experts also viewed Humility as a display of modesty and recognizing one's strengths and weaknesses as a surgeon, there is clearly some overlap between this competency and Positive Interactions with Staff.

Differences between Expert and Novice Competency Results

There were several differences between the experts and novices. For instance, several competencies that emerged from the novice data were not found in the expert data, including Ability to Communicate in Nontechnical Terminology and Maintaining Composure. Ability to Communicate in Nontechnical Terminology was the highest-ranking competency for novices, but it was not mentioned by the experts. The experts were also much less inclined to discuss the ability of surgeons to remain calm during stressful or critical procedures.

There were four competencies that were exclusive to the expert participants. First, expert surgeons viewed Integrity as an integral component of excellence in surgery. Many experts believed that a surgeon's strength of character was directly linked to his or her level of performance. Second, the expert comments revealed that exceptional surgeons have high Intellectual Giftedness and Curiosity. In other words, they display curiosity, creativity, and innovation when dealing with both academic and non-academic medical issues. Third, experts were more likely to describe Devotion to the Field as an important competency. They believed that exceptional surgeons are extremely passionate about their work and dedicated to their profession. Finally, the experts were much more focused than the novices on the link between surgical excellence and Passion for Teaching. Only the experts mentioned the important role that surgeons play in training the next generation of medical students and residents.

Similarities between Expert and Novice Results of a Poor Surgeon

Both expert and novice participants identified Apathy toward Patient Care as one of the main characteristics of a poor surgeon. Experts and novices commented that poor surgeons are inflexible and even indolent when they are asked to exert extra effort on behalf of a patient (e.g., when they need to return the hospital after a shift is over). In addition, both groups indicated that poor surgeons tend to display Aggressive Behavior.

Differences between Expert and Novice Results of a Poor Surgeon

According to the novice participants, poor surgeons tend to demonstrate a Lack of Concern for Others' Feelings. Novices made more comments than experts regarding surgeons who are rude or disparaging toward patients, staff members, and other physicians. Although the experts did not mention this characteristic, they identified two other qualities that the novices did not consider: Dishonesty and Lack of Preparation and Focus. Overall, the expert participants focused more on the integrity of exceptional surgeons and lack thereof in poor surgeons.

Similarities between Expert and Novice Results of an Exceptional Surgeon of the Future

Both experts and novices commented that exceptional surgeons of the future must be willing to incorporate new technologies and procedures into their practice. Although experts and novices agreed that the acceptance and integration of technology will be paramount to future surgeons, they also believed that the fundamental characteristics of an exceptional surgeon will transcend changes in technology. In other words, both groups stated that the core traits of an exceptional surgeon of the future will remain very similar to what they are today.

Differences between Expert and Novice Results of an Exceptional Surgeon of the Future

There was more variability between the expert and novice comments regarding the characteristics of an exceptional surgeon in the future. The experts generated four themes while the novices generated only two. The experts noted that exceptional surgeons in the future must resist the work shift mentality that may become associated with the 80-hour work week recently instituted in residency programs. They also indicated that future surgeons may gravitate toward higher degrees of specialization. The novice participants did not mention either of these themes in their interviews. Instead, the novices discussed that an exceptional surgeon of the future will remain the same as they are for surgeons today. They also indicated that future surgeons must be willing to integrate new technologies into their surgical practice.

DISCUSSION

The overall intent of this study was to gain a better understanding of surgical excellence by interviewing a sample of outstanding surgeons. The main objective of the primary analysis was to develop a detailed list of competencies of an exceptional surgeon as well as a list of characteristics that define a poor surgeon. The second objective was to develop a list of themes that would describe exceptional surgeons in the future. In addition, a smaller sample of novice surgeons was interviewed and three similar lists were generated to understand how these surgeons conceptualize surgical excellence. The final objective was to examine both data sets for similarities and differences in the way experts and novices define excellence. Therefore, a comparison was made between the expert and novice lists of competencies, as well as the lists of characteristics of a poor surgeon and themes impacting future surgeons to determine if different cohorts place varying emphases on the cardinal traits of an exceptional surgeon.

Primary Analysis: Expert Comments

Competencies Expected to Emerge

Based upon previous research, as well as the ACGME competencies used in resident training, several predictions were made regarding the expert data. It was anticipated that several competencies would emerge including technical skill or proficiency, critical thinking, leadership ability, intelligence, and interpersonal skill.

Technical Skill

In the field of surgery, technical skill is referred to by several names. For instance, technical skill may be called hand-eye coordination, mechanical excellence, or psychomotor ability. In the present study, technical skill was defined specifically as proficiency in two psychomotor factors: manual dexterity and hand-eye coordination. Surgeons are expected to have the technical skills to handle and maneuver their instruments with the greatest respect for tissue and maintain economy of motion during their actions. Thus, the first prediction was that technical skill would emerge from the expert data as an important competency.

Although seven experts mentioned technical skill as an important characteristic of the exceptional surgeon, it did not reach the criteria to be included on the list of competencies. Therefore, this prediction received only partial support. Instead, the majority of experts thought that technical skills would eventually be mastered by most surgeons. In other words, technical skill is necessary but not sufficient for becoming an outstanding surgeon. Most of the experts seemed to suggest that other characteristics, such as Dedication to Patient Care, Humility, and Integrity, were more important for distinguishing truly talented surgeons.

Critical Thinking

As previously stated, a high performing surgeon must possess a combination of technical skills and higher-order cognitive processes, such as critical thinking and independent thought. In the present study, critical thinking was defined as mental processes that allow a person to analyze and evaluate critical medical decisions, particularly when limited data are available. The second prediction was that critical thinking would also emerge as a key competency of exceptional surgeons. In other words, it was believed that the ability to make critical decisions, such as deciding whether to operate, determining diagnoses, and determining the level of risk to which a patient could be exposed by operating, would be necessary for surgical excellence.

The experts did refer to critical thinking; however, critical thinking was subsumed within two separate competencies: Rapid Decision Making and Preparedness. Experts indicated that exceptional surgeons make swift, informed decisions and are able to quickly analyze the risks and benefits of multiple courses of treatment for a patient. The competency definition provided for Rapid-Decision Making was very similar to the way in which critical thinking was originally conceptualized in the present study. Although the ability to anticipate complications before they arise in the OR was not hypothesized specifically, it would certainly be considered a component of critical thinking in surgery. It is also likely that the experts were referring to another aspect of critical thinking when they discussed the importance of Preparedness. Surgeons who are strong critical thinkers are typically prepared to handle unexpected problems or changes in a patient's status. Since it was anticipated that experts would mention the relationship between critical thinking and surgical excellence, the emergence of both Rapid Decision making and Preparedness as competencies supports this prediction.

Leadership

Surgeons have the responsibility of leading a team in the OR. Since the skills necessary to be a strong leader often come with many years of experience, it was predicted that the experts would describe leadership skills as another important competency of exceptional surgeons. Although leadership skills did not emerge as one of the top ten competencies, it is possible that the interview questions may not have prompted the experts to discuss the topic of leadership explicitly. Moreover, aspects of leadership may have been subsumed in other competencies. In the present study, leadership was defined by qualities including the ability to communicate effectively, demonstrate integrity, and display professionalism. Therefore, it is conceivable that facets of leadership were included in Dedication to Patient Care, Integrity, and even Humility.

The experts who were interviewed are clearly leaders in their field. However, they may not think of leadership in the same way as leaders in other professions, such as business and the military. Also, since the experts tended to be older surgeons, they may not have been aware of recent leadership research emphasizing team dynamics in the OR. In fact, several articles in the past few years have focused on the importance of leadership in surgical teams (e.g., Edmondson, 2003; Wells, Jr., 2002). Therefore, it is very likely that future generations of surgeons may aspire to have some of the same leadership characteristics commonly observed in other fields such as business.

Another reason why the experts did not mention leadership more frequently could be that most surgeons do not have many opportunities to observe their colleagues in the OR. Although they may learn about the outcomes of other surgeons' procedures, they may not know whether they are strong leaders or whether they successfully facilitate collaboration among team members. Since other members of surgical teams (e.g., residents, nurses, and surgical assistants) are aware of and affected by a surgeon's leadership skills, they might be more likely to mention the importance of such skills than the surgeons sampled for this study.

Intelligence

It was also predicted that the experts would mention the importance of intelligence in surgery. For this study, intelligence was described as a combination of analytical, creative, and practical thinking skills and all three facets were expected to be mentioned by the experts. The results revealed that experts viewed analytical and creative intelligence to be the most relevant forms of intelligence for exceptional surgeons. In fact, Intellectual Giftedness and Curiosity was ranked fifth on the competency list. Experts believed that exceptional surgeons tend to grasp new concepts very quickly and remain inquisitive about the field throughout their career. The ability to grasp new concepts quickly reflects analytical intelligence. The experts also mentioned that Intellectual Giftedness and Curiosity involves the ability to tackle medical issues in an innovative manner. Clearly, this ability is directly related to creative intelligence.

Practical intelligence, which is most often viewed as "street smarts," "common sense," or intelligence that functions in the real world, was not discussed explicitly. However, since practical intelligence refers to the application of learned information, it is likely subsumed within several of the competencies, including Rapid Decision making and Preparedness. For example, the ability to make swift and informed decisions is largely contingent on years of experience that contribute to common sense, as well as the knowledge necessary to solve practical problems. Given the frequency with which most experts discussed intellectual ability in general, this prediction was fully supported.

Dedication to Patient Care and Compassion

As noted earlier, several researchers have offered descriptions of a high performing surgeon. For example, Cuschieri, Francis, Crosby, and Hanna (2001) noted that outstanding surgeons tend to possess an amalgam of skills and abilities including, clinical skills, technical ability, academic potential, administrative skills, good judgment, and the ability to maintain strong relationships with patients and other health care professionals. Although the present competency model did not include technical ability or administrative skills, it did account for the other characteristics. Specifically, Dedication to Patient Care and Compassion are directly related to clinical skills and the ability to relate well to patients and health care professionals. Dedication to Patient Care, which emerged as the highest ranking competency, includes an unwavering willingness to address all of a patient's questions and fears. Compassion, which ranked seventh on the list, relates to the caring and empathetic manner in which excellent surgeons relate to their patients. Because two competencies concerning interpersonal skills emerged, the prediction was also fully supported.

Unanticipated Competencies that Emerged

Five competencies emerged on the expert list that were not anticipated: Integrity, Tireless Work Ethic, Humility, Devotion to Field, and Passion for Teaching. Possible explanations for why the experts deemed these competencies to be important are considered below.

Integrity

Integrity was the second highest-ranked competency on the list. Integrity is a characteristic that is valued in nearly every profession. The experts seemed to view Integrity as particularly important to surgery because an inability to admit to one's weaknesses or accept responsibility for one's mistakes puts patients at risk. Several experts mentioned having fired surgeons for falsifying data or records or for shirking their responsibility when complications arose. Since surgeons hold a position of great esteem in the hospital and in society, their opinions and medical orders often go unquestioned. According to many of the experts, surgeons who appreciate and respect the power they hold and consistently act with integrity may be less common than most people realize. Therefore, the experts may have included Integrity as an important competency not only because it is closely tied to patient safety, but because it is difficult to find a surgeon who consistently acts with integrity.

Tireless Work Ethic

Similar to Integrity, a high level of energy and drive is related to excellence across many professions. Given that most surgeons have long and exhausting work schedules, those who work through the fatigue and remain motivated and productive distinguish themselves from the majority of surgeons. It seems inevitable that most surgeons would reach a point in their careers where they could potentially burn out if they did not reduce their hours. On the other hand, there is a small percentage of surgeons who enjoy their work to such a degree that they maintain a high level of drive throughout the career. These are the surgeons who the experts believe are truly exceptional.

Humility

Humility is another characteristic that was not anticipated. Nonetheless, many experts believe that those surgeons who display modesty when interacting with patients and colleagues are often viewed as excellent surgeons. Although the stereotypical view of a surgeon's personality is often one of arrogance, the experts indicated that outstanding surgeons actually display the opposite demeanor. Once again, it is conceivable that the powerful position held by surgeons in hospitals may make them susceptible to developing a "God complex." The experts seemed to feel that great surgeons keep their ego in check and do not feel entitled to special treatment. It does appear to be a challenge; however, for most surgeons to maintain their modesty over time. This may be the cumulative result of hundreds of patients and other healthcare professionals treating them with deference. Regardless of reasons why many surgeons might lose their modesty, it is not surprising that the experts would deem Humility to be indicative of surgical excellence.

Devotion to Field

Devotion to Field was another unanticipated competency that emerged on the expert competency list. Many experts indicated that exceptional surgeons differ from average ones in the degree to which they are devoted to the profession. The experts noted that a small minority of surgeons are so passionate about their work that they believe it is their calling in life. A few experts added that some devoted surgeons have no intention of retiring and actually become depressed if they are forced into retirement. It would seem that this level of devotion would easily distinguish exceptional surgeons from the rest.

Passion for Teaching

The last competency mentioned by the experts that was not expected at the outset, was Passion for Teaching. Although it was the lowest-ranking competency, many experts indicated that exceptional surgeons display a love for education that is disproportionate to most other surgeons. Because the majority of experts in this sample were academic surgeons, it seems logical that they would focus on a surgeon's dedication to teaching others. Although this competency may not apply to surgeons working in private practice, it would seem to differentiate between average and exceptional surgeons in academic institutions.

Themes Expected to Emerge

In addition to the competencies, it was predicted that three themes related to surgery in the near future would be mentioned by the experts. Specifically, the experts were expected to mention the resident work hour mandate, new technologies and skill sets, and recertification and professional development. The interview data actually revealed four themes regarding competencies surgeons would require over the next ten years to achieve excellence in the field.

<u>The Resident Work Hour Mandate</u>

As stated earlier, many experienced surgeons oppose the ACGME's 80-hour work week limit. In fact, the Society of University Surgeons (SUS) released a statement indicating that restricted work hours "do not prepare residents for the real world of surgical practice" (Cole, Bertagnolli, & Nussbaum, 2002). Further, Komenaka (2003) commented that a different type of medical student may now be attracted to the surgical professional. He argued that students who prefer "lifestyle specialties" (e.g., dermatology, emergency medicine, anesthesia) may now be attracted to surgical programs because time commitment and training obligations are less taxing under the new mandate. In the present study, the experts did indeed indicate that a major issue facing surgeons today, and one that will continue to impact them throughout the next decade, is this work hour restriction. The majority of experts had strong opinions concerning whether this mandate would be a benefit or detriment to the field. Few surgeons believed that the work week restriction would produce better surgeons. In fact, the consensus was that residents would be less prepared than their predecessors to handle complicated cases or work the long hours required for surgery. Many experts also feared that the 80-hour work week would eventually decrease to 50 or 60 hours per week as it has in Western Europe (Pickersgill, 2001). It was generally believed that exceptional surgeons in the future will need to resist the work shift mentality that may result from this restriction if they wish to distinguish themselves from other surgeons. Given the frequency with which the experts discussed the impact of the ACGME work hour restriction, the results of the present study support the statements made by the SUS and Komenaka.

New Technologies and Skill Sets

Advancements in technology are rampant in nearly every field of medicine including surgery. The experts were expected to discuss the impact of technology on the role of future surgeons. As predicted, most experts believed that surgeons must be prepared to adopt new technologies and develop new skill sets throughout their careers. Experts indicated that surgeons who make the effort to keep abreast of new technological advances, such as lasers and robot assistants, will be more likely than others to excel in the field.

Recertification and Professional Development

One way to ensure that surgeons continue to develop new skills sets is through certification and recertification/revalidation programs. These programs ensure that surgeons maintain a high professional standing and acceptable "qualifications of practice" (i.e., skills) in their surgical specialty, as well as a commitment to continuing education (Patil, Cheng, & Wong, 2003). Although it was predicted that the issue of recertification and professional development would emerge as an important theme for future surgeons, experts did not discuss this topic during their interviews. Since all board-certified surgeons must adhere to the same guidelines, the certification process may not distinguish between exceptional and typical surgeons in the future.

Unanticipated Themes that Emerged

Stability of Attributes

The experts mentioned two themes they believe will impact future surgeons that were not anticipated at the outset. One of these themes concerns the core attributes of an exceptional surgeon. Specifically, they indicated that the core attributes will not change over the next ten years. Although the experts acknowledge that advances in technology will always impact the field, they argued that technology does not characterize excellence in surgery. Several surgeons stated that the qualities of an excellent surgeon are the same today as they were one hundred years ago and are likely be the same over the next hundred years. Experts indicated that a strong commitment toward patients will always be a defining characteristic of an outstanding surgeon. Furthermore, personality traits such as Integrity, Humility, and Compassion will be important regardless of the era in which a surgeon works.

Surgeons Will Become Highly Specialized

The final theme mentioned by the experts concerned specialization: future surgeons are likely to gravitate toward more specialized surgical subfields. The experts mentioned that they have already noticed many surgeons limiting their practice to perform smaller numbers of similar procedures. This theme is related to the notion that the 80-work week restriction is creating a different mindset among today's younger surgeons, many of whom are seeking ways to make surgery fit their lifestyle rather than to adapt their lifestyle to meet their patients' needs. The majority of experts expressed disdain toward this new breed of surgeons who they described as lacking commitment to the profession. Therefore, the idea that surgeons are moving away from being generalists so that they can have more control over their schedules and increase their income is consistent with the fear experts expressed regarding the "clock-watching" mentality of the next generation of surgeons.

Secondary Analysis: Novice Comments

Comparison of Competencies Mentioned by Experts versus Novices

The objective of the primary analysis was to use the expert data to create a list of competencies. A second set of interviews was conducted with 14 novice surgeons. The two data sets were compared to identify patterns that distinguish how exceptional and novice surgeons conceptualize surgical excellence.

Similarities between Expert and Novice Competency Results

It was anticipated that some degree of overlap would exist among the competencies provided by the experts and novices, but on the whole they would look quite different. That prediction was confirmed. Turning first to the few similarities, both groups mentioned three specific competencies: Rapid Decision making, Preparedness, and Tireless Work Ethic. The underlying theme of Rapid Decision Making and Preparedness is the ability to perform at the top of one's game in the OR in the face of sudden complications or crises. Experts and novices alike commented that exceptional surgeons are always prepared for a procedure and remain vigilant for any problem that may arise. In addition, experts and novices agreed that exceptional surgeons differ from average ones because experts can make swift, yet informed decisions in high pressure situations. In other words, such individuals are not hesitant or self-doubting. They have gained the experience and knowledge to make good decisions with confidence.

Experts and novices also agreed that a Tireless Work Ethic is another distinguishing characteristic of exceptional surgeons. The majority of surgeons reach a point in their careers where the hectic pace of their schedules becomes less appealing. Many surgeons will begin taking steps to devote more time to their personal lives. However, both participant groups believe that exceptional surgeons are different because they have energy and an intense drive that allows them to continue to work long hours and sacrifice personal time for their patients. Although novices were more likely to focus on the personal and familial sacrifices made by exceptional surgeons for their patients, both groups noted that outstanding surgeons consistently view their patients as their highest priority throughout their careers. Accordingly, experts and novices alike believed that the drive to work as many hours as necessary for their patients was one of the most important characteristics of an exceptional surgeon.

Although the experts and novices sometimes used different language to describe the personality of exceptional surgeons, there were several similar underlying concepts. For example, novice surgeons discussed the importance of a good bedside manner while experts often used the words "compassion" and "concern". Both groups attempted to define this trait as the tendency to be warm, caring, and respectful toward patients and their family members. Experts and novices described exceptional surgeons as truly connected to patients and willing to comfort them, particularly when bad news must be delivered. Moreover, both groups believe it is crucial that surgeons treat not only their patients well, but also other staff members and physicians. Outstanding surgeons acknowledge the collaboration inherent in surgical teams and therefore, never diminish or invalidate the efforts of nurses, technicians, and other individuals who assist them in their efforts.

Differences between Expert and Novice Competency Results

As expected, there were more differences than similarities between the expert and novice competency results. There were four competencies exclusive to the experts: Integrity, Intellectual Giftedness and Curiosity, Passion for Teaching, and Devotion to the Field. Integrity describes a willingness to appraise one's strengths and weaknesses honestly and admit when one is wrong. Integrity emerged as the second most important competency on the expert list, however, the novices rarely discussed this quality. Since the experts have been in a position to observe and train other surgeons for many years, they may have had more opportunity to witness instances of dishonest behavior than did the residents in their limited experiences. Residents, by contrast, may be less able to recognize unethical behavior in a more senior surgeon and they would not be in a position to reprimand another surgeon or terminate his or her employment. It is likely that novices will gain a greater appreciation for the importance of integrity as their training continues.

Only the experts noted the relationship between exceptional surgical performance and Intellectual Giftedness and Curiosity. In other words, experts believe that exceptional surgeons grasp new concepts very quickly and display an insatiable inquisitiveness about the field. By contrast, most residents are still struggling to learn their specialty. Therefore, it is possible that the novices did not mention qualities related to intellectual giftedness because they may perceive themselves at an intellectual disadvantage compared to more seasoned surgeons.

Furthermore, only the experts believed Devotion to the Field was a characteristic important enough to be included among their competencies. It is quite possible that the experts actually attained their levels of distinction within the profession because they possessed such strong devotion. On the other hand, the novices who were interviewed were not selected on the basis of their achievements. In essence, they represented a typical sample of surgical residents. Therefore, the novices may not necessarily have viewed devotion to surgery as a necessary component of a successful surgeon.

Likewise, it is also not surprising that the residents failed to mention the relationship between surgical excellence and Passion for Teaching. Because the novices in this sample were in the early to middle years of their residencies, most had not reached the stage of instructing other surgeons. It is also possible that many residents do not intend to remain in an academic environment after they complete their training. If that is the case, they are unlikely to view a passionate attitude toward education as essential to surgical excellence. The majority of the experts in this study were academic surgeons, and more specifically, chairs of surgery departments. As such, many of them mentioned that a love for teaching was an important competency for exceptional surgeons, although it was the lowest-ranking competency on the expert list on the expert's list.

Just as the experts identified unique competencies, the novices also offered two distinct competencies: Ability to Communicate in Nontechnical Terminology and Maintaining Composure. The Ability to Communicate in Nontechnical Terminology was the highest ranking competency among the novices, but was not mentioned by the experts. It is possible that novices emphasized this competency because they are still learning to put complicated concepts into language that laypeople can understand. Residents may be able to converse easily with other medical personnel, but they may not have enough experience with patients to adequately express medical terminology clearly and succinctly to non-experts. If this is true, residents would be impressed by more senior surgeons who can readily shift their communication style to match the needs of their audience.

It is also not surprising that residents viewed the ability to remain clam in critical situations as an essential characteristic of exceptional surgeons. The majority of residents admitted that they still become anxious during critical procedures or when complications arise. They hold surgeons who are able to maintain composure in high regard. Although experts surely believe that is important to remain calm in the OR, they made very few comments related to this competency. Perhaps it has become second nature to expert surgeons to maintain their composure in stressful situations having dealt with many such experiences in their careers. It is possible that the residents will eventually regard Maintaining Composure and the Ability to Communicate in Nontechnical Terminology as less essential to surgical excellence as they advance in the careers.

Similarities between Expert and Novice Characteristics of a Poor Surgeon

Experts and novices agreed that two attributes characterize a poor surgeon: Apathy toward Patient Care and Aggressive Behavior. The majority of interviewees contended that poor surgeons often fail to make patients their top priority. Both groups commented that this type of surgeon would rather shift patient schedules around to accommodate their personal interests than adapt to their patients' needs. It is not surprising that experts and novices alike believed that Apathy toward Patient Care should be on the list of characteristics of defining a poor surgeon because both groups clearly articulated the opposite attitude toward patients in their descriptions of an exceptional surgeon.

Both participant groups also believe that poor surgeons exhibit aggressive behavior. Experts and novices alike commented that poor surgeons tend to yell, swear, and even throw instruments to express their frustration. The majority of participants could recall examples of surgeons they knew who fit this mold. Further, most participants described stories of surgeons who either acted aggressively or bullied others in the OR. Given the frequency with which experts discussed belligerent and bullying surgeons, it is not surprising that both experts and novices described aggressiveness as a characteristic of poor surgeons.

Differences between Expert and Novice Characteristics of a Poor Surgeon

One major difference that distinguished how experts and novices defined a poor surgeon was that the former group commented on a lack of honesty. Dishonesty can manifest in several ways, including falsifying records and data, submitting the same publications to different journals or conferences, and performing surgeries that are ethically questionable. In most situations, residents are not in a position to know whether other surgeons falsify information or submit dual publications. These activities could be easily shielded from novice surgeons who are in a subordinate position to senior surgeons. Moreover, residents may not know the qualifications of other surgeons. Therefore, residents may assume that a more senior surgeon is qualified to perform a particular procedure when in reality he or she is not. In essence, the naiveté of novice surgeons may serve to obscure some of the dishonest actions of another surgeon, particularly when that surgeon is their superior. Experts also indicated that poor surgeons tend to display a lack of preparation and focus in the OR. According to several expert remarks, many poor surgeons can be characterized as self-doubting and hesitant. Since the majority of surgical residents may also fit this description, they may not recognize these qualities as being characteristic of poor surgeons.

Unlike the experts, novices indicated that poor surgeons tend to demonstrate a lack of concern for the feelings of patients, staff members, and other healthcare professionals. A possible explanation for why only the novices commented on this characteristic is that residents may be part of a new generation of surgeons who place more emphasis on protecting the feelings of those individuals with whom they interact. In fact, in a recent *Bulletin of the American College of Surgeons*, Chao and Wallack (2004) urged educators to "teach our residents to embrace the definition of a surgeon as a skilled, compassionate healer" (pg. 15). Given the growing number of recent articles and books devoted to producing compassionate young physicians (e.g., Carmel & Glick, 1996; Crawshaw, 2002; Kim, Kaplowitz, & Johnston, 2004), there is good reason to believe that current residents may be concerned than older, more experienced surgeons with developing communication, listening, and teamwork skills.

Similarities between Expert and Novice Views of an Exceptional Surgeon in the Future

Experts and novices agreed on two themes that will be important for an exceptional surgeon in the future. The first theme is that future surgeons must be willing to adopt new technologies and skill sets if they wish to achieve exceptional status. Both groups stated the surgeons of the future will need to stay abreast of the latest technology, whether that includes taking continuing education courses throughout their career or practicing their skills in training laboratories that are equipped with simulators. Moreover, these surgeons must be able to discern which technologies are most beneficial to their patients and which may be passing fads.

Experts and novices also agreed that the primary qualities of an exceptional surgeon will be no different in the future than they are today. Both groups commented that although advances in technology will continue to transform the field of medicine, the core attributes of an outstanding surgeon will not change. Therefore, the list of competencies produced from the present study will probably be apropos to future generations of outstanding surgeons.

Differences between Expert and Novice Views of an Exceptional Surgeon in the Future

The experts mentioned four unique themes that will be important for an exceptional surgeon in the future and the novices discussed two. The first theme that was exclusive to the experts concerned the impact of the 80-hour work week. It is surprising that the novices did not discuss the 80-hour work week restriction because it affects them directly. However, it is conceivable that many residents welcome the restriction in hours since it affords them more personal time. Because many current residents have not been permitted to work more than 80 hours per week, they have no basis for comparison. By contrast, the experts are from a generation in which there was no restriction on the number of hours they could work; thus, they are able to compare the new type of surgeon with those from previous generations. As stated earlier, the majority of experts are unhappy with this restriction and are extremely concerned that future surgeons will be less prepared and motivated than those in the past.

Also, only the experts mentioned that surgeons in the future are likely to become more specialized. They believe there will be fewer general surgeons as increasing numbers of graduates choose to reduce their workload by concentrating on narrower surgical subspecialties. The residents did not predict this trend toward greater specialization. It is likely they did not comment on this issue because they are too new to the field to recognize this shift toward greater specialization. In sum, residents may simply lack the requisite experience to make educated predictions about future trends in surgery.

Moving From Novice to Expert

As noted earlier, several differences were found between the expert and novice competency models. An important follow-up question is whether these differences reflect a new way of conceptualizing surgical excellence among younger surgeons. One way to answer this question would be to compare views of today's residents with those of other eras. Since that is not possible, a second approach is to examine views of residents from other eras based on "descriptions" in the literature.

In 1979, medical sociologist, Charles Bosk published *Forgive and Remember: Managing Medical Failure,* a seminal book about surgical education. Bosk performed an ethnographic study in a prestigious American teaching hospital. He was interested in uncovering how surgeons perceive, classify, and account for medical errors. Moreover, he described how surgical faculty dealt with residents' errors and how residents modified their behavior to avoid the wrath of attending surgeons.

Bosk's study resulted in a categorization of four types of medical errors: technical, judgmental, normative, and quasi-normative. A technical error reflects one's level of skill. Bosk observed that as long as a surgeon learns from his or her technical errors, they are forgivable within the surgical community. A judgmental error occurs when a surgeon chooses an inappropriate treatment strategy. For instance, a surgeon may fail to create a clear strategy for a patient with a chronic condition. Bosk found that these errors are also forgivable if a surgeon learns from them and perhaps undergoes further training. Normative errors, on the other hand, are violations in the etiquette and norms that come to be expected between attending surgeons and residents. If a resident fails to adhere to his or her role, perhaps by not keeping the attending surgeon fully informed of a patient's status, he or she is committing a normative error. Further, residents who treat nurses, staff members, or patients rudely are also culpable of normative errors. Bosk found that these errors were difficult to overlook because they are considered to be a direct reflection of a surgeon's integrity and ability to handle responsibility. Finally, quasi-normative errors occur when residents do not follow the protocol of a particular attending surgeon. In essence, residents who commit these errors appear insubordinate to authority figures. When residents blatantly disregard the expectations of their attending surgeon, they are committing a quasi-normative error.

Bosk observed that technical or judgmental errors made by residents were tolerated and even expected. They were forgivable as long as they were not repeated. By contrast, normative and quasi-normative errors could actually have a deleterious effect on a surgeon's career. An occasional technical or judgmental error that occurred on was not likely to have a lasting negative impact as long as the resident did not attempt to cover up the error. Bosk found that surgeons could be transferred or even fired if they were not honest about the errors they committed or if they did not interact appropriately and respectfully with staff and patients.

Two of the four types of errors that Bosk identified were related to the competencies in the present model. In particular, normative and quasi-normative errors are directly related to the model. Surgeons whose integrity is questioned are often viewed as unreliable and untrustworthy. In his study, Bosk noted that several surgeons were placed out of prestigious hospitals for demonstrating "a lack of integrity and a desire to take the easy way out" (p. 162). In addition, Bosk revealed that surgeons would also be removed from esteemed programs if their interactions with patients, staff members, and authority figures could not be trusted. Therefore, in Bosk's study, surgeons were expected to demonstrate the competencies, Integrity, Humility, and Compassion identified in the present model.

The views of experts in the present study support Bosk's findings in that they both highlight the notion that character flaws are more likely to prevent a surgeon from achieving excellence than a lack of technical ability. Bosk's findings suggest that most surgical faculty expect inexperienced surgeons to commit technical and judgmental errors. In fact, none of the experts in the present study mentioned that they had reprimanded or fired surgeons for making technical errors. However, several experts commented that they had fired surgeons due to their dishonest behavior, such as falsifying data in a research study.

Bosk also observed how the values of the attending surgeons influenced the behavior of the residents in his study. The attending surgeons expected residents to respect the chain of command that exists within every surgical service. Consequently, a resident must be willing to humble himself and "acknowledge his subordination to the group and its standards" (p. 180). Residents who failed to adjust their behavior and accept their position in the service could be asked to leave. The values of the attending surgeons observed by Bosk are similar to those espoused by the experts in this study. They both believed it was important for surgeons to display humility and respect toward other healthcare professionals. According to many of the experts, poor surgeons not only lack humility, but they often disparage other surgeons and staff members.

One of the main findings from Bosk's study was that surgeons of that generation viewed technical errors as "easily correctable shortcomings" but errors of morality and character were punishable offenses (p. 175). It is conceivable that today's surgical residents espouse a somewhat different view of surgical excellence than their predecessors. Recall that in the present study the novice competency model differed from the expert model in that it placed greater emphasis on effective communication with patients, a strong bedside manner, and sociability. Other than these differences, there was a good deal of overlap between the two models. It is possible that younger surgeons simply value interpersonal skills more than surgeons from previous generations. A second explanation is that novice surgeons are still idealistic in their thinking and therefore, their view of the qualities that comprise an outstanding surgeon do not yet coincide with those of more experienced surgeons. Thus, an interesting follow-up question is whether surgical residents will consistently regard communication and sociability as important competencies throughout their career.

Biography of an Outstanding Surgeon

One of the most renowned surgeons of the past century, Denton Cooley, was a pioneer in cardiovascular surgery. In 1968, Cooley performed the first successful human heart transplant in the United States. The following year he became the first heart surgeon to implant an artificial heart into a man. Cooley's biography reveals a detailed account of his personal and professional accomplishments (Minetree, 1973). Since there are few biographies that focus on outstanding surgeons, this particular one provides a rare opportunity to examine the characteristics of a truly exceptional surgeon. According to Minetree, Cooley shares many of the attributes that were found in the present competency model.

One of Cooley's most salient qualities was his absolute commitment to the profession and his patients. In fact, Minetree (1973) noted that Cooley was "a man who spent more time inside human hearts than his own home" (p. 22). Cooley even insisted that his family vacations be spent in locations near hospitals that were equipped for heart surgery. Minetree noted that Cooley's personal and familial obligations nearly always came second to his work. In fact, Cooley's dedication to his patients prevented him from spending a lot of time with his five daughters. This quality is akin to the Dedication to Patient Care and Devotion to Field competencies within the present model. Minetree also provided many examples of Cooley's conscientious nature. In fact, Cooley referred to himself as a "work addict" who became depressed during slow periods. He would use gaps in his work schedule to perfect complicated operations. This compulsive tendency reflects the Tireless Work Ethic competency identified in the present model.

An additional competency that Cooley appeared to reflect was Preparedness. Cooley was a surgeon who had a tremendous capacity for pressure. Despite the fact that he was participating in ground-breaking and life-threatening procedures, he was consistently described as not only having the ability to remain calm, but he was able to rally his surgical team under periods of high pressure. Cooley also displayed Compassion. In an interview with Minetree, Cooley noted that he tried to temper his comments toward young surgeons when they made mistakes in the OR. He stressed the importance of handling these situations with patience and understanding. Finally, Cooley was described throughout the biography as a highly intelligent man. He also possessed an insatiable curiosity about cardiac surgery and devotion toward developing new and improved heart procedures. Therefore, Cooley also mirrored the competency, Intellectual Giftedness and Curiosity.

Cooley also possessed several characteristics that were not reflected in the present competency model. For instance, Minetree described Cooley as having "a sense of competitiveness that bordered on fanatic" (p. 23). Although it is likely that a successful person in any profession displays some degree of competitiveness, a competitive nature did not emerge within the present model. In addition, Minetree described Cooley as a "technical wizard." Although technical ability is clearly necessary for surgery, it did not reach criteria for inclusion in the final competency model.

Comparison of the Expert Competency List and the ACGME Competencies

The ACGME established a list of six competencies that residents are expected to master throughout their medical training (Dunnington & Williams, 2003). It was predicted that there would be some overlap between the ACGME competencies and the expert list of competencies, but that additional knowledge, skills, and abilities would distinguish the two lists. In other words, it was anticipated that experts would identify additional KSAOs unique to exceptional surgeons.

Similarities between the Expert List of Competencies and ACGME Competencies

Interestingly, none of the experts mentioned the ACGME competencies during their interviews. One possible reason that the experts did not mention this topic was that the interviewer did not use the word "competency" in the actual interview questions. Rather, experts were asked to think of the finest surgeons they knew and explain the rationale behind their choices. It is more common and effective to use this phrasing in a competency interview rather than to simply ask participants to list the qualities that they would deem to be competencies in their profession (Lucia & Lepsinger, 1999). In addition, this format personalizes the interview process for the participants and thus generates more discussion.

One of the most noticeable similarities between the expert and ACGME lists is that they both emphasize patient treatment. The first ACGME competency, Patient Care, refers to patient treatment that is "compassionate, appropriate, and effective for the treatment of health problems and the promotion of health." The expert competencies, Compassion and Dedication to Patient Care, are clearly linked to the ACGME competency of Patient Care. A second ACGME competency, Interpersonal and Communication Skills, is also related to Compassion and Dedication to Patient Care, but perhaps less directly than the aforementioned ACGME competency. The ACGME defined Interpersonal and Communication Skills as those "skills that result in effective information exchange and collaboration with patients, their families, and other healthcare professionals." It involves both caring and effective communication with others. Although the experts did not offer a competency that focused exclusively on communication skills, aspects of communication components were subsumed within Compassion and Dedication to Patient Care.

Another ACGME competency related to the expert competencies was Medical Knowledge. The ACGME defined this competency as "medical knowledge about established and evolved biomedical, clinical, and cognate sciences and the application of this knowledge to patient care." Although the term, medical knowledge, was not explicitly used by the experts, it was subsumed in several of their competencies. For instance, medical knowledge involves the use of scientific and clinical information in operative decision making and patient management. It also concerns the ability to demonstrate basic and clinical knowledge, as well as critically evaluate scientific information. Therefore, this definition is somewhat related to the expert competencies, Rapid Decision Making and Intellectual Giftedness and Curiosity.

Professionalism is defined by the ACGME as "commitment to carrying out professional responsibilities, adherence to ethical principles, and sensitivity to a diverse population." Thus, Professionalism is directly related to the expert competency, Integrity. Although the ACGME competencies and those of the experts are referred to by different names, their definitions are interrelated. Both competencies address the ethical conduct of physicians as it relates to their patients and fellow healthcare professionals. Furthermore, elements of Humility may be subsumed within Professionalism. Humility refers to treating patients and healthcare professionals with respect regardless of their rank. Likewise, Professionalism involves treating patients and other healthcare workers with respect and sensitivity, particularly in regard to their age, gender, and cultural background.

The ACGME competency, Practice-Based Learning and Improvement, is defined as "the investigation and evaluation of one's own patient care, appraisal and assimilation of scientific evidence, and improvement of patient care." According to this ACGME competency, physicians must be able to integrate scientific evidence when diagnosing patients and developing treatment plans. This notion is related to the expert competency, Rapid Decision making, which involves the ability to make the best decisions for patients based on available data. Furthermore, "the evaluation of one's own patient care" is related to the expert competency, Integrity, which involves taking an honest look at one's strengths and weaknesses. Finally, Practice-Based Learning and Improvement involves the effective use of information technology to manage information. Although the competencies did not mention the importance of using technology, the experts discussed this topic as a theme impacting future surgeons. Specifically, Practice-Based Learning and Improvement is directly related to the expert theme, Willingness to Adopt New Technologies and Skill Sets.

Differences between the Expert List of Competencies and ACGME Competencies

Only one ACGME competency, System-Based Learning, was unrelated to the expert competencies. Recall that the ACGME defines System-Based Learning as "system-based practice manifested by actions that demonstrate an awareness of and response to the larger context and system of health care and effectively call on system resources to provide optimal care." This competency may be demonstrated by an understanding of the role played by different specialties and other health care professionals in overall patient management. It could also reflect the ability to access and mobilize outside resources. Although the experts probably deemed an awareness of and response to the health care system as an important quality for surgeons, they did not appear to think it would be sufficient to distinguish between experts and average surgeons. An understanding of the system in which surgery is practiced is important knowledge that surgeons should attain during their career, but possessing that knowledge most likely does not ensure surgical excellence.

Several expert competencies emerged that were not among the ACGME competencies. Specifically, Tireless Work Ethic, Devotion to Field, and Passion for Teaching were not included in the ACGME list. Tireless Work Ethic and Devotion to Field reflect the vigorous efforts of exceptional surgeons to excel in their profession and propel the field forward. Since a purpose of the ACGME competencies is to guide the educational and training objectives used across academic institutions, it would be difficult, and possibly inappropriate, to assess physicians' level of devotion or commitment to the field unless, of course, their lack of commitment compromises their ability to treat patients. Similarly, the ACGME cannot mandate that physicians be evaluated on their love of teaching, especially since many physicians in training do not intend to remain in an academic setting or teaching hospital upon graduation. Nonetheless, the experts believed that a passionate attitude toward education was a characteristic that distinguishes between outstanding and typical surgeons.

Caveats of the Present Study

The present research is unique because it is the first of its kind to distill interview data from twenty-six expert surgeons into a detailed model that describes the knowledge, skills, abilities, and other characteristics (KSAOs) associated with surgical excellence. However, given the nature of the competency modeling approach, there are several concerns regarding the external validity of the results that should be noted. Most of these concerns are tied to the characteristics of the sample. For instance, the majority of experts who participated were from academic institutions. Specifically, 22 surgeons were drawn from academic institutions but only 4 were drawn from private practice. Given that some of the criteria for inclusion in the study were having multiple literature citations, editing textbooks, and holding offices or titles in professional societies, it should not be surprising that the majority of participants were drawn from teaching hospitals and academic institutions. Consequently, comments from surgeons working strictly in private practice were limited. However, a comparison of the information provided by experts from these two settings yielded no appreciable differences. In fact, two of the experts from private practice commented that outstanding surgeons tend to have a great love for teaching. Therefore, the limited representation from nonacademic surgeons probably had minimal impact on the final competency model.

Another concern regarding the sample was that it contained only one female expert. Given that most of the participants were at least 50 years of age, they finished their residencies in a time when males represented the vast majority of surgeons. Thus, it is not surprising that the expert sample was predominantly male. The low female representation probably did not have a significant impact on the results because the competencies identified were sex indifferent. In other words, none of the competencies could be labeled as strictly male or female issues. In fact, the comments from the female participant in the sample were indistinguishable from the comments made by the male participants. More specifically, her comments reflected seven of the ten final competencies. Therefore, there is little reason to believe that additional female experts in the sample would have had any appreciable impact on the results.

Unlike the experts, however, fifty percent of the participants in the novice sample were women. The different proportions of males and females in the two samples reflect actual demographic shifts in surgery. In fact, the Association of American Medical Colleges reported that as of 1999, the number of women in general surgery had increased to 21% (Baumgartner, Tseng, & DeAngelis, 2001). The greater number of females in the novice group allowed for a direct comparison between male and female comments. Once again, there was nothing unique about the comments from females and males. Both male and female comments reflected a majority of the competencies that were included in the final model. Interestingly, males and females placed equal emphasis on the importance of effective communication, empathy toward patients, and an excellent bedside manner.

The results from the present study provide the foundation of a model that could be used for selecting and training excellent surgeons. However, the model still needs to be validated. It is important to emphasize that the approach taken in the present study represents the initial phase in this process. Since a job analysis or competency model for surgeons does not presently exist, it was necessary to create such a model before any selection, training, or appraisal methods could be developed. Thus, this study should serve as a platform for future quantitative projects. For example, it would be important to determine whether each competency measures a unique construct or whether there is some overlap among them. Consequently, a questionnaire based on the competencies would need to be developed so that each competency could be examined in more detail. The questionnaire would then be administered to a much larger sample of surgeons than used in the present study. The results from the questionnaire would be subjected to a confirmatory factor analysis (CFA) to determine whether each competency (i.e., subscale) measures a single construct. The CFA procedure is important because it can establish whether the number of dimensions or competencies conforms to the number found in the model. Further, the CFA would show how the ten competencies could be condensed into fewer dimensions if overlap exists among them.

In addition, the subscales could be correlated with existing and well-validated measures. For example, to establish construct validity, the Rapid Decision Making and Preparedness subscales might be correlated with the California Critical Thinking Skills Test (CCTST; Facione & Facione, 1998) described above since its scales measure many of the important characteristics and behaviors related to these competencies. For instance, one scale on the CCTST focuses on inductive reasoning. An important aspect of inductive reasoning concerns how individuals use their past experiences to make predictions about future events (Facione, 1990). Thus, one would expect this subscale of the CCTST to be positively correlated with the competencies, Rapid Decision Making and Preparedness, identified in the present study.

To determine construct validity, it is also necessary to establish discriminant validity (Cascio, 1998), that is, the absence of correlations among measures of unrelated theoretical constructs (Campbell & Fiske, 1959). Therefore, the subscales derived from these competencies should also be assessed with established tests of unrelated constructs. For example, Rapid Decision Making and Preparedness might be evaluated with a measure of emotional intelligence because critical thinking is considered to be unrelated to emotional intelligence.

An additional use of such a questionnaire would be to discriminate between outstanding and typical surgeons. Since competencies are those KSAOs that have the most direct impact on success for a surgeon, the model should distinguish among surgeons. In many organizations, competencies are often correlated with performance measures such as productivity, increases in sales or profit, and performance ratings (Lucia & Lepsinger, 1999). In the case of a surgeon, performance measures are a more complicated concern because measurable indicators of performance are less common. Nonetheless, the competencies could be correlated with patient satisfaction scores, complication rates, or scores received from standardized patient encounters.

Implications for Training and Selection

Once competencies are identified, they are often used to guide and improve training and selection procedures for organizations. Likewise, the results of the present competency model could be incorporated into residency programs. The following section provides some examples of how training and selection processes for surgical residency programs could benefit from the competencies identified in the present study.

Enhancing the Training Process

Once competencies are identified and validated, the next logical step is to consider how they could be used to train outstanding surgeons. In other words, what type of training could be implemented to help typical surgeons become excellent surgeons?

Interpersonal Skills Training

Based upon the present competency model, it is reasonable to believe that surgeons are more likely to achieve excellence if they possess strong interpersonal skills. Therefore, it is recommended that some form of interpersonal skills training be incorporated into the curriculum. One method that is currently used for interpersonal skill training and evaluation is "standardized patient encounters" (Ainsworth, Rogers, Markus, Dorsey, Blackwell, & Petrusa, 1991). Standardized patients are healthy individuals who are trained to portray patients by simulating the symptoms of a variety of illnesses, as well as the history, personality, and response patterns of typical patients. Although standardized patient encounters are well accepted as a method for improving interpersonal skills, their use as a formal method has yet to be fully integrated into many medical schools or surgical residency curricula (Yedidia et al., 2003). Because the present results indicate that there is a strong link between strong interpersonal skills and surgical excellence, it is recommended that validated standardized patient encounters be incorporated into surgical residency training.

In addition to the use of standardized patients, medical schools and residency programs should place greater emphasis on communication skills. On an informal level, it is important for experienced surgeons to use casual opportunities that arise during clinical activities to model good interpersonal skills. On a more formal basis, classes or workshops on communication skills could be offered. Further, it is important to provide regular assessment and feedback to ensure that these skills are learned and maintained. One instrument that might be used to assess interpersonal skills is the Doctors' Interpersonal Skills Questionnaire (DISQ; Greco, Sweeney, Broomhall, & Beasley, 2001). This instrument may be completed by patients or surgeons who are in a position to train and evaluate residents. Two examples of items on the DISQ include, "On this visit I would rate the doctor's ability to really listen as _____" and "The respect shown to be by this doctor was _____". When responding to these questions, individuals are given a scale that ranges from "poor" to "excellent."

Professional Ethics Seminars

Given the frequency with which the experts discussed the importance of Integrity, it is also suggested that surgical residents take a seminar in ethical training during their residencies. By exposing residents to this topic, faculty members will demonstrate that they take professional ethics very seriously. Such seminars should provide theoretical foundations, as well as practical skills required for ethical reasoning (Hattab, 2004). Potential topics for discussion during professional ethics seminars could include informed consent, end-of-life care, and methods for dealing with medical error. It may also be beneficial to include role play opportunities in these seminars.

Enhancing the Selection Process

Residents can acquire many important skills through on-the-job training and formal coursework. However, there are some important characteristics that may be less amenable to training, such as the character-related competencies found in the present study (e.g., Compassion, Humility, and Integrity). When training alone may be inappropriate or insufficient for certain competencies, it may be worth considering new methods to enhance the selection process used by many surgical residency programs. The following section contains several recommendations for improving the selection of surgical residents.

Critical Thinking

Given that Decision Making and Preparedness emerged as important competencies, it is recommended that residency programs also include a measure of critical thinking or decision making ability in their selection process. As mentioned earlier, the CCTST is a standardized and validated multiple-choice measure of critical thinking skill (Facione & Facione, 1998). Although it is considered to be a discipline-neutral test, it has been used previously in medical research (Bondy, Koenigseder, Ishee, & Williams, 2001). Just as this measure would be appropriate for establishing evidence of construct validity, it would also be a useful selection device because it measures many of the important characteristics related to critical thinking (e.g., inductive and deductive reasoning). An alternative to the CCTST could be a context-specific decision making test. If a context-specific measure is used to assess critical thinking, subject matter experts should be instrumental in its formation.

Characteristics of a Poor Surgeon

The experts identified several characteristics of a poor surgeon, including Apathy toward Patients, Dishonesty, and a “clock-watching” or work-shift mentality. If the selection process could distinguish applicants who possess these characteristics, residency programs would save a great deal of time and resources because, if selected, these individuals might eventually be removed from the program or require additional attention and training. One way to identify candidates with a tendency toward apathetic or uncaring attitudes is to administer an emotional intelligence test, such as the Bar-On Emotional Quotient Inventory (EQi; Wagner, Moseley, Grant, Gore, & Owens, 2002). In particular, the Interpersonal and Stress Management Scales of the EQi would be appropriate to use in this context. The former measures one's ability to be empathetic and develop strong interpersonal relationships while the latter assesses impulse control and stress tolerance. Questions from an emotional intelligence test could also be adapted into structured interview questions.

Characteristics Unique to a Competency Model for Surgery

One might expect that the present competency model is unique to surgery. In order to make this assertion, it is necessary to compare the present model to models from other domains. Lucia and Lepsinger (1999) created and validated several models for various professional roles, including manager, salesperson, finance employee, attorney, and research associate in a consulting firm. Some of the competencies listed for a manager include Informing, Monitoring, Delegating, Planning, Problem Solving, and Mentoring. Clearly, this competency model differs from the surgeon's model. According to Lucia and Lepsinger's research, a successful manager should disseminate relevant information to employees, review their progress, assign responsibilities, determine strategic objectives, systematically analyze problems, and facilitate employees' career growth. Unlike the model for a surgeon, there were no competencies that related to one's character or personality. However, many of the competencies for a manager relate to one's obligation toward subordinates. While most of the competencies for a surgeon are not related to their subordinates (i.e., residents), they are directly related to patients.

The competency model for an attorney is closer in scope to the surgeon's model. Some of the competencies for an attorney include Writing Skills, Oral Communication Skills, Analytical Thinking, Detail Handling, Planning and Organizing, Influencing and

Negotiating, Competitiveness, Reflectiveness/Introspection, and Endurance. Models for attorneys and surgeons are similar in that they both emphasize Analytical (or critical) Thinking, Planning and Organizing (or Preparedness), Endurance (or Tireless Work Ethic) and Reflectiveness/Introspection (Integrity). In fact, Reflectiveness/Introspection for attorneys refers to a willingness to admit to mistakes. However, the experts in the present study did not comment on the importance of written or oral communication skills, nor did they mention Detail Handling, Influencing/ Negotiating, or Competitiveness.

The present model appears to be different from models in other domains for several reasons. First, surgeons are expected to make rapid, well-informed decisions in high pressure situations. In addition, the field of medicine is one of the few domains in which a significant part of the job involves the ability to relate well to patients and their family members. Consequently, the present model is also unique in that successful surgeons are expected to demonstrate empathy and to allow their relationships with patients to take priority over their personal needs and obligations.

CONCLUSIONS

The present study was designed to identify the competencies associated with excellence in surgery. Twenty-six expert surgeons were interviewed and their comments aggregated to establish a collective opinion of the KSAOs required of an outstanding surgeon. The interviews resulted in 10 competencies revealing that outside of intelligence, success in surgeons is largely contingent upon their interpersonal and communication skills.

As noted above in Dr. William Silen's keynote address at the 2003 Annual Meeting of the Society of University Surgeons, he stated that the apprenticeship model of training surgeons is no longer viable and that there is almost no time available for practicing, teaching, and thinking. Not only is the "see one, do one, teach one" approach to surgical training now considered obsolete, but even with the 80-hour work week restriction many residents find themselves drained by their work schedules. In the present study, it was extremely difficult to find novice surgeons to participate in the 30-minute interview. It took twice as long to recruit half as many novices as experts. In fact, many novices agreed to participate but had to withdraw due to their hectic schedules. Silen's point appears to be true. Many residents seem overwhelmed by their workload and simply do not have enough time to sleep, much less participate in a voluntary interview.

The process of executing the present study, as well as the results obtained, also support the idea that what is needed to train the next generation of surgeons may be changing. At the outset, it was expected that exceptional surgeons would differ from others in their intellectual abilities and technical skills. The results provide only partial support for this view. On the one hand, Intellectual Giftedness, Preparedness, and Rapid Decision Making are clearly related to excellence in surgery. On the other hand, the importance of technical skills was not emphasized in the competency model. This does not suggest that manual dexterity and procedural skills are unimportant. Rather, technical skill may be necessary, but not sufficient to achieve surgical excellence. Instead, many of the qualities that set exceptional surgeons apart from the rest are related to one's character. The present model demonstrates that a truly outstanding surgeon must also display compassion, humility, and integrity. Historically, these characteristics have not received much attention in surgical education. Thus, the traditional Halstedian training paradigm that stresses procedural skills may be ill-suited to produce the breadth of qualities expected in exceptional surgeons.

Surgical educators may need to consider offering mandatory courses or workshops to help residents recognize and develop the behaviors associated with these competencies. On the other hand, the present model revealed that there are certain characteristics that educators will not be able to address through formal educational methods. For example, surgical excellence involves a tireless work ethic and a tremendous devotion to the field. Although educators can encourage residents to approach their work with passion and energy, there is no prescribed curriculum that will produce surgeons with these competencies.

From a psychological perspective, the present study showed that many of the characteristics of an outstanding surgeon are personality related. A comparison of the competency model for surgeons with those from other professions revealed several common "core" competencies (e.g., communication skills, detail-oriented, planning, etc.).

In this respect, there may be opportunities to include surgeons in future research aimed at identifying common traits among leaders. On the other hand, some of the competencies for surgeons were unique. Specifically, the top competency identified in the present study was Dedication to Patient Care. It is unlikely that one would find this level of dedication to the "customer" in any other service industry. Thus, future researchers may be interested in studying the psychological processes that underlie this commitment to helping and healing others.

Finally, it should be noted that surgical educators could benefit from I-O psychologists who have expertise in selection, training, and performance assessment. For example, physicians may currently rely on standard questionnaires developed for other applications as indirect measures of competency. Industrial-Organizational psychologists, however, could develop measures that specifically assess competencies at a behavioral level. Regarding the present competency model, I-O psychologists could assist the surgical community through the development of reliable and valid tests that measure personality-related competencies. For example, since Integrity emerged as an important competency, I-O psychologists may wish to work with subject matter experts to develop and validate a specific measure of integrity that can be used to screen surgical candidates. Thus, if the requirements for the next generation of surgeons are to reflect the competencies identified in the present study, it is likely that I-O psychologists will help surgery its vision.

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APPENDIX A

RECRUITMENT LETTER

Dear Dr. ________,

My name is Hope Hanner-Bailey. I am a graduate student in Industrial-Organizational Psychology, studying at Old Dominion University in Norfolk, Virginia. In my dissertation, I am investigating the job of a surgeon. More specifically, I am looking at the characteristics that distinguish expert surgeons from average ones. The objective of this study is to develop a thorough description of competencies that can ultimately be used to enhance curriculum development, selection, training, and performance evaluation of surgical residency programs.

You have been identified by a small group of surgeons at Eastern Virginal Medical School as an exceptional surgeon in your specialty. I am conducting brief phone interviews with several exceptional surgeons from across the country. The interview consists of seven questions and it will be approximately 30 minutes in duration. In this interview, you will be asked to share your opinions regarding some of the traits, skills, and abilities that combine to form the truly exceptional surgeon.

Thank you very much in advance for considering to be interviewed for my dissertation. If you have any questions, or if you are willing to participate, please e-mail me at: hhanner@odu.edu and I will work around your schedule to find at time that is convenient for you. I look forward to hearing from you.

Thank you,

Hope Hanner-Bailey

APPENDIX B

CONTENT AREAS AND COMMENTS BY EXPERTS THAT FAILED TO MEET THE INCLUSION CRITERION

Technical Skill

1. An exceptional surgeon has highly honed technical skills.
2. This surgeon can maneuver difficult pelvic areas and tumors.
3. They have great hand-eye coordination.
4. Technical part- relatively fast in the OR because he has a plan and he sticks to it. Economy of motion.
5. An exceptional surgeon displays technical excellence.
6. He is technically excellent.
7. They have amazing technical ability.
8. They are technically adroit.
9. He takes pride in any difficult operation that others would have a hard time performing.

Leadership Skill

1. Being a leader- one people go to with problems.
2. Being a strong team leader. Prefers to work alone but also does well in a group setting.
3. Being a strong leader.
4. The third example was a great technician and a great leader. People respected him and wanted to emulate him. It is very difficult to find all three examples/qualities in a single surgeon.
5. Collaborative; willing to share the playing field with others.
6. Values the opinions of everyone he works with, including physician assistants. They often can tell him how other surgeons in his practice perform and offer advice "Dr. Such and Such does it this way." He wants to create a climate where everyone's input matters.
7. He remained a calm team leader. He had the presence of mind to fix the problem.

Communication Skill

1. They are good communicators. They communicate (verbally and written) well with patients and other professionals.
2. S/he must be a strong communicator.
3. They speak very clearly.
4. He has the ability to communicate well.
5. Communicates well with patients, particularly when dealing with complicated ideas- much more important than technical skill.
6. They use appropriate language; they quickly size up patients to determine what they can understand and what to tell them about their illness.

7. Great ability to communicate.
8. They are emotionally intelligent and good communicators.

Ability to Maintain Composure

1. These surgeons remain very calm and patient under stress.
2. This surgeon brought her current OR in order. The nurses commented that everything had quieted down since her arrival.
3. They present a calm appearance during consultations, dealing with families, dealing with emergencies, and in the OR.
4. They exhibit patience.
5. He is a patient surgeon.

Critical Nature

1. They have a critical nature. They critically evaluate their work. They are great at self-evaluation and self-analysis.
2. They are skeptical of their own research findings.
3. He is self-critical.
4. Continual self-improvement- they are never totally satisfied.
5. They are incredible at self analysis; they are self critical. They can analyze what went wrong.
6. Constant self-analysis and self improvement (always try to make themselves better).

Self-Confident

1. They have confidence in their ability to do the case at hand- although being over-confident can get you in trouble.
2. They are confident in general.
3. Fearless – very little scares them.
4. They are confident with their skills.
5. Courage- not boldness though. Sometimes the most courageous option is not to intervene.
6. Supreme confidence to handle situations.

Sense of Humor

1. Sense of humor- with residents, nurses, patients, family members, etc.
2. He has a good sense of humor.
3. Good sense of humor/doesn't take himself too seriously. Able to laugh at himself.
4. They have a sense of humor.

APPENDIX C

CONTENT AREAS AND COMMENTS BY NOVICES THAT FAILED TO MEET THE INCLUSION CRITERION

Technical Skill

1. They are talented and have very good technical skill.
2. Strong technical skills and decision-making skills.
3. Excellent technician/brilliant takes on complicated cases.
4. He has excellent technical skills.
5. They have good manual dexterity.

Ability to Distill Problems

1. He has the ability to reduce a problem to its more basic components. Ability to focus and discern crucial from periphery.
2. Focusing on essentials of problems.
3. They have the amazing ability to decipher what is and is not important; cut through the details. Boil it down or distill information

Devotion to Field

1. These surgeons have a sense of duty, a calling. They are the marines of medicine. They have an overwhelming sense that they are going to get the job done.
2. They have an extreme sense of commitment to the field.
3. Dedication to the field- if they are not doing surgery, they are not happy.
4. They are extremely dedicated.
5. He is dedicated to the field.

Passion for Teaching

1. He was willing to back up residents.
2. They enjoy teaching medical students and residents.
3. They are strong educators/mentors.
4. Taking a junior resident through a case safely and confidently. Helping them to get out of trouble.

Awareness of Limitations

1. Great surgeons are aware of their limitations.
2. They are open to other people's opinions, have no issue asking others for help and incorporating their advice into action.
3. Patient has unusual surgical problem and surgeon wasn't sure how to resolve it. Surgeon explained available options to the patient. He started researching related

articles and he implemented a procedure that was in the article. He asked residents and medical students for their input as well.

Efficiency

1. An exceptional surgeon does procedures very quickly and efficient. He or she doesn't get bogged down.
2. They don't take shortcuts even though their work is time consuming and technically demanding. They work quickly.
3. Efficiency in the OR. Knowing the proper speed to go; being able to cut down on anesthesia.
4. They are thorough and efficient individuals.

Team Leaders

1. They believe in teamwork.
2. They have the ability to build coalitions and teams.
3. They lead others by example.
4. He has the ability to build and maintain a team.

SURGICAL SKILL PERFORMANCE UNDER COMBAT CONDITIONS IN A VIRTUAL ENVIRONMENT

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ABSTRACT

A group of medical students were taught to perform a tube thoracostomy on a mannequin simulator in a traditional medical school setting and demonstrate competency in that environment. Immediately afterward and again four months later, they performed the procedure in a CAVE virtual environment running a combat simulation under day and nighttime lighting conditions. The results showed that accuracy suffered in the simulation. Participants also needed more time to perform the procedures under the nighttime conditions. Further, performance did not change over the retention interval. The results suggest that although the surgical skills acquired by students in a traditional medical school setting are robust, they may still be compromised under hazardous conditions. More important, these findings show that virtual environments can provide a safe and effective venue for military medical personnel to train for dangerous duty.

INTRODUCTION

Simulators have been a standard component of military training for many years in a variety of contexts including aviation, ground operations, weapons training, and decision making in command and control operations. Simulation-based training has been an essential part of combat preparations to give our men and women in uniform the competitive advantage. Unfortunately, the availability of simulators to train those who must care for the wounded has been virtually non-existent. Recently, however, several mannequin-based and virtual reality-based medical simulators have reached a level of sophistication allowing them to be included in medical school curricula (Dawson, 2002; Satava, 2001; Scerbo, 2006). Although many of these simulators address important fundamental medical procedures (i.e., airway management), they were not developed to address the unique requirements of combat casualty care. Consequently, military medical personnel who have been in war often acknowledge that the training they receive in traditional medical school contexts does not always transfer to combat situations (Miller, 2003).

Scerbo et al. (2004) note that simulation training can provide many advantages including controlled environments, immediate feedback regarding performance and the opportunity to practice or acquire skills under unique or rare conditions. Perhaps the most important advantage of simulation-based training is that it permits one to train under conditions that would be too dangerous in actual operational settings. Moreover, virtual environments have been shown to be effective media for training other dangerous jobs such as the dismounted soldier (Knerr et al., 1998) and military checkpoint guards (Catanzaro et al., 2003). Although this represents a standard use of simulation for training in the military, it has been largely overlooked in the medical arena. Toward this end, the goal of the present study was to examine the performance of emergency surgical skills in a virtual environment (VE) under simulated combat conditions. Specifically, the study was designed to determine the extent to which surgical skills acquired in a traditional medical school setting might be compromised in a simulated combat scenario.

Medical students were taught an emergency surgical procedure and then performed the procedure in a CAVE virtual environment under simulated combat conditions including visual and auditory depictions of munitions fire, gunfire, and a virtual sniper who shot at the participants. They performed the procedure under both day and nighttime lighting conditions. Two lighting conditions were included to enhance the realism of working under different levels of workload and stress. Specifically, the nighttime condition was included because the conditions for visibility might be variable in a military combat situation. The students were assessed immediately after learning the procedure and then again four months later. It was expected that performance would suffer in the simulation and more so under the night conditions. Further, these deficits were expected to be greater after the four-month interval.

METHOD

Participants

Fifteen medical students (6 males and 9 females) from the Eastern Virginia Medical School in Norfolk, VA participated in the study. All students were in their second or third year of training and had no prior experience with the thoracostomy procedure or the simulators used in this study. The participants received compensation for their time.

Virtual Environment Combat Simulation

The combat scenario was presented in a CAVE Automatic Virtual Environment. The system consists of two computers connected through a 100-mbps network switch. A 4-pipe SGI® ONYX® 2 computer was used for the display and to provide the sound. This computer used MultiGen-Paradigm's Vega software running on the IRIX® 6.5 operating system. The second computer was an SGI® O2 and served as the main console to launch the application. The images were presented with a resolution of 1024x768 on three 10x10 ft walls. In addition, a barricade of boxes was created within the CAVE. A modified Radio Shack invisible beam entry alert system was fixed to the top of the boxes about 3 ft above the ground. This sensor detects when the trainee's head is above the safe cover of the barricade and signals the virtual sniper to engage (see below).

The combat simulation depicted a small town under fire with one building in flames. Combat was simulated using the VEGA special effects module to trigger visual and auditory explosion events and background gunfire at specific times. The events were timed to repeat at specific intervals and the entire scenario ran in a continuous loop until the participant finished the procedure.

The audio track was created with sound samples from unrestricted sources on the internet. Vocal utterances were monophonic and sampled at a 22.1 kHz. Background and other supplemental audio sounds included gunfire, explosions, machine gun fire, and some M1 tank fire. The audio files were presented over two channels with left and right speakers placed at approximately 45 and 315 degrees relative to the participant, respectively. The speakers were mounted on speaker stands at an elevation of approximately five feet. None of the audio sounds exceeded 90dB during the session.

Day and nighttime conditions were created using different settings of the time-of-day feature in the VEGA software. The daytime conditions produced enough ambient illumination from the CAVE walls to make the barricade, mannequin, and instruments easily visible. Under the nighttime conditions, however, very little illumination was provided by the CAVE walls forcing the participants to perform the procedure in almost total darkness except for occasional explosions that provided temporary increases in illumination.

Procedure

All students received a didactic session covering the fundamentals of tube thoracostomy (chest tube insertion). This procedure requires the surgeon to make a 1-2 cm incision in the skin near the pectoralis major muscle, puncture the pleural space, and guide a tube into the opened pleural space to permit drainage of fluid. Participants were then instructed to perform the procedure on the TraumaMan® System mannequin (Simulab, Inc., Seattle, WA) used throughout the world for surgery education and approved for the Advanced Trauma Life Support® (ATLS) Surgical Skills Practicum by the American College of Surgeons. The mannequin is a realistic anatomical model of the neck, chest, and abdomen containing latex replaceable tissue components and fluid reservoirs. Students worked in teams of two and were allowed approximately 90 minutes of practice under the supervision of an attending surgeon qualified to teach ATLS®. After training, each student was required to perform a successful procedure in less than two minutes with good tube placement (as determined by the surgeon) to move on to the simulation session. Tube placements were rated as good, adequate, or poor for topographical location, angulation, and final tube position. All participants met these criteria.

For the initial test session, participants reported to the CAVE facility within two hours of training. All participants were tested individually. The participants were told to play the role of an Army medic with a team of soldiers under fire and that they needed to get to the patient and perform the procedure as quickly as possible. Each trial began with the participant standing at a point marked on the floor. They were told to listen for a call for a medic and start as soon as they heard the call. They were also told not to assess the need for the procedure or to anesthetize the patient. When they finished, they were told to return to the starting mark on the floor.

In addition, they were warned of a sniper in one of the nearby buildings. They were told to take cover behind the barricade because the sniper would shoot to kill if he got them in his sights. If they were fired upon, they would hear a loud rifle shot. If the sniper missed, a message was played that warned them to "Get down." If they were killed, they would hear the phrase, "Hasta la vista, baby." Although at that point they were considered dead, they were told to finish the procedure. Each participant performed the procedure twice: once under daylight and once under nighttime conditions (order of conditions was counterbalanced across participants). Four months later, the participants were contacted to come back and perform a second test, again under day and night conditions.

RESULTS

Because not all of the participants returned for the second test session, data were analyzed for the 11 participants who completed both test sessions. A mixed 2 (day/night condition) x 2 (immediate/long-term retention interval) x order (night-day/day-night) ANOVA was performed on the completion time data. The first two variables were manipulated within subjects and the order of conditions was manipulated between subjects. Mean completion times were well under the 2-min training criterion (see Table 1). A main effect of day/night condition was found $F(1,9) = 5.17, p<.05$, suggesting that performance suffered more under the nighttime condition. No other sources of

Figure 1: Participant performing the procedure under daylight combat conditions.

Table 1
Mean Completion Times (in seconds) for Immediate and Long-Term Retention and Day/Night Conditions (standard deviations in parentheses).

	Immediate	Long Term	Mean
Daylight	76.10 (23.00)	75.45 (32.08)	76.83
Nighttime	91.36 (16.05)	84.55 (12.68)	88.10
Mean	83.98	80.95	

variance were statistically significant. Thus, completion times did not differ between the first and second test sessions.

The accuracy of the tube placements was rated using the same criteria as in the training session. The proportions of tube placements rated "Good" are shown in Table 2. Because all of the students had to obtain "Good" ratings on the procedure prior to participating in the experiment, one-tail t-tests were used to examine the deviations from the expected proportion of 1.00. There was a significant decline in the quality of the tube placements under both lighting conditions for the immediate retention test ($p < .025$). There was no significant difference between long-term test and the expected proportion or between the immediate and long-term test ($p > .05$).

Table 2
Proportion of Tube Placements Rated Good for Immediate and Long-Term Retention and Day/Night Conditions.

	Immediate	Long Term	Mean
Daylight	.61	.82	.715
Nighttime	.67	.85	.76
Mean	.64	.835	

There were also several instances in which participants were "killed" by the virtual sniper. Most of the participants who were killed were shot during the first test session (3 during nighttime conditions and 2 during daylight conditions) versus the second session (1 under day conditions). Although six participants were fired upon in the long-term retention condition, only one participant was killed. If the scores from the participants who were killed are removed and the data reanalyzed for those who "survived", none of the findings reach statistical significance; however, the overall pattern of results for lighting conditions and retention intervals remains the same except for a 5-sec increase in overall completions times. This finding suggests that the faster performers were more vulnerable.

DISCUSSION

The primary goal of the present study was to examine how training in a typical medical school environment would generalize to simulated combat conditions in a VE. The findings were mixed. On one hand, the results for completion times were encouraging. The participants were fairly efficient at performing the procedure. Overall, the mean times to complete the procedure were 84 and 81 sec for the immediate and long-term retention conditions, respectively. Both of these times were well below the two-minute criterion established for their practice session. As expected, the completion times were affected by lighting conditions. Specifically, the participants took 11 sec longer on average to perform the procedure under nighttime conditions. It is also important to note that when participants were tested four months later, their completion times were not significantly longer than those from their initial session. In fact, they were slightly shorter. These results suggest that participants were indeed able to retain the skills necessary to perform the thoracostomy procedure over a four-month interval and that their performances had become stable.

Conversely, the quality of the procedures performed suffered under the simulated combat conditions. There were significantly fewer tube placements rated "Good" in the immediate retention condition. Although the accuracy levels were better in the long-term retention condition, there were still tube placements not rated "Good" and therefore below what was achieved during initial training in a typical medical school setting.

It is important to note that these results may present an optimistic picture of performance. There were seven instances in which the participants failed to heed the warning shot and were "killed" before they could complete the procedure. Although participants were asked to continue with the procedure after having been shot in this simulation, under genuine circumstances they might have been killed themselves. A finding such as this is indeed troubling because it suggests a potential loss of critical medical personnel in addition to jeopardizing the safety of the patient. Also, there was some evidence that the faster performers were more susceptible to sniper fire. Further, these results suggest the possibility of attentional narrowing. Research has shown that under stressful conditions, even well trained individuals can fixate on a particular stimulus or strategy to the exclusion of other potentially relevant information (Dirkin & Hancock, 1984). Thus, it is possible that even the levels of stress created by this *simulated* combat conditions caused some participants to engage in inappropriate and potentially dangerous behavior that would likely be exacerbated under genuine combat conditions.

To our knowledge, the present study represents the first time that performance with a standard mannequin-based medical simulator has been studied within a fully immersive VE. From this perspective, our results show that VEs can be a valuable tool for military medical training because they provide a rich context in which to examine performance. Moreover, VEs provide a safe environment for studying performance under simulated hazardous conditions. Virtual environments open up the possibility of examining a wider variety of medical procedures performed under an unlimited number of conditions.

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Transfer of Training Measures

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Transfer of training paradigms provide an index of skill generalization and help establish the efficacy of training for performance in real-world settings. Consequently, determining the efficacy of simulation-based training requires a comparison to some standard. Often, the standard is based on skills acquired in the operational environment. However, the standard could also be an alternative form of training. In some industries, this information is difficult to obtain, but in medicine training in the operational environment is still the norm.

Numerous measures of transfer have been described. To illustrate some of these measures, hypothetical data from a typical training scenario are presented in Table 1. Although performance and training time metrics are used to illustrate the calculations, other metrics such as the number of trials needed to reach criterion or level of proficiency could also be used.

Table 1. Hypothetical Training Data for Calculating Transfer Measures

Group	Training Time with Simulator	Initial Task Time in OE	Training Time in OE	Criterion Time
Grp. C		60 min	20 hrs	30 min
Grp. S	10 hrs	45 min	12 hrs	30 min

Two groups of participants undergo training. Group C is the control group and trains in the operational environment (OE). Group S trains with a simulator and then transfers to the OE. Participants are expected to be able to attain a task completion time of 30 minutes in the OE. For Group C, completion time on the initial attempt is 60 min. They require 20 hours of training in the OE to reach the criterion of 30 min. Group S trains with the simulator for 10 hrs and then moves into the OE. Their completion time on the initial attempt is 45 min. Group S continues to train in the OE for another 10 hrs until they reach the 30 min criterion.

One of the simplest methods for measuring transfer represents a comparison of training times in the OE (Micheli, 1972). Based on the time needed to reach criterion performance, the percent transfer is calculated as follows:

$$\frac{\text{Training Time Grp. C} - \text{Training Time Grp. S}}{\text{Training Time Grp. C}} \times 100$$

Using data from Table 1, Group C required 20 hours in the OE to achieve a completion time of 30 minutes and Group S group required 12 hours in the OE (after practicing on the simulator). Therefore, in this example the simulator provides 40% positive transfer to the OE.

Singley and Anderson (1989) offer an alternative method for measuring transfer. Specifically, this method can be used to compare training in the OE with the simulator-based training by focusing on improvements in criterion task performance. Their formula is as follows:

$$\frac{\text{Initial Task Time Grp. C} - \text{Initial Task Time Grp. S}}{\text{Initial Task Time Grp. C} - \text{Criterion Time Grp. C}} \times 100$$

Again, using data from Table 1, the Initial Task Times for Groups C and S are 60 min and 45 min, respectively. The Group C Criterion Time is 30 min. Thus, training with the simulator results in 50% transfer. With this measure, values generally fall between 0 and 100%; however, it also possible to obtain values greater than 100%. Under these circumstances, training with the simulator produces performance benefits greater than those that can be obtained in the OE. This formula will also return negative values reflecting negative transfer when training with the simulator results in poorer initial task performance than training in the OE.

Transfer Effectiveness Ratio

Some authors have expressed concerns over the percent transfer measures because they do not take into consideration the time spent practicing with the simulator (Roscoe & Williges, 1980). Consequently, Povenmire and Roscoe (1973) suggested that transfer should be measured with the transfer effectiveness ratio (TER). The formula for TER is as follows:

$$\frac{(\text{Grp. C Training Time in OE} - \text{Grp. S Training Time in OE})}{\text{Grp. S Training Time with Simulator}}$$

Thus, the TER represents a ratio of the time saved in training to the time spent with the simulator. Using the data from Table 1, the TER would be (20-12)/10 or .80. TER values greater than 1 indicate that training with the simulator is efficient. By contrast, TER values less than 1 show that the simulator introduces inefficiency.

It is important to understand that TER values less than 1 do not necessarily mean that training with the simulator is inappropriate. Simulation-based training must be viewed within the entire educational curriculum (see below). For any hazardous activity that puts the trainee or patient at risk, the simulator may be the safest method of training even if it is inefficient. In medicine, TER values less than 1 may be entirely acceptable

given concerns over patient safety. That is, trainees who practice with simulators may be allowed more time in the OR to reach criterion if they make fewer errors.
There are also economic factors to consider. Training with the simulator may be less costly than training in the operational environment. Wickens and Hollands (2000) argue that investment in the simulator and the cost of training may impact decisions over the acceptability of TERs less than 1. They suggest determining the training cost ratio (TCR), a measure of training costs in the OE/divided by simulation-based training costs. For example, if the cost of training with a simulator is $150/hr and training in the OR is $300/hr, the TCR would be 2. A TCR value greater than 1 indicates cost savings for simulation-based training. Wickens and Hollands also suggest that by multiplying the TCR by the TER, one can obtain an index of cost effectiveness. Again, using the example from above, a TER of .80 multiplied by a TCR of 2.0 would result in a cost effectiveness value of 1.6. Values less then 1 indicate that simulation-based training is not cost effective.

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Realistic Irrigation Visualization in a Surgical Wound Debridement Simulator

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Background/Problem

Wound debridement refers to the removal of necrotic, devitalized, or contaminated tissue and/or foreign material to promote wound healing. Surgical debridement uses sharp instruments to cut dead tissue from a wound and it is the quickest and most efficient method of debridement. A wound debridement simulator [1] can ensure that a medical trainee is competent prior to performing a procedure on a genuine patient.

Irrigation is performed at different stages of debridement in order to remove debris and reduce the bacteria count through rinsing the wound. This paper presents a novel approach for realistic irrigation visualization based on texture representations of debris. This approach applies image processing techniques to a series of images, which model the cleanliness of the wound. The active texture is generated dynamically based on the irrigation state, location, and range.

Tools and Methods

Texture mapping is a standard and powerful rendering technique used in modern computer graphics and it enhances realism and details in a scene with only a modest increase in computational complexity. Texture mapping lays one or more digital images onto a surface or volume.

In the proposed approach, the wound cleanliness is modeled by a series of images, simulating a variety of debris on the contaminated wound; however, at any time, there is only one texture active over the whole mesh. The active texture is initialized to be the dirty image and updated dynamically at different stages of the surgical debridement, as a result of combination of several different images.

Denote the active texture as T, and the images representing dirty state and clean state as I_d, I_c, respectively (The irrigation is simplified into only two states in this abstract). The steps in the irrigation are as follows:

1. At the beginning of irrigation, let $T = I_d$.
2. During irrigation, detect the possible intersection between the wound and the prolonged syringe outline. Compute the intersection point P and the triangle that contains P. Assuming the three vertices of the intersected triangle has geometrical coordinates $\mathbf{v}_1, \mathbf{v}_2, \mathbf{v}_3 \in \mathbb{R}^3$ and texture coordinates $\mathbf{t}_1, \mathbf{t}_2, \mathbf{t}_3 \in \mathbb{R}^2$, the texture coordinate $\mathbf{t}_P$ of P can be computed as follows:
$$\mathbf{t}_P = \frac{\sum_{i=1}^{3} a_i \mathbf{t}_i}{\sum_{i=1}^{3} a_i},$$
where a_i, $i = 1, 2, 3$, are the barycentric coordinates of P, expressed as a convex combination of $\mathbf{v}_1, \mathbf{v}_2, \mathbf{v}_3$.
3. Assuming that the sizes of the texture and the images have been normalized into the range of $[0,1]\times[0,1]$, the texture T is updated as follows
$$T(\mathbf{t})_{\|t-t_P\|\le r} = (1-c)I_d + cI_c,$$
where r is the range of irrigation and c is a coefficient that determines the thoroughness of the irrigation.

Other critical techniques in the irrigation visualization include utilization of OpenSceneGraph [2], which is a high-performance 3D graphics toolkit, and the development of collision detection algorithms, which is omitted in this abstract due to space constraint.

Results

The irrigation results are shown in the figures that follow. Fig. 1 shows a simplified dirty wound with some dirt on the wound. Fig. 2 shows the triangular mesh of the thigh used in the wound debridement. The wound is being cleaned in Fig. 3; it can be seen that the boundary between the dirty area and the cleaned area is smooth, eliminating blocking or mosaicing artifacts exhibited by our previous work. Fig. 4 shows the wound after cleaning, which is ready for further operations such as cutting dead tissue in the wound debridement.

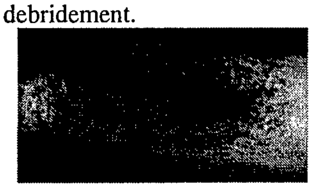

Fig. 1 Dirty wound

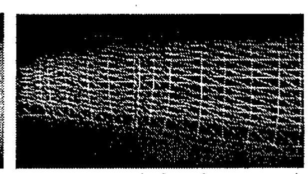

Fig. 2 Mesh for the wound

Fig. 3 Dirty wound is being cleaned

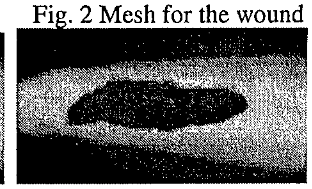

Fig. 4 Clean wound

Conclusion/Discussion

A novel approach for realistic irrigation visualization in a surgical wound debridement simulator is proposed, utilizing image processing techniques in a series of images modeling the wound cleanliness. The result is highly realistic and the algorithm is simple to implement with low cost.

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A Software Framework for Surgical Simulation Virtual Environments

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Abstract. Surgical simulators are an integration of many models, capabilities, and functions. Development of a working simulator requires the flexibility to integrate various software models, to support interoperability, and facilitate performance optimizations. An object oriented framework is devised to support multithreaded integration of simulation, deformation, and interaction. A demonstration application has been implemented in Java, leveraging the features that are built into the language including multithreading, synchronization, and serialization. Future work includes expanding the capabilities of the framework with a broader range of model and interactive capabilities.

Keywords. Surgical simulation, Framework, Java

Introduction

Surgical simulators are interactive systems that model surgical procedures on simulated biological tissues along with other processes relevant to surgical procedures. The simulation process is complicated by several scientific and technological limitations. Scientific limitations include an incomplete understanding of the properties of biological tissues and processes as well as identifying those aspects of a simulated procedure most amenable to training transfer. Technological limitations include the inability to provide real time performance for models at the desired fidelity. In addition, input devices may not provide a satisfying surrogate that is consistent with the manipulations required in a surgical procedure. In order to provide grounding to manage these issues and facilitating research, a flexible software architecture is necessary to support simulator system development. In light of these issues, an object oriented framework is proposed to support straightforward integration of the various functional components composing a surgical simulator. The work described here is part of a larger project [1]. This paper is organized in five sections including an introduction, a summary of related works, an overview of the software framework, presentation of a demonstration, and finally a summary and future work.

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1. Related Work

Surgical simulation holds the promise of giving medical practitioners the ability to perform some of their training on simulators, raising the expertise of practitioners when they first interact with patients. In Reference [2], a technology independent language CAML is introduced as a foundation for medical simulation systems. Specific to the work here, Spring [3] offers a framework for surgical simulation that includes many models for surgical intervention, a mass-spring model for soft tissue modeling, and distributive collaborative functionality. Finally, the GiPSi system [4] provides a framework with broad capabilities that organ level simulations of physical, functional, and spatial modeling.

2. An Overview of the Software Framework

The software framework is built upon an abstract class structure that holds the relevant parameters and references to support communication and interaction among the respective objects. The abstract classes are then extended to provide a specific functionality. All objects fundamentally share a common link in the form of the basic geometry which each act upon and update. Communicating this information among the objects and synchronizing the updates enables all to receive the most current information in a consistent fashion. Further, having different objects in separate threads limits the interactions among objects to the pure geometry information and provides a pathway to a coarse granularity parallel implementation through the use of threads. Among the geometry linked objects can include the tissue simulation, dynamic texturing, collision detection, remeshing, visual rendering, and haptics rendering. Each of these can function autonomously, each updating and responding at its necessary inherent update rate, provided up-to-date geometry is available. Figure 1 provides a generic perspective on the interaction among these threads. The wound debridement simulation companion paper [1] describes an application where this software framework could be used.

3. Demonstration Implementation

A prototype implementation of this framework has been developed in Java using the Java3D API. This platform was selected for convenience as it includes all of the powerful features of Java, i.e. object oriented class structure, multithreading, serialization, and synchronization. Furthermore, the Java platform provides some inherent capabilities that can be leveraged in collaborative applications. Among the features of the implementation, abstract classes are defined to hold information that must be synchronized among threads. Abstract classes define the generic features for each major thread and are extended to provide the functional implementations desired. Furthermore, different functionalities, i.e. model enhancements, model evaluation, can be easily replaced and evaluated without disrupting the rest of the application. Figure 2 shows an example screen capture of the demonstration application.

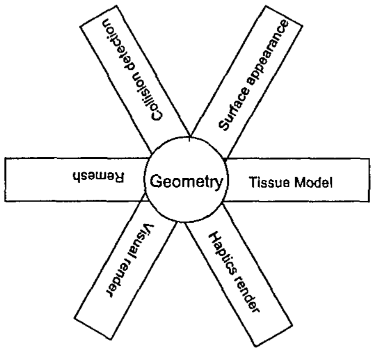

Figure 1. Software Architecture

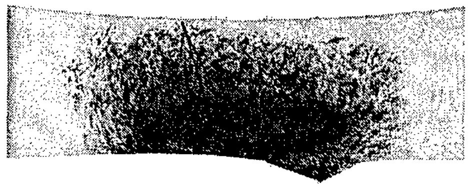

Figure 2. Example Image

4. Summary and Future Work

In this paper, we have presented a software framework that can be used in the development of surgical simulation virtual environments. We plan to continue to develop the framework, to investigate its operation on a C++ platform for enhanced performance, and work towards simpler integration with other libraries and commercial products.

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14. ABSTRACT
This project demonstrates the objective value of medical simulations as training tools for use by military medical personnel in training for tasks that are relevant to the effective and efficient medical care of military personnel in combat settings as well as in CONUS hospitals and clinics operated by the military. In addition, the project pursues an integration effort to provide a coherent set of medical simulations and the related medical education/training curricula in which these simulations will be used. Finally, the project provides an overview of the development of a high performance skill medical simulator.

15. SUBJECT TERMS
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