Biomedical Instrumentation SSY091

Study of virtual reality based simulations for surgical training

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April 14, 2021

Contents

1 Abstract

Surgical training has mostly been carried out by supervision by senior surgeons in the operating room [18] and by the use of live animal models [11]. These two methods have its disadvantages regarding cost [4], time [18] and ethical aspects [8]. There is a method for surgical training which could battle these disadvantages; virtual reality (VR) based simulation training. This study aims at exploring VR simulation based surgical training and state of the art technology in the field; discussing applications, advantages and disadvantages. It will describe different VR surgical simulators, how they work and future aspects and ethical concerns regarding them. Furthermore, implementation of artificial intelligence into the simulators is studied. To achieve this, a literature study was performed and interviews were held with an employee at Mentice, which is a company that develops surgical simulators.

In the report, several VR simulators covering a broad spectrum of medical procedures are presented. The advantages of using such simulators are many, with some being enhanced understanding and preparation before a surgery which can result in increased patient safety. Although, currently it is suggested that simulation training should be accompanied with professional supervision, and real experiences should not be skipped in surgical training. It will also be presented that the simulations can benefit greatly with proper data processing techniques, such as artificial intelligence (AI). AI could for instance improve the realism of 3D models or give the user relevant performance feedback. In conclusion the simulators can be a vital learning and visualization tool for trainees and surgeons, with the simulator undergoing research and development to improve the quality of the simulations.

2 Introduction

Dramatic changes in surgical technology in the 1990's led to concerns about patient safety due to inadequate amount of training with the new technologies [21]. For decades, supervision by senior surgeons in the operating room has been the main method for training doctors to acquire technical skills to receive surgical training [18]. However, due to higher costs, decrease in resident work hours and an increased number of trainees, the opportunities for training doctors to get individual hands on surgical experience, has been limited [18].

Another way of surgical training that has been practiced for almost as long as the aforementioned method, is the use of live animal models [11]. A significant disadvantage with this method is the cost; since working with animals requires housing, feeding and a dedicated operating room similar to the ones in hospitals [11]. In addition, there has to be a veterinarian present throughout the procedure [11]. The most evident disadvantage is the ethical aspect of humans performing surgical training on healthy animals [8].

One way to increase the time of surgical training and at the same time avoid ethical concerns regarding work with animal models, is to simulate an artificial surgery environment. Different kinds of simulations can be performed, for example synthetic replicas of the physical anatomy or simulations based on virtual reality (VR) [15]. The latter approach, VR, is rapidly becoming more popular and the simulations are becoming more realistic as more research is put into the field [21], [28].

This study will describe different VR surgical simulators which can replicate the operating room environment. Topics that are going to be discussed ranges from how the simulators works to future aspects and ethical concerns. The aim of the project is to explore simulation based surgical training programs as well as state of the art technology in the field; discussing applications, ethical concerns, advantages and disadvantages. Furthermore, implementation of artificial intelligence (AI) into the simulators is studied.

3 Method

The gathered data in this literature report was retrieved from books, articles, websites and interviews. Some books and articles were found from Chalmers library database and others were found from Google Scholar and Google. The key words for this report were: artificial surgery simulators, virtual reality, artificial intelligence in artificial simulations, surgical simulator advancements.

Two interviews with Carl Stein, a research and development (R&D) manager from Mentice were conducted. Mentice is a startup company founded in Gothenburg who specialises in endovascular simulations. They are a contract based company who designs products to meet their clients needs. The first interview consisted of Carl presenting the company, explaining the technology behind the simulation software and also performing digital simulations. In the second interview, Carl answered questions about Mentice products and future development of the company.

4 Results

This section presents the findings from the literature study and the interviews with Carl Stein. Multiple topics will be discussed in this section. The first topic is an introduction to different data types and data processing methods that are used in surgical simulators. Afterwards different VR simulators are presented and advantages and disadvantages of using them are described. Lastly, ethical issues regarding data processing and artificial surgery are introduced.

4.1 Data used in simulators

The aim of simulators is to create realistic, interactive simulations with high learning outcomes and skill developments [21], [29]. To accomplish this, different types of data are gathered to increase realism and feedback of the simulations [29]. Some gathered data are patient [2], medical professional [28] and user performance data [24]. In the following paragraphs three different types of data used in the simulators are presented.

4.1.1 Patient Data

Patient data in this study, is referred to images and additional information retrieved from patients to enhance the realism of 3D models and simulations. The backbone, also known as the foundation of the simulation program, is made of pre-made models composed of various patient data [2]. As Carl mentioned in the interview, Mentice uses a log book of anonymised patient data which contains computer tomography (CT) and magnetic resonance imaging (MRI) scans from patients. With the log book Mentice is able to

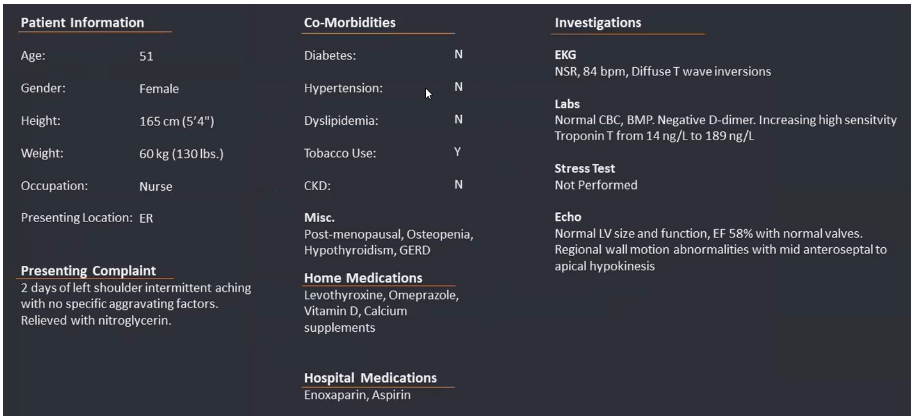


Figure 1: In the figure the patient data from a demonstration with Carl Stein from Mentice is displayed.

create their simulators. More about the log book is touched upon in the data processing section. Figure 1 is an example of a pre-made model using patient data from Mentice. Another way patient data can be used is by taking a specific patient's data, also known as patient specific data outside of the anonymised data, and uploading it into the simulator to recreate that patient's anatomy. [2], [23].

4.1.2 Medical Professional Data

Medical professional data is what its name implies; data provided by medical professionals [5]. The data can be used to tell the simulator at what angle one should operate on a patient, how deep to cut into the tissue, how much to remove of the area, which areas to avoid and more [5]. In addition, the medical professional data can contain task analysis for the trainee's to follow which could enhance the learning outcome [28]. An example of how medical data can help medical students in training is shown by Bissonnette et.al [5]. They explain that when a student preforms the simulation and does not complete the surgery correctly, the algorithm gives the student feedback and a video from an operating room with surgeons explaining how to perform the surgery [5]. In this case, the professional data helped build the simulators and helped students learn from their mistakes.

4.1.3 Users data

Different types of data can be gathered from individuals using the simulator to help improve it. Some data that can be retrieved is, the time it took for a user to complete the procedure, how well the procedure was carried out, errors, and economy of movement [28]. With the gathered data, a metric system which gives users feedback, can be built [5]. With the metric system, users are able to receive feedback from the simulators on their performance, such as what skills and at which steps the user should practice more [5], [24], [28].

4.2 Data Processing

As discussed above, there are different types of data that can be used in a simulator. This section will present how the data is implemented into the simulators and two different data processing methods will be introduced. The first is a traditional manual data processing method and the second will be data processing that implements artificial intelligence. This section is only intended to give a brief overview of the data processing methods.

4.2.1 Manual Data Processing

Manual data processing is when the data is uploaded manually to the simulator program. With the data, computer engineers are able to build the realistic image that can be seen on a simulator, Carl Stein says. Carl continues to explain, Mentice uses manual data processing for their simulators to build models of the human body. Once a model is created, Mentice manually programs different scenarios that can happen during different operations. Carl explains, a limitation to manual data processing is when transferring the CT and MRI scans from the log book into a computer. When doing transfer some pixels from the images are lost which makes the images less realistic.

4.2.2 Data Processing with Artificial Intelligence

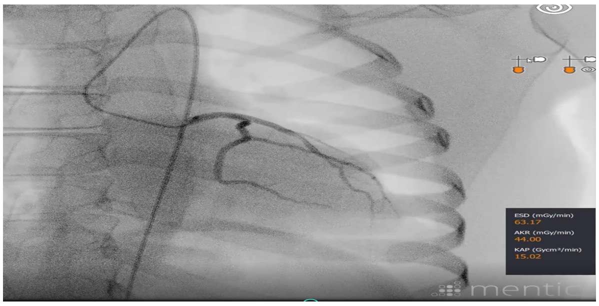
Data processing with artificial intelligence (AI) uses a machine learning algorithm that allows computers the ability to learn and grow in knowledge, when given a set of data [5]. The purpose of machine learning in AI is to mimic how a person learns [25]. The computer mimics a person's learning patterns by taking a given set of data and processes it with one of the three methods: supervised learning, unsupervised learning, and reinforcement learning [25]. For the purpose of this paper, only supervised learning will be discussed due the high impact it has on artificial surgery. Supervised learning is when the computer is given a set of data and is told what the data means [25]. Patient data, medical professional data and user data is fed into the AI algorithm and teaches it what is correct and what is wrong, allowing the algorithm to give accurate feedback [5]. In addition, an advantage AI has over manual data processing is the pixel recovery, when transferring the CT and MRI scans into the computer. Because AI has a high pixel recover, the image is fully removed and the simulation is more realistic.

4.3 VR Simulators

As of now there are plenty of surgical simulators on the market, which allows users to develop skills in different medical application. Such as endovascular methods [23], knee surgery methods [13] and aneurysm repair skills [28]. With a simulator both novices and experienced doctors, can navigate in a 3D reconstructed environment of the body and visualize the construction of the body without making incisions on patients [28]. For visualization the user either sees the anatomy through a screen with 2D view or through a head-mounted display with 3D view [18]. The common set up for computer based simulation consists of a computer with screens displaying the simulation and hardware with haptic feedback[1] [17], for instance see figure 2 (a) and figure 3. The biggest difference with the different actors in the market is what they attempt to simulate. In the following subsections some computer-based simulators which are currently in the market will be presented.

[1]Haptic feedback or haptic technology is used for creating touch experiences in a simulated environment by implementing forces or vibrations [28]

(a) Mentice VIST®G7. The simulator set consist of a computer, a screen, a navigation tool for the 3D environment (left of computer) and additional simulation hardware for the endovascular simulation.



(b) Screen shot of a X-ray image from the screen in the simulation which was demonstrated by Carl Stein , R & D manager at Mentice. The thread-like object is an inserted graft.

Figure 2: Endovascular surgery simulator VIST®G7 with simulated X-ray.

4.3.1 Mentice on Endovascular Simulations

Mentice, whom leads the market regarding endovascular simulations [22], has different types of simulators. One in endovascular simulation with the VIST®G7, one in advanced echocardiograpghy[2] with VIST®OneTEE, and another in radiation safety and basic angiograpghy [3] VIST®Radiation Safety [22]. Some types of medical procedures they offer as scenarios as add-ons are cardiac rhythm management, percutaneous coronary intervention[4] and peripheral vascular shunt repair[5].

One endovascular procedure which Mentice specializes in, is when a graft with self-expanding stents is inserted in a vessels that is swollen. The stent opens up the vessel by self-expanding and lets blood pass [7]. According to Carl, one of the main reason why Mentice has focused on simulating endovascular surgeries, is because of its minimal invasive property. In figure 2a the VIST®G7 simulator is displayed and in figure 2b an x-ray taken from Carl's demonstration is shown. In the demonstration Carl used VIST®G5 and what is seen on the x-ray in figure 2b is him, inserting a graft in the vessels close to the hip and pushing it upwards through the vessel until it has reached its destination.

The VIST®G7 physics engine has a built-in program named CASE-IT, which allows the user to put patient specific data into the simulator to build a model of the patient [23]. The data could be CT, MRI or 3D rotational angiography scans [23]. With the patients data uploaded into the simulator a model is built and the user can simulate an endovascular surgery on that patient.

[2]Echocardiography is a test where soundwaves is sent through the body to recreate live images of the heart.

[3]Angiography is a type of scan for the inside of the blood vessels or organs.

[4]Percutaneous coronary intervention is a procedure to treat narrowing of coronary arteries.

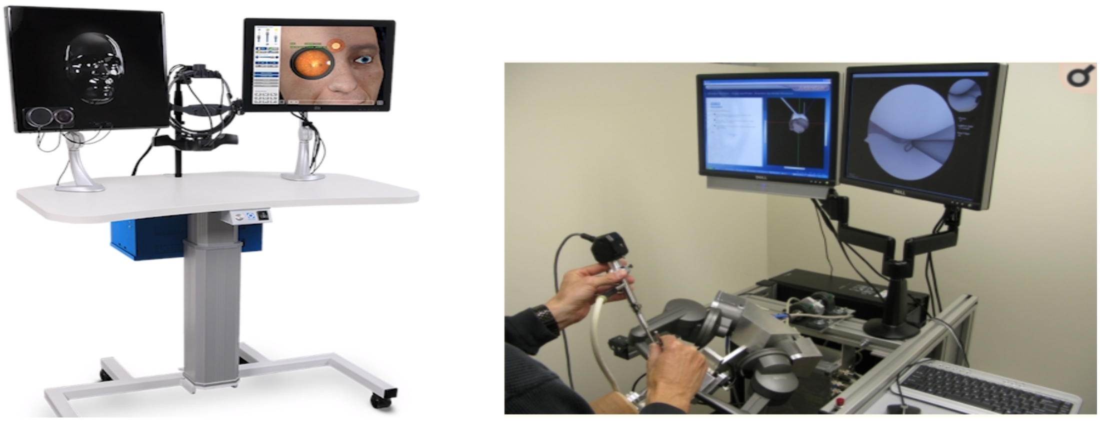
[5]For instance in shunt surgery a shunt (tube) is placed in the brain to lead excessive fluids to another part of the body [26]. The vascular shunt repair is a treatment when the shunt is blocked, and e.g. a graft is inserted to clear the passway.

4.3.2 Other simulators

Some of the other simulators in the market is Eyesi [10], KAST [19], The Virtual Operative Assistant [24] and they will be presented further in this section. Other well-established simulators in the market such as Reachin®, ProMis®, LapMentor®[28], ULIS, HURIS, Neurotouch and AngioMentor [29], will be omitted.

In figure 3, Eyesi and KAST are shown. Eyesi who was created by VRmagics [10], is a simulator which specializes in eye surgery simulations or eye visualization training. On the other hand, Kast is a knee surgery simulator by the American Academy of Orthopaedic Surgeons' Task Force on Virtual Reality. What these simulators have in common are they both offer high-fidelity simulations with surgery-like tool with realistic haptic feedback [10], [19]. The Eyesi and KAST as opposed to the VIST®G7 is more limited in the regards of creating patient specific models, and focuses more on the realism of the interaction [14], [19]. In addition, Eyesi has developed a performance feedback system which tells the user how they performed and what to improve in [10].

Similarly, The Virtual Operative Assistant is also a system which focuses on giving performance feedback. To accomplish this the Virtual Operative Assistant uses an AI algorithm [24]. The data used in the AI is gathered from both professional and novices using the simulation, in order to build an accurate performance feedback system [24].



(a) Eye surgery simulator Eyesi with augmented reality headset and two screens and belonging simulation tools. [10]

(b) Knee surgery simulator KAST[19] with tools for simulating surgery incisions and operation.

Figure 3: Two simulators used for training eye surgery and knee surgery.

4.4 Advantages and disadvantages of VR simulations

There are many advantages and disadvantages with VR surgery simulations. Some advantages include enhanced understanding of complex 3D body structures and improved handling of instruments for trainees, in a controlled, risk free environment [18]. However, Carl Stein from Mentice claimed that an experienced doctor could directly see that the 3D models of the simulations are inaccurate and that the skills developed in the simulation environment should be accompanied with real-life experiences. The accuracy of the simulations is not perfect due some properties being very hard to simulate, for example density, palpable propertied and convex surfaces [18]. Further the response rate and intensity of some haptic simulating devices do not correctly imitate the behaviour of the real device, for example the vibration from a drilling device [20].

Repetitive surgical tasks, for example suturing, are well suited for simulator training and patient safety regarding those procedures are improved when practicing those techniques [21]. Other surgical tasks could also benefit from VR training. In a clinical trial [27], the procedure of removing a gallbladder was performed with laparoscopic cholecystectomy. Eight surgeons performed the surgery with previous VR training and another eight surgeons performed it without VR training. The surgeons that did not undergo VR training were found to perform the surgery substantially slower and were more likely to cause injury, damage tissue or fail to progress with the surgery [27].

In our interview with Carl Stein from Mentice, Carl mentioned that not only trainees can benefit from the usage of the VR simulations, but also senior doctors can. He mentioned an example of stroke treatment when removing blood clots with a method called trombectomy. Since it is important to treat stroke patients fast to avoid damage of the brain, doctors are working on stand by and have to be ready to perform a trombectomy as fast as possible if needed. Having the possibility to refresh skills with a simulator in between surgeries for doctors who seldom performs the surgery, increases patient safety. Another benefit for senior doctors is that the workload of teaching doctors is saved since supervision of the training doctors is not needed when performing an artificial surgery with simulation [21]. Nevertheless the use of simulation is still best exercised under control of an educator due to the simulations often being insufficient realistic for an actual surgical experience [21].

Furthermore, an economic analysis comparing VR and animal laboratory training for endovascular skills training [4], suggested that VR training is less expensive than live animal training. Another advantage of the VR simulator compared to animal models is the simulators physiological realism and the case that anatomy of animals differs from human anatomy [3]. The VR surgical simulations are compared to animal models more realistic because of the the intuitive and graphical displaying of anatomic structures in 3D [18].

4.5 Ethics

As the field of artificial surgery broadens its spectrum and simulators successfully simulates more medical procedures, as well as more and more hospitals and companies chose to incorporate the simulators in their education [1], possible ethical dilemmas emerges. One dilemma is linked to the use of patient data to create realistic simulations. As presented in the Data Processing section; to create a realistic simulation there is a need of patient data. But since personal data is used, many believe that it is unethical and an invasion in privacy [12]. Another problem which could arise is if the data were to be redistributed to 3rd parties, without the patients knowing [9]. According to Gerke, a proposal to fix the dilemma is by offering an open dialog with patients about how the data is being processed and if the patients is still willing to share their medical records [12]. The other dilemma considers the problem of when the AI system goes wrong [16]. For instance what if the feedback is misleading or faulty, and the user learns the wrong skills and uses these in real surgeries.

5 Discussion

Three different ways of surgical training have been mentioned; conventional training in the operating room with supervision by a senior doctor, animal models, and VR simulators. All three methods of training aims at improving surgical skills of the doctors. The method of using a VR simulator is promising and has a lot of benefits compared to the two other two methods. Including its suitability of training repetitive surgical tasks, it is also more realistic and less expensive than animal training while avoiding ethical concerns regarding the use of live animals. VR training should also be more cost effective than conventional training since it is more time effective, but this depends on many factors, for example how expensive the equipment is. Thus making it hard to draw any conclusions. Additionally, VR simulation could be a preferred option of training when it is appropriate to minimize unnecessary patient contact, as in this time during the Covid-19 pandemic. The risk of spreading health care-associated infections is lowered when fewer people are in contact with the patient [6], hence the safety of both patients and health care workers are increased with the use of VR simulators.

VR simulators seems to be a potential method for training both novices and experienced doctors in surgeries, but it should as of yet not be regarded as a complete substitute for the conventional training. This is due to the fact that it is impossible to know how a person will react when facing the real situation in which unexpected events can occur, before actually facing the situation. In spite of that the simulators could prepare the students and make them more confident and less worried when they are starting to perform surgeries on real patients. In the simulation the student can learn in a safe environment and repeat procedures as much as desired. A problem can though arise, and that is if the safe environment instead results in the students getting sloppy. This problem could possibly be countered by well thought out step-by-step learning schemes and proper performance feedback.

As previously mentioned the VR simulations are not perfectly accurate, but according to Carl from Mentice this is not a big problem. More accurate simulators would not substantially change the learning outcomes of the simulator training. A development that actually would benefit the learning outcomes and increase the quality of education would be the implementation of AI with VR simulators. With AI incorporated into VR simulators, users are able to receive better feedback and learn how the surgery should have been performed and in which steps to improve. In addition, AI can be helpful in building better high - fidelity models. Even though, more accurate simulators do not make a difference in the learning outcome, why not build a high - fidelity model when you have the opportunity to do so.

Two ethical dilemmas regarding AI has been presented in the results. The first dilemma is linked to the of use of patient data to build the simulations. One argument against the use of the data is that it would be used by 3rd parties, thus there could be a distribution of the data. A counter argument could though be that the data is anonymous and only used for creating realistic scenarios or for feedback. But does all companies really get anonymised data such as Mentice does, could it be other regulations in other parts of the world that does not restrict the use of patient data in the same way as in the western world? And could there be corrupt companies that sells the data to 3rd parties? It is hard to know but one thing that is for sure is that without the patient data, the quality of the simulations could decrease dramatically. As presented in the results section, a proposal to fix the dilemma is by offering an open dialog with patients about how the data is being processed and if the patients is still willing to share their medical records. The second dilemma arises when the the simulator makes a mistake or gives inaccurate information, which could lead to doctors acquiring incorrect techniques. Who should then be punished, should it be the programmer who wrote the code of the algorithm? Maybe there should be some kind of responsibility of the user of the simulator to not blindly trust it, since it is not realistic for the algorithm to be programmed for every possible scenario. But in this case the developer is responsible to clearly inform that the simulator could make faulty decisions.

An interesting question to consider is whether the VR simulator has a bright future or not. At least according to Carl from Mentice, the market is increasing and he thinks that it will continue to increase in the next decade. This also seems to be supported just by considering the amount of research and the different kinds of simulators which are present on the market. Nevertheless there are still some issues with the simulators preventing them from fully replacing the conventional ways, and with the development of AI in other fields the tide can turn. As Carl speculated in the interview, if the development of a true AI takes place or if the development of robotic surgery then that could possibly outcompete the simulators. As such one can wonder how the situation could look like in the long run, would there even be any need for surgical training for humans in the future if robots take over surgical tasks?

6 Conclusion

In conclusion, virtual reality based surgery simulators can give many benefits in the learning process for students attempting to become surgeons, or for visualization and testing purposes for surgeons. While the simulators as of now have some limitations, constant research is being put into the field and new technology like AI, is implemented. Numerous medical procedures can already be simulated by different simulators on the market, while at the same time simulators continue to become more and more realistic and better educational tools.

7 Acknowledgements

We would like to thank Carl Stein from Mentice for taking the time to show us how Mentice simulations work and for answering all the questions we had on artificial simulations and discussing future developments.

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