VR-in-a-Box: Surgical Simulator - Supplementing Surgical Training for medical students and residents using a low-cost virtual reality simulator with real-time haptic feedback

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I. INTRODUCTION

In recent years, there has been a verifiable increase in the use of virtual reality (VR) simulation technology for clinical purposes. Although results are varied, studies have shown evidence that the use of VR in surgical training results in improvement in practicing surgical skills. Unfortunately, such simulators are expensive and thus are not targeted for use by student populations outside of their training facility. Yet, given the current climate of budget reductions and reduced allocations to aid hospitals to pay for training of new residents and medical students, the development of effective, but low-cost training options, is no longer a luxury, but a necessity. This is especially true given that currently mandated restrictions on the maximum hours in which a resident can participate in clinical activities correspondingly decreases exposure to the number of operations performed by general surgery residents. As such, the specific aims of this project are 1) to examine the efficacy of a low-cost Virtual Reality surgical simulator for training residents and medical students assigned to Grady Memorial Hospital and 2) to compare the learning effect between two training schedules using the low-cost VR surgical simulator on improving practicing surgical skills.

Twelve student subjects, distributed between training residents and medical students, will be recruited for this study. Subjects will be randomly assigned to three training groups (distributed VR training group, massed VR training group, and baseline group). In the distributed VR group, subjects will receive additional VR training for 5 sessions per week, 30 minutes per session for 6 weeks; in the massed group, subjects will receive additional VR training for 2 sessions per week, 75 minutes per session for 6 weeks; and the baseline group will receive no additional VR training. All subjects will continue participating in their regular operating room training activities. All subjects will be assessed throughout the study period: prior to training, at the end of the 3rd week of training, immediately after the completion of the 6-week training period, and 3 weeks after the training cessation. The results from this study are designed to provide quantitative results to document the efficacy of a low-cost VR surgical training system by comparing the learning effects between two practice schedules of VR training as compared to a baseline. This will lay the preliminary groundwork for securing additional funding to research the design of adaptive Virtual Reality training systems for individualizing the learning cycle to improve surgical skills training through adaptation, human observation, and feedback. This project directly contributes to the goals of the HIP and ACTSI seed grant proposal call in addressing issues of healthcare quality and costs.

II. SPECIFIC AIMS

The goal of this study is to evaluate the benefits of using a low-cost VR training platform in transferring VR-trained skills to surgeon skills measured in the operating room. Our test case will focus on laparoscopic cholecystectomy, which is one of the most common surgeries currently performed in the United States and is often used as the training case for laparoscopy due to its high frequency and perceived low risk.

Virtual reality (VR) surgical training systems seem to be a potential useful method in improvement in practicing surgical skills [1-3]. However, the current literature on VR training has not discussed the efficacy of VR systems that are useful outside of the training facility. In addition, there is a lack of a systematic manipulation on dosing of training (e.g. training frequency, duration, etc.) to determine the optimal VR training schedule needed for improving practicing surgical skills. This proposed study will be the first study...
of a series to systematically examine the training dosage by comparing the effect of two training schedules against the current baseline. The specific aims of this study are:

1) To examine the efficacy of a low-cost VR surgical simulator on improving practicing surgical skills, measured by an objective skills assessment tool, in residents and medical students assigned to Grady Memorial Hospital.

2) To compare the learning effect between two practice schedules of VR (30 minutes per session x 5 sessions per week versus 75 minutes per session x 2 sessions per week) on improving surgical skills with respect to a baseline in residents and medical students assigned to Grady Memorial Hospital.

III. BACKGROUND AND SIGNIFICANCE

A. Laparoscopic cholecystectomy
Laparoscopic cholecystectomy is one of the most common surgeries currently performed in the United States and is often used as the training case for laparoscopy due to its high frequency and perceived low risk. Since its introduction to surgery in the 1980s, the laparoscopic removal of a diseased gallbladder (laparoscopic cholecystectomy) has become the gold-standard [4]. It is the most commonly performed elective abdominal procedure in the United States. However, the performance of this procedure can be technically challenging, and injuries occur in 1 of 200 laparoscopic cholecystectomies performed by experienced surgeons. Common bile duct injuries, which affects the body’s ability to drain bile from the liver into the gastrointestinal system, is the leading cost of medical malpractice cases filed against general surgeons. In addition, patients who have sustained common bile duct injuries during the performance of laparoscopic cholecystectomies are susceptible to complex repairs by hepatobiliary specialists and can become extremely ill or die.

The present instructional method for learning laparoscopic surgery involves an apprenticeship to a senior surgeon. Studies have shown that additional training, beyond the hours of initial guidance, is a necessary component for establishing expertise [5]. For example, in the study discussed in [6], surgeons who did not have additional training after completing an 18-day training seminar were 3.39 times more likely to have at least one complication than those surgeons who had additional training. In [7], it was shown that the chances of a bile duct injury conducted by an experienced surgeon decreased from 1.7% during the first case to .17% after 50 cases. And [8] documents that 90% of bile duct injuries occur within the first thirty cases performed by a practicing surgeon.

B. Effect of Virtual Reality (VR) on Surgical Skills
Virtual reality simulators enable the creation of interactive 3D environments within which human performance can be motivated, recorded, and measured. Nearly a decade ago, Satava [9] first proposed using these virtual reality environments in the training of surgical skills. Although results are varied, studies have shown evidence that VR training results in technical skills acquisition at least as good as, if not better than, traditional residency training [1-3]. Unfortunately, VR simulators for laparoscopy and colonoscopy training have been reported as still too expensive [10]. Costs of simulation systems were documented as ranging from $5K for most laparoscopic simulators to approximately $200K for highly sophisticated anesthesia simulators. As such, although, based on published studies, VR seems to be a promising tool to use in training and improving surgical skills, there is still a 1) lack of studies evaluating the effect of low-cost VR systems and a 2) lack of studies evaluating the ideal intensity, duration, and frequency of the training protocol.

C. Effect of Different Distribution of Practice on Skill Learning
The spacing of practice (i.e. practice distribution) has been a popular topic in motor learning literature. A number of studies have compared the effect of massed or distributed practice trials on the learning of motor skills [11-12]. Generally, it has been determined that the effect between different practice schedules depends on the type of task to be learned. If the task is relatively simple with low mental requirement and high physical requirement, the effect of the distributed practice schedule is better than the massed practice schedule. However, if the task is complex with high physical requirements, there is no difference between massed and distributed practice schedule. To our knowledge, the effect between massed and distributed
practice schedule in VR-training of surgical skill has not been addressed in previous literature, especially with respect to low-cost VR-training systems.

IV. RESEARCH DESIGN AND METHODS

A. Low Cost Virtual Reality Surgical Simulator

The most important goal of any training method is to increase the level of skill that can be brought to bear on a clinical situation. To enable simulation of such procedures as laparoscopic cholecystectomy, the designed virtual training system must employ the same ergonomics applicable to laparoscopic surgery while teaching appropriate muscle memory for the safe performance of a laparoscopic cholecystectomy. As such, our VR-in-a-Box: Surgical Simulator System consists of 1) a virtual environment for emulating patient-specific anatomy and surgical instrument interaction with soft-tissue rigid-body dynamics, 2) motion sensors for tracking and assessment of the student’s hand and arm motions for control of the VR surgical instruments, and 3) haptic feedback devices for providing a simulated realization of the surgical tools and for providing feedback during achievement of the surgical operation.

In prior work, the PIs have created a number of applications using virtual reality systems for learning in both clinical and educational settings [13-15] (Figure 1). These efforts used VR technology to create relevant simulation environments that allowed for the assessment of cognitive and motor-driven functions. The current study will utilize these previously developed tools, as described below, to create the VR system specific to laparoscopic cholecystectomy.

Figure 1. a) TabAccess Game for improving motor skills, b) Towers of Hanoi Robot Game for improving spatial reasoning, c) VR training for transference of skills from virtual to real-world robot control

B. The Virtual Reality Environment

SPRING is an open-source real-time soft-tissue simulation platform for building and running surgical simulators to be used in medical education of surgeons [16]. Using this infrastructure, we can create the gall bladder surgery environment (Figure 2) for use in our proposed study.

C. Controlling the Virtual VR Surgical Instruments

Kinect’s motion sensors enable the control of VR characters through a user’s own movements and gestures. Using these low-cost sensors, our VR environment can be turned into a virtual operating room in which student arm and hand movements can control the VR surgical instruments. This involves obtaining joint angles from the user and applying them to control the virtual versions of the surgical tools. We have applied this approach in prior work in which a humanoid robot was controlled by mimicking movements of a user using the Kinect device (Figure 3).

D. Real-Time Feedback on Surgical Performance

For providing haptic feedback, we utilize a Wii remote controller (Wiimote). The Wiimote is an interactive game controller that has several buttons for input and a motor for creating a vibration. This is a highly
portable device and, with Bluetooth connectivity, allows serial communication with any paired computing platform. Haptic feedback is provided by coding functions that modulate the strength and duration of the Wiimote vibrations associated with the type of feedback needed. In the proposed study, haptic feedback will be provided to the student by correlating haptic response to correct (or incorrect) steps identified by evaluating surgical instrument interactions with the soft-tissue dynamics of the gall-bladder model. We have applied this type of haptic feedback mechanism for enabling blind students to interact with their environment [17] and in transferring motor skills between expert and novice users [18].

E. Evaluation
A randomized controlled trial design will be used in this study.

E.1. Participants and Procedures
Twelve student subjects, distributed between training residents and medical students, will be recruited for this study. Subjects will be randomly assigned to three training groups (distributed VR training group, massed VR training group, and baseline group). In the distributed VR group, subjects will receive additional VR training for 5 sessions per week, 30 minutes per session for 6 weeks; in the massed group, subjects will receive additional VR training for 2 sessions per week, 75 minutes per session for 6 weeks; and the baseline group will receive no additional VR training. All students will be required to maintain the frequency and duration of their regular operating room training activities throughout the study period.

E.2. Measurements - Surgical Skills Assessment Tool
All subjects will be assessed using an Objective Structured Assessment of Technical Skills (OSATS) for laparoscopic cholecystectomy [18]. Assessment will be conducted throughout the study period: prior to training, at the end of the 3rd week of training, immediately after the completion of the 6-week training period, and 3 weeks after the training cessation. The comparisons between baseline and 3 weeks of training, immediately after training, and 3 weeks after training cessation can be used to answer Specific Aim 1 to determine the efficacy of the low-cost VR training system. The comparisons between two practice schedule at 3 weeks of training, immediately after training, and 3 weeks after training can be used to answer Specific Aim 2 to determine which practice schedule is more beneficial to improve surgical skills.

V. ANTICIPATED RESULTS
This research will examine the efficacy of a low-cost VR system on improving surgical laparoscopic cholecystectomy skills and will also compare the effect of two different practice schedules on that improvement. The results of this study will not only be disseminated through a written publication in the year following the study, but this study will lay the groundwork for securing additional funding through NSF and NIH, both of whom will be pursued – NSF for funding to design adaptive Virtual Reality training systems for individualizing the learning cycle and NIH for conducting a full clinical effectiveness study with the developed technology.

REFERENCES
2. Grantcharov T.P., et al.. “Randomized clinical trial of virtual reality simulation for laparoscopic skills