The assessment of stability and reliability of a virtual reality-based laparoscopic gynecology simulation system

W. H. Sung[1], *M.S.*; **C. P. Fung**[2], *Ph. D.*; **A. C. Y. Chen**[3], *M.D.*; **C. C. Yuan**[3], *M.D.*; **H. T. Ng**[3], *M.D.*; **J. L. Doong**[1], *Ph. D.*

[1]*Department of Mechanical Engineering, National Central University, Chung-Li*
[2]*Department of System Engineering, Chung Cheng Institute of Technology, Tao-Yuan*
[3]*Department of Obstetrics and Gynecology, Taipei Veterans General Hospital, and National Yang-Ming University Taipei (Taiwan)*

Summary

Purpose of investigation: Surgeons require practiced skills in laparoscopic surgery. A virtual reality-based simulator system was developed for extensive training. The purpose of this study was to assess the feasibility of a virtual reality-based laparoscopic gynecology simulation system.

Methods: Laparoscopic tools and three-dimensional virtual environments were included in the simulation system. Ten healthy, non-disabled volunteers were recruited. The surgical procedure is a process of tubal sterilization by cauterization. Volunteers followed the training procedure, 15 trials in the first test and retest, respectively.

Results: Stable performances were obtained after about seven trials for all subjects. The intraclass correlation coefficients were 0.935 and 0.425 for task time and error frequency, respectively.

Conclusion: The results of this study indicate that the system is stable and has a fair high test-retest reliability. Therefore, the VR-based laparoscopic gynecology system is feasible.

Key words: Virtual reality; Laparoscopic gynecology.

Introduction

Minimally invasive surgery is a technique in which operations are performed through small incisions on patients and, therefore, minimize the trauma to surrounding healthy tissues and organs. The small spatial extent of the tissue injury greatly reduces patient pain and recovery time, while the overall quality of medical treatment is improved. With these advantages this new technique has become very popular and replaced most traditional open surgeries. Now the surgical procedures performed using minimally invasive techniques can be found in many surgeries of the human body such as laparoscopic surgery [1], arthroscopic knee surgery [2], and gastrointestinal surgery [3].

In the procedure of laparoscopic surgery a laparoscope is inserted with a cannula through a 10 mm diameter incision in the abdominal wall [4]. A specialized camera mounted on the laparoscope transmits the necessary visual information to a monitor viewed by the surgical team. However, the operative site is viewed as a two-dimensional image. The less stereo-touched two-dimensional images can hardly give the information about the depth of surgical operating space. Therefore, the two-dimensional image presentation modes do not completely meet the requirements of intraoperative executing guidance. Moreover, the dexterity of manipulating tools is significantly reduced due to the geometrical constraints posed by the external control of the surgical instruments. Surgeons performing operations under these conditions need specific skills, which are normally gained with extensive training. Usually the skills are learned and practiced by doing animal experiments and using some synthetic tissue-covered training devices. However, the low availability and high cost of animal specimens as well as the lack of realistic tissue reactivity strongly restrict their use for everyday surgical training. A virtual reality-based simulator system can offer a solution to this training problem.

The virtual reality (VR) is a computer graphic technology. It can be used to create fictitious objects and events that simulate a realistic three-dimensional scene and allow segments of a scenario to be manipulated [5, 6]. Several research groups have recognized the potential of virtual reality technology and proposed VR-based simulator systems in the past few years to familiarize surgeons and students with surgical procedures for laparoscopic surgery [7-9].

Some research groups have focused on the methods for simulating the physical behavior of deformable tissue. One of the common methods has been to model a surface or volume as a mesh of mass, spring, and damping elements [10, 11]. The finite element method has also been a popular and powerful tool for solving engineering problems. Some researchers [8, 12, 13] employed it to model tissue deformation and interaction between organs and

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instruments. Additionally, deformable contours or splines [14, 15] were also developed. The development of haptic sensation for the VR-based simulator system was very young. Asana *et al.* [16] designed new interface for laparoscopic surgery. Suzuki *et al.* [17] developed the device to provide force feedback in open surgery.

The purpose of the present study was to assess the feasibility of the VR-based laparoscopic gynecology simulation system. A personal computer, a digital foot pedal, and laparoscopic tools are included in the system. Three-dimensional virtual environments are developed using Virtual Reality Modeling Language (VRML). All the positions and orientation of the laparoscopic tools are continuously recorded and stored by a data acquisition software module. To validate the stability and reliability of the system in the surgical training procedure, ten healthy, non-disabled volunteers ranging from 20 to 30 years old were recruited. The surgical procedure is a process of tubal sterilization by cauterization. Volunteers followed the training procedure - 15 trials in the first test and retest, respectively. From the experimental results it can be concluded that the system is stable and the system reliability is acceptable. Therefore, the VR-based laparoscopic gynecology simulation system is feasible.

Materials and Methods

Subjects

The subjects recruited in the study were ten male volunteers ranging from 20 to 30 years old. The subjects were presumed healthy and non-disabled because none reported any history of neuromuscular, metabolic or ophthalmic disease. The experimental procedures were approved by the local institutional review board for human research and adhered to the Occupational Health and Safety Administration regulations. Each subject had to give his informed consent to participate in the experiment.

System configuration

The VR-based laparoscopic gynecology simulation system includes a personal computer, a digital foot pedal, laparoscopic tools and three-dimensional virtual environments (VE). As the user operates the laparoscopic tools, the motion of a pair of laparoscopic surgical instruments can be simulated and appear in the VE. Moreover, the operating dynamic data such as rotation, translation and open-close of the laparoscopic tool are recorded and stored in a personal computer.

The device used to track the motion of a pair of laparoscopic surgical instruments is the Virtual Laparoscopic Interface (VLI), from Immersion Corporation, San Jose, CA. The VLI includes five degrees of freedom for each of two instruments: the pitch and yaw motions from a surgical tool pivoting about its insertion point, the spin of a surgical tool about its insertion axis, the insertion and retraction of a surgical tool, and the open-close motion of the tool handle. Basically, these five degrees of freedom for each tool encompass the motion of most laparoscopic procedures. The motions of two surgical tools are tracked simultaneously at an angular resolution better than 0.064 degrees and linear position resolution better than 0.05 mm, and the data are transmitted to a PC through a standard RS-232 serial port. The latency is less than 1 ms, resulting in an update rate of 1000 Hz for the virtual environment displayed. The digital foot pedal is made to control the action of electrocauterization. Its on-off digital signal is transmitted to the PC via a game port.

The virtual environment is based on the process of tubal sterilization, raising the left fallopian tube and cauterizing it. The 3-D objects are constructed using VRML. The object behaviors and VE software are programmed using VC++ language. Finally, the virtual scene is displayed through ComsoPlayer ActiveX on a desktop Pentium III PC platform.

Procedures

The experimental tools for the process of tubal sterilization are set on a table. The screen is located in front of the laparoscopic tools, as shown in Figure 1. The subject operates the laparoscopic tools while watching the screen.

Before the study the examiner explains the test requirements to each subject and answers questions. After that, subjects watch a demonstration film. Then in the following regular process, each subject follows the steps shown in the demonstration film: (1) selecting incision position, (2) selecting surgical tools, (3) raising left the fallopian tube with the left tool, (4) clipping the fallopian tube at the first position with the right tool and stepping on the digital foot pedal, (5) repeating the preceding step at the second position. The frame shown in Figure 2 illustrates the action of clipping the fallopian tube at the first position.

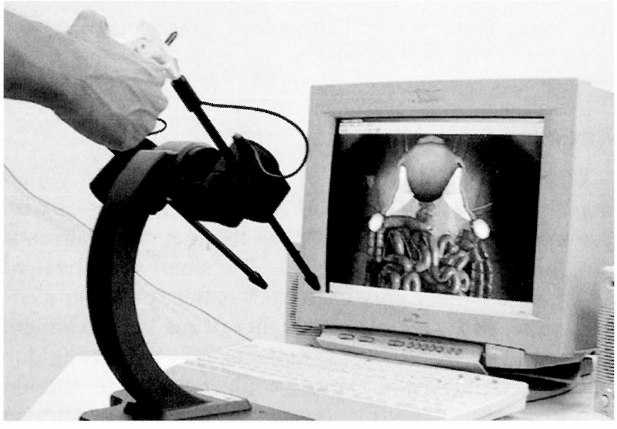

Figure 1. — A subject manipulates the virtual reality system.

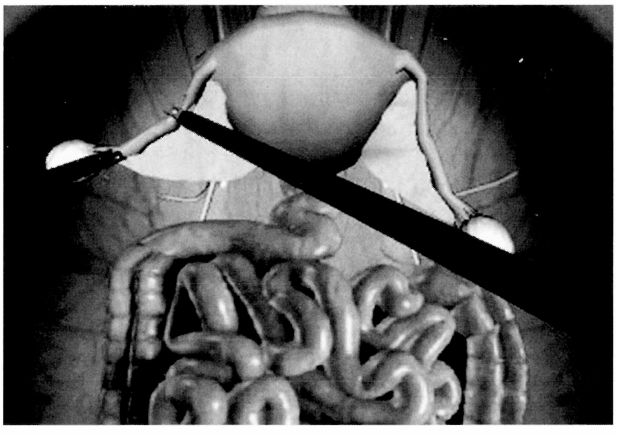

Figure 2. — A VR frame illustrates the action of clipping the fallopian tube at the first position.

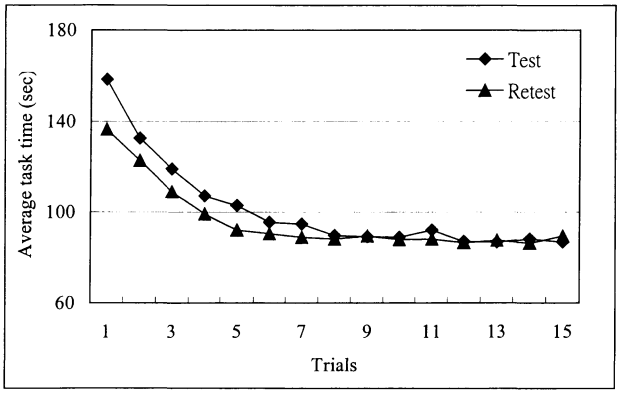

Figure 3. — Average task time of the ten subjects in each trial.

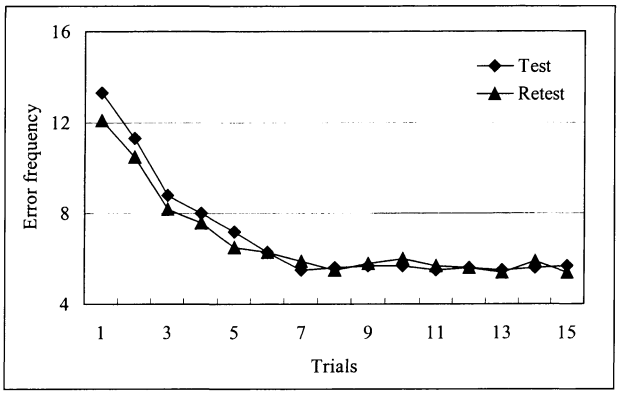

Figure 4. — Error frequency done by the ten subjects in each trial.

Experimental design and measures

The study was designed to determine how many trials are required to obtain a steady performance of the tubal sterilization. Ten subjects performed the procedure - 15 trials in the first test. Two weeks later, the ten subjects were asked to execute the same process, 15 trials again, in the retest to assess system reliability.

In each trial the task time (the time period of executing the procedure of tubal sterilization) and the number of errors are recorded.

Results

The average task time of ten subjects in each trial is shown in Figure 3. The average time all subjects took at the first trial was 158.5 seconds. Then the time was gradually reduced with more trials. At the eighth trial the average task time was reduced to 89.8 seconds. After that, the time taken by subjects did not change too much at each trial. The average task time taken by the same subjects in the retest is also shown in Figure 3. The average task time at each trial was less than the first test results. The task time of the first trial in the retest was 136.4 seconds. It was also reduced with more trials. The difference between the first test and retest was 22.1 seconds at the first trial. But at the eighth trial the difference was down to 1.5 seconds and the amount of difference was not enlarged after that.

Other recorded data, the error frequency at each trial, done by the ten subjects in the first test and retest are shown in Figure 4. In the first test the error frequency was improved from 13.3 at the first trial to 5.6 at the eighth trial and the frequency did not change too much in the following trials. The conditions in the retest were quite the same as the first test while a little improvement was obtained. The error frequency was 12.1 at the first trial. It was 1.2 less than the previous result. At the eighth trial the error frequency was reduced to 5.5.

The average task time and error frequency after seven trials in the first test and retest for each subject are listed in Table 1. In the first test the minimum task time was 76.31 seconds by subject J, and the maximum task time was 107.91 seconds by subject H. The total average task time was 88.57 seconds. In the retest, the minimum and maximum task time were 78.14 and 103.6 seconds, respectively. The total average time was 88.03 seconds. The intraclass correlation coefficient (ICC) was 0.935. As for the error frequency, in the first test the minimum was 4.43 made by subject A. The maximum was 7.29 made by subject H. The total average error frequency was 5.64. In the retest the total average error frequency was 5.69. Although the data was very close to the value in the first test, the intraclass correlation coefficient was only 0.425.

Discussion

System stability

To determine how many trials are required to obtain a steady performance of the tubal sterilization, ten subjects

Table 1. — *The average task time and error frequency in the first test and retest for each subject.*

Item	Subject										Total
	A	B	C	D	E	F	G	H	I	J	
Task time											
Test (SD)	79.62 (4.69)	86.32 (5.62)	90.28 (4.92)	85.88 (5.06)	89.24 (8.12)	91.17 (3.03)	92.91 (6.72)	107.91 (7.35)	85.98 (6.02)	76.31 (1.69)	88.57 (9.68)
Retest (SD)	81.05 (14.1)	90.50 (4.91)	90.50 (4.91)	83.31 (6.74)	87.05 (8.16)	93.54 (7.34)	88.84 (8.58)	103.60 (6.79)	83.72 (5.51)	78.14 (7.03)	88.03 (10.1)
ICC											0.935
Error frequency											
Test (SD)	4.43 (1.98)	6.00 (1.52)	5.57 (1.81)	5.43 (2.14)	7.00 (2.82)	4.86 (0.69)	5.29 (2.21)	7.29 (1.79)	5.00 (1.00)	5.57 (2.22)	5.64 (1.99)
Retest (SD)	6.00 (2.30)	5.14 (1.46)	5.00 (1.41)	7.00 (1.73)	5.43 (1.51)	5.43 (2.14)	5.43 (2.76)	5.14 (2.91)	6.00 (2.08)	6.29 (1.70)	5.69 (2.02)
ICC											0.425

did 15 trials of the procedure. The average task time at each trial in the first test and retest is shown in Figure 3. It can be seen that the task time taken at the first trial is the longest as was expected. Subjects operated the VR-based laparoscopic tools for the first time. They had no similar experience and therefore they spent more time to finish the process. The results of error frequency at each trial in the first test and retest, shown in Figure 4, also explain the condition. As the subjects were not familiar with the new tools, not only the task time, but also the error frequency was the highest. After the first trial, both the task time and error frequency were reduced with more trials. This trend of the data present the effect of learning. The results showed that the best performance was obtained after about seven trials. With the experience subjects learned from the first few trials their performances were quite stable in the following trials. Moreover, VR-based laparoscopic tools offer a stable system for students and surgeons to practice the process of tubal sterilization.

System reliability

The system reliability was assessed by the procedure of test-retest. The same subjects took the retest two weeks after they took the first test. The intraclass correlation coefficient was calculated from the results of the first test and retest to assess the VR-based laparoscopic tools. The results of the task time and error frequency obtained from the retest are shown in Figures 3 and 4. It can be seen that subjects performed just as they had two weeks before in the first test. Both the task time and error frequency were reduced with more trials in the retest. Probably it was because familiarity with the tools was lost after a period of two weeks. However, with the experience obtained from the first test, subjects' performances in the retest were still a little better than they were in the previous one. The stable performance was obtained after several trials. Presenting the experimental data of the first test and retest in one figure could make the assessment of system reliability easier. From Figures 3 and 4 it can be seen that after the performances were stable the experimental data in the first test and retest showed almost no difference. This means that the reproducibility of the experiment data was very good. Moreover, test-retest reliability can be analyzed using an intraclass correlation approach. Table 1 lists each subject's experimental data in the first test and retest. The ICC values were calculated based on the analysis of variation with these repeated measures. They were 0.935 and 0.425 for task time and error frequency, respectively. The high ICC values from the test-retest assessment showed the VR-based laparoscopic system can offer a highly reliable gynecology simulation.

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Address reprint requests to:
C. P. FUNG, Ph.D.
Department of System Engineering,
Chung Cheng Institute of Technology
33509 Tao-Yan (Taiwan)