Design and Simulation of a Training Simulation of Microvascular Anastomosis with Visual and Haptic Feedback

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Abstract- Computer graphics based 3-Dimensional (3D) modeling has a great impact on the rapid transformation of surgical training. Surgical training has led to a new way of learning microsurgery due to the expanded pressure of decreasing the utilization of animals. We have designed a 3D computer modeling based system with real-time visual and haptic interaction for microsurgery training. All kind of microvascular suturing can be practiced with this virtual blood vessels and surgical tools. This application of our system exposes many phases, comprising simulation of deformable organs, tool interactions, collision detection and suture simulation. In this paper we present a detail overview of the safe and hygienic system, which can resolve the ethical issues.

Index Terms- Microvascular Anastomosis, visual and haptic interface, deformable organs, collision detection, real-time interaction.

I. Introduction

Microsurgery is a specific surgery technique which is operating under a microscope of very high magnification (10-50 times). The advanced level of developments of the techniques permits suturinghttp://en.wikipedia.org/wiki/Anastomosis of successively narrower nerves and blood vessels (typically less than 2 mm in diameter). Using microvascular anastomosis procedure, re-joining of severed parts and transfer of flap tissue from a particular portion of the body to another can be successfully done. The field of microsurgery began with the introduction of the operating microscope when Jacobson and Suarez described the anastomosis of blood vessels [1]. In the 1960s, increasing triumph was seen with finger replacement and digital blood vessel repairs, as microsurgical procedures were improved. This built the base for microsurgical composite tissue transfer, which became popular in the 1970s [2]. The plastic surgeons use the microsurgery most widely. The microvascular suturing techniques are also used by several specialties in recent times, particularly those are entangled with reconstructive surgery such as: orthopedic surgery, oral and maxillofacial surgery, neurosurgery, gynecological surgery, otolaryngology, and pediatric surgery.

Professor M. G. Yasargil, the pioneer of micro-neurosurgery and founder of the Zurich Microsurgery Course, recommended that trainees spend at least 3 months learning microsurgical techniques in the laboratory before proceeding to practical neurosurgery [2]. Microvascular anastomoses require regular and repetitive practice for one to expert it because it is still a difficult and risky suturing procedure. As an opportunity for practicing microsurgery regularly on real patients, the surgeon should practice alone to maintain and enhance their performance. Typical microvascular training is carried out on artificial materials (such as silicon tube) and *in vivo* (such as anesthetized rats) and *in vitro* (such as swine and chicken-wing arteries) animal models [3].

In this paper, we present a design of simple and accessible computer based training simulation with 3D graphics, visual and haptic interaction which can be set up rapidly under safe and hygienic conditions and with no involvement of ethical questions. A haptic master device is connected with visual and haptic interface and the computer graphics is displayed in screen. Trainee can move the master device with his hand and can feel the haptic sensation. New surgeons can be experienced enough by repetitively practicing through this training simulation and the experience surgeons can maintain their skill by practicing regularly.

II. Background Research

Research on design and development of training simulation for microvascular anastomosis has increased significantly in the past few decades. Some of them used human blood vessels discarded from operation and some used animal vessels like chicken [4]. A group of Japanese people lead by Matsumura designed a pocketbook-sized microvascular practice card by using six small diameter silicone tubes. The available diameters of the tubes are 2.0, 1.0, 0.5, 0.3mm.

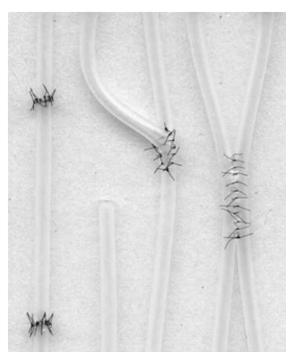

Figure 1: Microvascular Practice card [5]

ISSN 2250-3153

No of practice and variation of scenarios are very limited with these training systems. To build a training simulation with unlimited practice session and various vessel size, computer based simulation system is the ultimate choice.

Brown J. et al from Stanford University developed a computer based microsurgery simulation system for the graphical visualization of complex surgical objects and real-time interaction with these objects using real surgical tools [6].

Figure 2: Computer-based microsurgery simulation system [6]

They focused on modeling deformable organs and interaction scenarios but did not consider the restriction of workspace due to the depth of incision present in real procedure. In this design, we consider the constrained workspace with depth of incision by giving haptic feedback to restrict the user from moving out of the workspace. We also differentiate the simulation environment for beginner and expert users by considering vessel diameter and depth of incision.

III. MATERIALS AND METHODS

In this study, a Computer based training system consists of visual and unique haptic feedback is designed. The 3D models of deformable blood vessels are modeled with simple mass-spring model like the figure below [6]. The thickness of the vessels was represented by the differences of double-hulled tubular object. The tubes are made of evenly spaced nodes whose are connected by springs and dampers. In real surgery, the ends of the vessels are clamped by temporary vessel clamp. To make the simulation more realistic, we have fixed end layers of each vessel. The micro forceps were modeled with triangles and displayed after texture mapping. To reduce the computational load, the forceps were modeled as three line segments connected together to represent two jaws and the tube. The suture was modeled as an articulated object of several small linear links and spherical joints. These spherical joints permit 2D rotational movements. At a particular end of the suture, couples of links fixed together to play the role of a needle.

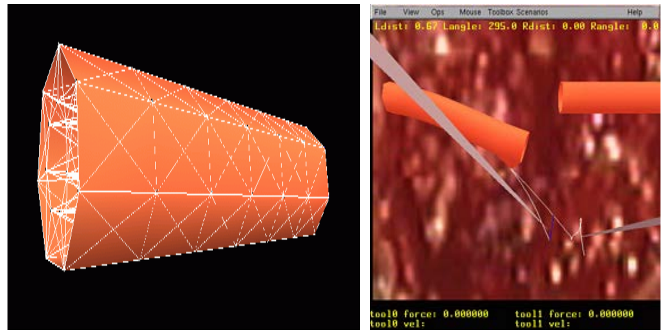

Figure 3: Deformable model of blood vessel, forceps and suture

Since the sense of touch with the vessel which has less than 2mm diameter is negligible, the main purpose of the haptic feedback in our simulation is that guiding the trainee to the right direction rather than add the tactile reality. In the real surgery, the workspace is very small to suture little vessels and sometimes surgeons need to insert the surgical devices in the patient's body deeply through narrow incision area like neurosurgery or vascular surgery. This situation greatly constrains the operation area and increase the difficulty of the surgery. In the existing training simulation such as using rat model, cylindrical equipment is installed on the surgical area and trainee insert their device through it to build the constrained situation. In our simulation, the trainee has the opportunity to select the constraints of workspace by choosing area and depth, and this condition is notified by the haptic feedback. This unique feature provides the option to the user to select the mode of practicing microvascular anastomosis. When the devices operated by the trainee touch the boundary of the workspace previously set up, resisting force will be exerted on the trainee's hands and it restrains the movement of their hands toward restricted direction.

Figure 4: Constrained workspace without and with depth of incision

The haptic feedback is also provided at the tip of the forceps to protect the blood vessels from rupturing due to excessive grasping force and too much dilation (1.5times of its original diameter). Therefore if the trainee exerts excessive force on the vessel wall or extends it too much, force feedback will restricts them and notify that they are on the extreme situation.

The collision was detected between forceps and vessels, forceps and suture, and suture and vessels for real-time interaction.

Quinlan's bounding sphere hierarchy was used for collision detection and distance computation.

The magnification level was adjusted by the foot pedal during the simulation to minimize the interruption of the hands. Magnifying and de-magnifying effect affects not only the size of the object but also the sensitiveness of the movement of the tools.

Figure 5: Visual Interface

The visual feedback provides an excellent user interface. There are status screen and guidance/ feedback screen along with main display. In the Figure 3, we can see that the trainee has the opportunity to select the level of the microsurgery as well as the diameter of the vessel, level of magnification and depth of workspace. The user can also choose the needle of different diameter and size. The guidance/ Feedback screen helps users by supplying varieties of information like grasping force and dilation of vessel, no of suture, elapsed time, and step-by-step guidance. Step-by-step guidance assists the beginner by showing the next step to do. There is an evaluation screen which will appear with score and comments regarding on performance after finishing the test.

IV. RESULT

The aim of our research was designing a graphics based training simulation of microvascular anastomosis for users to practice alone and repetitively with visual and haptic feedback. Microsurgery is a challenging suturing technique due to the lack of opportunity for practicing regularly and personally. The 3D models of blood vessels and surgical tools with real time interactions has made this simulation suitable for practicing alone in home and as much time as you want. The outstanding idea of visual and haptic interface with constraining workspace by using haptic feedback has made this simulation remarkable. Novice user can start with a circular workspace which has no incision depth and improve his skill concentrating on suturing. Step-by-step guideline is also very helpful for beginners. Hand-eye-coordination practice under the very high magnification is the main challenge to become expert. The diameter of vessel will decrease, and the depth of incision and the magnification will increase with the level of expertise of this procedure. The user is evaluated by focusing four prime issues: handling tissue without damaging, required time and motion accuracy, micro-instrument movements, and performance of suturing.

V. CONCLUSION AND DISCUSSION

We have designed a training simulation of microvascular anastomosis technique with the aid of 3D computer graphics in augmented reality to train young inexperienced surgeons. There is visual and haptic feedback integrated with this simulator. We decided to simulate the suturing technique of very thin blood vessels under different magnification to illustrate the capability of the upgraded system and the proposed computer graphics. This simulation technique includes the real-time rendering of computer based 3D models of a needle applier with 10.0 needles, micro forceps and the blood vessels. Physics based modeling of deformable tissue and display of force and touch sensations to the user through the haptic interactions among the needle, the forceps and the blood vessels are also included. For real-time simulation of the visual and haptic interactions between the augmented objects, couples of assumptions and simplifications were made in the 3D graphics and interaction phases. Simple 3D models of the surgical tools and blood vessels decrease the computational time of collision detection. For example, to detect real-time collision with thin blood vessels, the graphics of forceps were designed as three connected line segments. Similarly, the needle was modeled as a group of nodes linked via springs and dampers, to detect its collisions with the triangular mesh of the thin tubes. As the needle is inserted into the surface of the blood vessels, increasingly more particles collide and the computational load increases. This approach can be stretched to simulate two arbitrary shaped 3-D models, though our targeted surgical procedure includes the simulation of interactions between two thin pipe patterned objects. A group of nodes that are strategically distributed upon the surface of a 3-D model of needle may be used for collision detections with a 3-D polygonal model of blood vessels. Real-time rendering speed can be obtained as the collision detection technique only checks a set of actuating 3-D nodes inserting through a 3-D polygon.

To combine the haptic and visual interactions together special software was developed. This software uses different threads for the visual and haptic interactions to synchronize. This type of synchronization is very important for the optimization of computational power even though the interaction systems have different sensing properties.

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