Off-Pump Coronary Artery Bypass Surgery Procedure Training Meets Serious Games

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Abstract—The off-pump coronary artery bypass grafting (OPCAB) cardiac surgical procedure allows for a blocked coronary artery to be bypassed with a healthy artery or vein from another part of the body while the heart is beating in contrast to traditional coronary artery bypass grafting (CABG) which requires the use of a cardiopulmonary pump. Eliminating the cardiopulmonary pump, leads to a reduction in the number of postoperative complications. Despite the benefits associated with OPCAB and more specifically, its non-reliance on the cardiopulmonary pump, the OPCAB procedure itself is complex and technically challenging and therefore, it has been suggested that “appropriate training” be provided before operating on patients. Here we describe the preliminary development of an interactive, multi-player serious game for the purpose of training cardiac surgeons/residents the series of steps comprising the OPCAB procedure. By learning the OPCAB procedure in a “first-person-shooter gaming environment”, trainees will have a much better understanding of the procedure than by traditional learning modalities.

I. INTRODUCTION

Coronary artery disease (CAD) is a consequence of plaque accumulation in the coronary arteries that feed the muscle of the heart. The accumulation causes either narrowing (stenosis) or occlusion of these arteries causing insufficient oxygen-rich blood delivery. This can lead to angina pectoris (chest pain discomfort), shortness of breath, and, in more severe cases, heart attack [1]. Coronary artery bypass graft (CABG) surgery is a method of restoring blood flow to the inadequately supplied heart muscle. A combination of arteries and veins are taken from the patients’ chest, arm or legs and used to create bridges to the more normal coronary arteries, in effect “bypassing” the blocked portion by providing a new path for the oxygen-rich blood flow [1]. During a conventional CABG procedure, the patient’s heart is connected to a heart and lung machine (cardiopulmonary bypass circuit, CPB). The CPB circuit assumes the function of the heart and lungs allowing the heart to be arrested while the rest of the body is perfused. The arrested heart provides a still and bloodless surgical field facilitating the bypass procedure. The use of CPB is not without consequence. More specifically, it may contribute to a number of postoperative problems including systemic inflammatory response, renal, pulmonary or neurological complications, bleeding, and multiple organ dysfunction [2].

In an effort to avoid the potential complications of CPB, Off-pump coronary artery bypass (OPCAB) was introduced by Goetz in 1960 [3]. Techniques and technologies have been developed to position the heart and stabilize the segments of interest for allowing the bypass grafting to be performed as the heart beats spontaneously without CPB. When compared to conventional CABG, OPCAB has been suggested to result in less atrial fibrillation, fewer blood transfusions, decreased mechanically ventilated hours, decreased hospital length of stay, decreased stroke, decreased renal failure, decreased neurocognitive dysfunction, decreased myocardial enzyme release, decreased sternal wound infection and decreased cost [4]–[6]. However, OPCAB is performed in only approximately 16% of all coronary bypass operations in Canada [7] and up to 30% worldwide. There is lack of clear-cut evidence for the advantage of OPCAB, a technically more challenging operation over conventional CABG from conflicting reports in the literature. The units with the best results are those with a high volume of experience where OPCAB is performed almost exclusively and where specialized training is rigorous [8], [9]. As the current patient population is increasingly complex with more comorbidities, training on live patients may be less desirable.

At the University of Toronto, we have developed a progressive simulation augmented curriculum for training cardiac
surgical residents and fellows in the technique of OPCAB. The program highlights a needs-driven education approach, defining training objectives and creating simulation scenarios to achieve these objectives. In addition, corresponding assessment tools for both formative and summative purposes have been designed. The current version of the program features a physical beating-heart model and is comprised of five simulation stations arranged in order of difficulty according to the Challenge Point Framework [10]. For each station we have designed specific learning outcomes with the corresponding performance assessment checklists. Further advances would necessitate developing a multi-modality simulation approach that employs custom-designed modular physical as well as virtual reality simulators and scenarios that allow training technical and cognitive skills by means of a distributed and deliberate practice with feedback.

In relation to the virtual reality simulator, we have begun development of an interactive, multi-player serious game as an educational tool that allows cardiac surgeons/trainees to learn and become familiar with the series of steps comprising the OPCAB procedure. The content of the various training scenarios are being designed using cognitive task analysis, “think-aloud” techniques and specific learning objectives that will allow for incorporating progressive difficulty levels [11], [12]. We hypothesize that by learning the OPCAB procedure in a “first-person-shooter gaming environment”, trainees will have a much better understanding of the procedure than by traditional learning modalities (i.e., in-theater training known as the apprenticeship model). We are also hypothesizing that by clearly understanding the steps of a procedure and the surgical decision making that goes along with it (i.e., the cognitive skills), trainees will be able to focus solely on the technical aspect of the procedure (i.e., the actual execution) in higher fidelity models or in the operating room. Once physical and virtual simulators are developed and integrated, we will test the educational effectiveness of the curriculum by implementing randomized-controlled trials to evaluate various types of simulation-based learning conditions.

A. Paper Organization

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

II. BACKGROUND

Surgical training over the last 200 years has followed the master-apprenticeship model whereby the resident (trainee) acquires the required surgical techniques, skills, and knowledge in the operating room in a see one, do one, teach one manner [13]. However, such “hands-on” training of residents leads to increased resource consumption (e.g., monetary, faculty time, and time in the operating room) and has generally become more costly [14]. There is a growing trend of decreasing resident work hours in North America and globally due to political mandate [15]. This has lead to decreased training time in the operating room and hence less operative exposure, teaching, and feedback [16]. 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 [17] and indicates a positive correlation between volume and patient outcome [18]. Regardless of the above, it is evident that given the increasing time constraints, trainees are under great pressure to acquire complex surgical cognitive and technical skills. Therefore, efforts must be made to optimize operative room exposure.

Alternative methods for surgical training include the use of animals, cadavers, or plastic models, each option with its share of problems [19]. More specifically, animal anatomy can vary greatly from humans, cadavers cannot be used multiple times, and plastic models don’t necessarily provide realistic visual and haptic feedback [19]. 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 [20]. Although virtual reality-based technologies have been incorporated in the teaching/training 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 (which will become tomorrow’s health care practitioners and surgeons), 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. 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 [21]. Serious games support the development of various skills including analytical and spatial, strategic, recollection, and psychomotor skills as well as visual selective attention [22]. Further benefits of serious games include improved self-monitoring, problem recognition and solving, improved short- and long-term memory, and increased social skills [22].

Virtual simulations and serious games have been employed in a variety of surgery-based training applications. Although to
the best of our knowledge a serious game or virtual simulation for the OPCAB procedure is not available. That being said, a number of virtual simulations have been developed for cardiac surgery training in general including the simulation developed by Sørensen, et al, where a deformable heart model is constructed from MRI data [23], and the simulator of Nakao et al. that is intended to teach palpation of the aorta during cardiovascular surgery [24], with respect to games, several whose purpose is primarily intended to educate the general public (i.e., the “layman”) on cardiac surgical procedures do exist. For example, the Australian Broadcasting Corporation (ABC) Radio’s Virtual Open Heart Surgery [25] is a 2D game that can be played in a web browser. The player takes on the role of a surgeon performing a coronary bypass surgery. The game is organized into thirteen overly simplified steps. On-screen instructions guide the player through each step which typically involves dragging objects to the correct location or carefully manoeuvring a scalpel along a dotted line. Medical terminology is used throughout the game, but no medical training is needed to follow the steps. The game is too simple to train medical professionals but it could be used by a lay-person to gain a basic understanding of the procedure. Nova Online [26] provides a simple heart transplant surgery game for anyone wishing to learn about the procedure. The game guides the player through 19 steps using non-technical instructions. The player simply drags tools from a tray unto the patient to complete each step. No prior knowledge is required to play the game. Upon completion, the player will have a very basic understanding of the procedure. The graphics are colorful and “cartoonish” making the game suitable for kids. In contrast to these two games, we have decided to take a situated learning approach in which the learning environment is modeled on the context whereby the knowledge is expected to be applied [27], [28]. In other words, given that the trainees will be applying their acquired knowledge and skills in an operating room, the serious game places the trainee in this same context taking on the role of the surgeon. Furthermore, 3D technologies (graphical and sound rendering) will be employed to provide sensory realism consistent with the real-world ensuring that the knowledge gained within the serious game can be more easily recalled and applied when the trainee is placed in the real world scenario [28]. As a result, we have chosen to focus on realism and more specifically, rendering of very accurate models, the complex lighting requirements of the operating room, and faithful auditory/acoustic cues.

III. OVERVIEW

Users will begin the serious game in the operating room taking on the role of the cardiac surgeon, viewing the scene in a first-person perspective (the world is viewed through the viewpoint of the user’s avatar and as such, the avatar’s body will not be in view although their hands will). Several other avatars will also appear in the scene including the patient (lying on a bed), assistants, and nurses. Avatars will be animated using simple pre-defined motions and the option of controlling them remotely by other users or controlled using artificial intelligence techniques is also be provided. The trainee has the ability to move and rotate the “camera” (the view as seen from the user’s avatar) 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 (greater details regarding the implementation of the glow effect are provided below).

When a highlighted object is clicked on, a menu will appear 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 will also be selectable using the cursor and once a particular tool is selected, it will appear in the hands of the user’s avatar. Once the tool has been chosen, the user will be able to perform a particular step (which step to be performed will be chosen from a list of potential steps presented to the user). 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 for that step. Answering correctly results in a number of “points” earned which are added to an accumulating score.

The is for the user/trainee to successfully complete the OPCAB procedure, 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 (player’s) actions). A mechanism that allows “games within the game” whereby at various points in the game, the user can be presented with a “sub-game” where they are required to perform a small task related to the step they are performing is also available.

A. Technical Details

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. Preliminary, non-textured model samples are provided in Figures 1. 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. We are also accounting for the following user interface considerations [29]: i) reduce screen clutter (clean, simple layout),
Fig. 2. Shader example. The metallic shader adds the metallic look to the tools, trays, and tables, while the outer glow effect is used to highlight objects of interest.

Fig. 1. Sample preliminary non-textured models. (a) Heart, (b) Medtronic Octopus tissue stabilizer, and (c) torso.

ii) call attention to important areas of the screen using visual and/or auditory cues, iii) concise messages, and iv) start with the basics (do not overwhelm the trainee/student with too much information from the start).

1) Shader Details: Environment mapping [30] using a sphere map is used to generate the metallic effects and accomplished using a number of shaders specifically written to provide the metallic look to the tools, trays, and tables in real-time. A sphere map is used as opposed to a cube map as we wanted one map to represent a reflection at any part of the room and because the detail provided by cube maps was not necessary. Our sphere map texture has a large range of values and is primarily gray-scale, providing a metal look to the objects it is applied to. There is a hint of beige in the lower half of the map to represent that largely beige floor. A slight blue tint in the upper half of the sphere map represents the blue blanket and clothing. The upper half of the map is very bright given that all of the lights in the operating room are close to the ceiling.

The metallic shader uses a normal map to allow a surface to contain bumps and additional detail. A third texture map provides color information as well as “baked-in” lighting such as ambient occlusion and shadows. One of the main problems with sphere mapping is that reflection do not respond to lighting dynamically. Therefore, in contrast to standard sphere maps, this shader also responds to dynamic lighting with an adjustable specular highlight and it can also darken surfaces facing away from the light source if desired. The shader uses three textures in total: i) a texture map to provide the color and occlusion lighting, ii) a normal map adds additional surface detail, and iii) a sphere map to represent the environment.

The outer glow effect is achieved by combining three different shaders. First the object that we want to glow is rendered with a simple shader that applies a solid color to the model ignoring lighting. This same shader is used to render other objects in the scene (that may occlude the glowing object) black. The scene is rendered with a resolution of $256 \times 128$. Next the scene is blurred using a blur shader that blurs both horizontally and vertically in one pass. Next, all of the objects in the scene that are not glowing are rendered normally. Then the glow image is applied to the scene additively. Finally, the objects that are glowing are rendered normally. An example rendering that illustrates both the metallic and outer glow shaders is provided in Figure 2.

2) Game Sound: Background sound comprised a recording made during an actual OPCAB surgical procedure in an operating room. Although the background sound does not include any dialogue, it does capture the typical ambient sounds present during the OPCAB procedure including the prominent sound of the anaesthetic machine. Background (mono) sound recordings were made using a Zoom H4n portable field recorder with a 24-bit quantization level and a 44.1 kHz sample rate. Dialogue (speech) from the nurses and surgical assistants will also be included within the game in the future. Dialogue/speech will be used for output only to in order to provide the user with feedback and an indication of how well or poorly the player is doing.

IV. SUMMARY

The off-pump coronary artery bypass grafting (OPCAB) cardiac surgical procedure allows for a blocked coronary artery to be bypassed with a healthy artery or vein from another part of the body while the heart is beating, thus eliminating the cardiopulmonary pump postoperative complications associated with it. However, the OPCAB procedure itself is complex and technically challenging and therefore, it has been suggested
that “appropriate training” be provided before operating on patients. In this paper we described the preliminary design and development of a serious game for OPCAB education and training that will be used on a standard PC allowing trainees (e.g., cardiac residents and surgeons) to educate themselves on the series of steps for the OPCAB procedure on their own time prior to entering the operating room. The content of the various training scenarios are being designed using cognitive task analysis, “think-aloud” techniques and specific learning objectives which will allow for decomposing the procedure into teachable components and for incorporating progressive difficulty levels. We hypothesize that by learning the OPCAB procedure in a “first-person-shooter gaming environment”, trainees will have a much better understanding of the procedure than by traditional learning modalities. Once the serious game has been completed, its effectiveness will be evaluated to determine if learning the cognitive process of performing the OPCAB procedure in online gaming scenario can enhance retention of the surgical steps, decision making, and troubleshooting surrounding the procedure as compared to or in addition to traditional teaching techniques such as reading textbooks. The OPCAB serious game will also be integrated within the University of Toronto OPCAB simulation-based curriculum to provide training and assessment of technical and non-technical skills by following a multi-modality simulation approach.

ACKNOWLEDGMENT

The financial support of the Social Sciences and Humanities Research Council of Canada (SSHRC) in the form of an Image Text Sound and Technology (ITST) grant to Bill Kapralos, and Adam Dubrowski, and individual Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery grants to Bill Kapralos and Adam Dubrowski is gratefully acknowledged.

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