Serious games for knee replacement surgery procedure education and training

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Abstract

Total knee arthroplasty (TKA) is a commonly performed surgical procedure whereby knee joint surfaces are replaced with metal and polyethylene components that serve to function in the way that bone and cartilage previously had. Here we describe a multiplayer, serious game that was designed to train orthopedic surgical procedures to orthopedic surgical residents, and to gauge whether learning in an online serious gaming environment will enhance complex surgical skill acquisition. The serious game allows residents to focus on and develop an understanding of the procedure itself (the ordering of each of the steps in the procedure, and the various tools used). By clearly understanding the steps of a procedure and the underpinning surgical decision making processes, when placed in real operative environment, trainees will be able to focus on the technical aspect of the procedure.

Keywords: Knee replacement; virtual simulations; learner-centered teaching; serious games; interactive learning.

1. Introduction

Total knee replacement or total knee arthroplasty (TKA) is a surgical procedure whereby the painful arthritic knee joint surfaces are replaced with metal and polyethylene components that serve to function in the way that bone and cartilage previously had, providing patients with painful, deformed, and unstable knees reproducible pain relief and improvement in function (Park et al., 2007). While the primary indication to perform TKA is pain relief, a large number of arthritic knees have associated knee deformities which must be corrected during the procedure to ensure mechanical stability of the limb, the prosthesis, adequate joint range of motion and to create the greatest likelihood of implant longevity. Approximately 130,000 knee replacements are performed annually in the United States alone.
and the procedure has been rated among the most successful surgical interventions across all surgical specialties as rated by reliability of results and patient satisfaction (Lavernia et al., 2000). Identifying, assessing and correcting knee deformities surrounding arthritic knees requires an understanding of normal and pathologic knee anatomy and biomechanics as well as the strategies necessary to restore normal knee kinematics.

Much of the success of modern TKA can be traced to the development of a well described, reliable, systematic method of prosthesis implantation. In short, TKA involves replacing articular joint surface of the femur, the tibia and possibly the patella. Relatively speaking, the tibial and patellar component implantation require fewer steps and fewer considerations. Correct implantation of the femoral component however is an extremely “position sensitive” surgical procedure and must take into account joint range of motion, limb alignment, degenerative and genetic anatomic abnormalities, and soft tissue releases amongst other (Laskin, 1991). The TKA procedures is comprised of a number of steps that are followed sequentially and each step may involve the use of a variety specialized surgical tools and equipment.

The nuances, problem solving, and trouble shooting that surrounds surgery in general including orthopaedic surgery is acquired in the operating room as the trainee/resident is simultaneously focusing on his/her technical skill. However, such “hands-on” training of residents leads to increased resource consumption (e.g., monetary, faculty time, and time in the operating room). A study by Lavernia et al., (2000) examined the cost of TKA surgery at teaching hospitals vs. non-teaching hospitals. They found patients who underwent surgery at the teaching hospital had higher associated charges ($30,311.00 ±$3,325.00 as opposed to $23,116.00 ±$3,341.00 in a non-teaching hospital; in US funds) in addition to longer times in the operating room (190 ±19 minutes as opposed to 145 ±29 minutes in a non-teaching hospital). They attribute the increases in resource consumption to the “hands-on” approach required to train residents. There is a growing trend of decreasing resident work hours in North America and globally due to political mandate (Zuckerman, et al., 2005). This has lead to decreased training time in the operating room and hence less operative exposure, teaching, and feedback (Weatherby, et al., 2007). Operative time must be maximized in order to maintain a high level of surgical training. Although the amount of repetition necessary to obtain the surgical competence required of residents is still unclear, medical literature suggests that technical expertise is acquired through years of practice (Ericsson et al., 1993) and indicates a positive correlation between volume and patient outcome (Halm et al., 2002). Regardless of the amount of repetition necessary to obtain the surgical competence which is required of residents, it is evident that given the increasing time constraints trainees are under to acquire complex surgical cognitive and technical skills, efforts must be made to optimize operative room exposure.

Teaching technical skills and operative procedures to surgical residents away from the operating room is not common practice. On the contrary, trainees are responsible for reading and learning about a surgical procedure independently before entering the operating room. There is little available time either for the attending surgeon or the trainee given other clinical and academic responsibilities. However, available alternative methods for surgical training include the use of animals, cadavers, or plastic models, each option with its share of problems (Heng et al., 2004). More specifically, animal anatomy can vary greatly from different humans, cadavers cannot be used multiple times, while plastic models don’t necessarily provide realistic visual and haptic feedback (Heng et al., 2004). Simulations offer a viable alternative to practice in an actual operating room, offering residents the opportunity to train until they reach a specific competency level. Simulations range from decontextualized bench models and virtual reality-based environments to high fidelity recreations of actual operating rooms (Kneebone, 2009). Although virtual reality-based technologies have been incorporated in the teaching/learning curriculums of a large number of professions across various industries (including surgery) for several decades, the rising popularity of video games has seen a recent push towards the application of video game-based technologies to teaching and learning. Serious games, that is video games whose main purpose is not entertainment but rather teaching and learning, leverage the advances made in the video game realm along with the growing popularity of video games, particularly with today’s generation of students/learners, to overcome some of the problems and limitations associated with traditional teaching methods including surgical training techniques. Although virtual simulations and serious games are similar and can employ identical technologies (hardware and software), being a video game, serious games should strive to be fun and include some of the primary aspects of games including challenge, risk, reward, and loss.

We have begun development of an interactive, multi-player serious game for the purpose of training orthopaedic surgery residents the series of steps comprising the TKA procedure. We hypothesize that by learning the total knee
arthroplasty procedure in a “first-person-shooter gaming environment”, trainees will have a much better understanding of the procedure than by traditional learning modalities. We are also hypothesizing that trainees who are pre-trained using the serious game will perform better technically due to their better understanding of the cognitive process and ability to focus solely on the technical aspects of learning. Moreover, by clearly understanding the steps of a procedure and the surgical decision making that goes along with it, trainees will be able to focus on the technical aspect of the procedure in higher fidelity models or in the operating room.

The remainder of the paper is organized as follows. A brief review serious games and virtual simulations along with their use in surgery and in TKA, is provided in Section 2. An overview of serious game proposed here is provided in Section 3. Finally, concluding remarks and plans for future research and development are provided in Section 4.

2. Background

In contrast to traditional teaching environments whereby the teacher controls the learning (e.g., teacher centered), serious games present a learner centered approach to education in which the student as player controls the learning through interactivity. Such engagement may allow the student-player to learn via an active, critical learning approach (Stapleton, 2004). Game-based learning provides a methodology to integrate game design concepts with instructional design techniques to enhance the educational experience for students (Kiili, 2005). Video games provide students the opportunity to learn to appreciate the inter-relationship of complex behaviors, sign systems, and the formation of social groups (Lieberman, 1997). Games inherently support engagement and if engagement is sustained, it may facilitate experiential learning by providing students with concrete experiences and active experimentation (Kolb, 1984; Squire, 2008). By designing the scenario appropriately, a problem-based learning approach can be realized (Savery and Duffy, 1995). Similar to a good game designer, an educator should provide trainees/learners with an environment that promotes learning through interaction (Stapleton, 2004). Virtual environments and video games offer students the opportunity to practice their skills and abilities within a safe learning environment, leading to a higher level of self-efficacy when faced with real life situations where such skills and knowledge are required (Mitchell and Savill-Smith, 2004).

Gaming and interactive simulation environments support learner-centered education whereby learners are able to actively work through problems while acquiring knowledge through interactive practice learning thereby allowing the player to learn via an active, critical learning approach (Stapleton, 2004). With these experience-based, instructional methods, faculty work as facilitators, facilitating the experience and subsequent knowledge acquisition. These experience-based methods incorporate more complex and diverse approaches to learning processes and outcomes; allow for interactivity; allow for cognitive as well as affective learning; and perhaps most importantly, foster active learning (Ruben, 1999). Game-based learning provides a methodology to integrate game design concepts with instructional design techniques to enhance the educational experience for students (Kiili, 2005). Video games provide students the opportunity to learn to appreciate the inter-relationship of complex behaviors, sign systems, and the formation of social groups (Lieberman, 1997). Games inherently support experiential learning by providing students with concrete experiences and active experimentation (Kolb, 1984). By designing the scenario appropriately, a problem-based learning approach can be realized (Savery and Duffy, 1995). Similar to a good game designer, an educator should provide trainees/learners with an environment that promotes learning through interaction (Stapleton, 2004).

Although no particularly clear definition of the term is currently available, serious games usually refer to games that are used for training, advertising, simulation, or education and are designed to run on personal computers or video game consoles. Serious games provide a high fidelity simulation of particular environments and situations that focus on high level skills that are required in the field. They present situations in a complex interactive narrative context coupled with interactive elements that are designed to engage the trainees. Goals and challenges require the trainees to solve specific problems that they may have never seen prior to engaging in the game increasing the fun factor. In addition to promoting learning via interaction, there are various other benefits to serious games. More specifically, they allow users to experience situations that are difficult (even impossible) to achieve in reality due to a number of factors including cost, time, and safety concerns. In addition, serious games support the development of various skills including analytical and spatial, strategic, recollection, and psychomotor as well as visual selective attention (Mitchell and Savill-Smith, 2004). Further benefits of serious games include...
improved self-monitoring, problem recognition and solving, improved short- and long-term memory, increased social skills and increased self-efficacy (Michael and S. Chen, 2006).

Virtual simulations and serious games have been employed in a variety of surgery-based training applications. However, a complete review is beyond the scope of this paper. Here we describe several virtual simulations developed specifically for orthopaedic knee surgery. Park et al., (2007) present a virtual simulation system for total knee replacement. Their system is based on mechanical computer-aided design (CAD) software and implemented using basic CAD functionality such as shape modeling, assembly, automation, etc., allowing surgeons to determine important surgical parameters prior to the operation itself. Ting et al., (2003) describe a virtual reality system for unicompartmental knee replacement surgery training using a typical PC-based system and low-cost, six-degrees of freedom (motion) and three-degrees of freedom (force/resistive) manual manipulator. They model both the soft and skeletal tissue of the knee (based on computerized tomography scans) in addition to an assortment of surgical tools. Using the manual manipulator, trainees are able to interact with the model, performing the surgical steps. In addition to virtual simulations/serious games for total (or unicompartmental) knee arthroplasty, a number of virtual simulations have been developed for arthroscopic knee surgery. Mabrey et al., (2002) developed a virtual reality system for arthroscopic knee surgery. Their system consists of a typical PC, video display, and two force-feedback haptic devices. Forces that would normally be applied by the surgeon to the lower limb during the arthroscopy procedure are directed to a surrogate leg. Proprietary software provides a mathematical representation of the real-world while mimicking the mechanical, visual, and behavioral aspects of the knee. Cannon et al., (2006) describe the development of an arthroscopic virtual reality knee simulator to train orthopaedic residents in arthroscopic surgery before they begin to practice with “live patients” in the operating room. Their simulation employs realistic human knee models derived from the US National Library of Medicine’s Visible Human Dataset. Arthroscopic virtual simulations have also been developed by Zhang et al., (2003), and Heng et al., (2004).

3. Overview

The TKA serious game is intended to serve as a memory aid to students learning the procedure and to be used in conjunction to other “traditional” learning materials including books and videos. The goal is for the user/trainee to successfully complete the TKA procedure focusing on the procedure itself (i.e., focusing on the ordering in which steps are performed and on the tools required to perform each step as opposed to the technical aspects of the procedure) while minimizing the time to complete the procedure and maximizing the score (points are either added or taken away based on the trainee’s actions). We also incorporate “games within the game” whereby at various points in the game, the user is presented with a “sub-game” where they are required to perform a small task related to the step they are currently performing (e.g., one or two multiple choice questions randomly selected from a pre-defined list of questions) and allows users to accumulate further points.

Users begin the serious game in the operating room taking on the role of the orthopaedic the surgeon, room viewing the scene in a first-person perspective (as shown in Figure 1), the world is viewed through the viewpoint of the user’s avatar and as such, the avatar’s body is not viewed but their hands are). Several other avatars also appear in the scene including the patient (lying on a bed), assistants, and nurses (see Figure 1(b)). Currently, although these avatars are animated using simple pre-defined motions, they are not user controllable (future versions will allow

![Figure 1. Sample operating room screenshots.](image-url)
them to be controlled remotely by other users or controlled using artificial intelligence techniques). The trainee has the ability to move and rotate the “camera” in a first person style thus allowing them to move within the scene. A cursor appears on the screen and the trainee can use this cursor to point at specific objects and locations in the scene. Objects that can be selected (“selectable objects” include assistants, nurses, patient tools) will appear to glow when the cursor is placed over them (see Figure 1(c)). When a highlighted object is clicked on, a menu appears providing a list of selectable options for this particular object. For example, clicking on a nurse or an assistant allows the user to interact with them (e.g., ask them to hand over a particular tool or perform a specific task). The surgical tools are also selected using the cursor and once a particular tool is selected, the tool appears in the hands of the avatar. Once the tool has been chosen, if the patient’s knee is selected using the cursor, a menu appears providing them with a list of potential steps they can perform with that tool at that stage with the tool they are holding; only one step is correct and their task is to choose the correct step. The user is expected to know the steps in the required order as well as the tool used to begin each step. If they select the correct step, they will be asked a multiple choice question to test their knowledge of that step. Answering correctly results in a number of “points” earned which are added to an accumulating score. If the user answers the multiple choice question incorrectly, they are corrected by an “animated angry assistant” (voice acted; this is intended to provide a “fun” factor) who also provides the correct answer along with an explanation (text and/or illustrations) to ensure they understand why their answer was incorrect. If the user chooses an incorrect tool(s) for the corresponding step or performs a step out of order, they are also corrected by an “animated angry assistant” and are presented a short video segment illustrating a surgeon performing that particular step on a “real” patient with the surgeon narrating the details of the step). When the procedure is complete, the player is shown a score card listing the completion time, steps selected out of order, and the percentage of correct multiple choice answers.

The 3D rendering engine is built “in-house” using the OpenGL 3D graphics API. Models are being developed using the Maya 3D modeling and visual effects software, 3Ds Max modeling and rendering software, and the Z-Brush “digital sculpting” tool. In contrast to many of the serious games currently available, we have chosen to focus on realism and more specifically, rendering of very accurate models and the complex lighting requirements of the operating room. The serious game is also unique in that it utilizes video game effects such as “outer glow”, “reflection mapping”, and “bloom filtering”. Rendering in real-time is accomplished using the graphics processing unit (GPU); “shaders” are written using the OpenGL Shader Language (GLSL). Sound effects are rendered using the fmod music and sound effects system.

4. Summary

Total knee arthroplasty (TKA) is a surgical procedure whereby knee joint surfaces are replaced with metal and polyethylene components that serve to function in the way that bone and cartilage previously had. Here we described the preliminary development of a serious game to train orthopaedic residents to perform total knee arthroplasty procedures in a fun and engaging manner. In addition meeting the needs of today’s technology savvy students, the serious game can be used on a standard PC allowing residents to learn the TKA procedure on their own time prior to entering the operating room. Once the serious game has been completed, its effectiveness will be evaluated to determine if learning the cognitive process of performing a total knee arthroplasty in an online gaming scenario can enhance retention of the surgical steps, decision making and troubleshooting surrounding the procedure as compared to traditional teaching techniques. Secondly, to determine if technical skill acquisition can be enhanced through an online surgical simulation. We hypothesize that by learning TKA in a “first-person-shooter gaming environment” trainees will have a much better understanding of the procedure than by traditional learning modalities and that trainees who are pre-trained with the simulator will perform better technically due to their better understanding of the cognitive process and ability to focus solely on the technical aspects of learning.

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