NEXT-GENERATION DISTANCE LEARNING SOLUTIONS FOR SURGERY

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ABSTRACT

In the last decade, advances in medicine, telemedicine, computer technologies, information systems, Web applications, robotics and telecommunications have enabled creation of new solutions for training and continued education in various medical disciplines. This paper presents most recent developments and future trends in distance learning for surgeons, focusing on the following goals: a) Building a comprehensive, world-wide, virtual knowledge base for various disciplines of surgery and telesurgery, including text documents, videos, case studies, expert surgeons' opinions, and relevant references; b) Building a virtual knowledge base for rare medical cases, conditions and recommended procedures; c) Interactive multimedia simulators for hands-on training in all surgical disciplines; d) Building a worldwide surgical community, to accelerate the accumulation and sharing of the latest surgical breakthroughs and technological advances throughout the world. Above all these goals, the most important goal is to improve patient health and convenience, and reduce risks of mortality and complications.

Keywords: Distance learning, Surgery, Virtual-Reality Simulators, Information Systems, Web Applications, Multimedia

INTRODUCTION

According to the U.S. Bureau of Labor and Statistics [13], employment of physicians and surgeons will increase annually 10% - 20% through the year 2012 because of the expansion of the health care industry. The growing and aging population will drive overall growth in the demand for medical services. Therefore, the demand for surgeons is expected to be favorable, although highly sensitive to changes in consumer preferences, healthcare reimbursement policies, and legislation. Reports of shortages in some surgical disciplines or geographic areas should attract new entrants (surgeons), encouraging schools to expand their programs and hospitals to expand available residency slots. On the other side, new entrants may be discouraged by demand for the long-term commitment and high expenses of surgical education and training. To become a surgeon, it takes 4 years of undergraduate school, 4 years of medical school, and 3 to 8 years of internship and residency.

Surgical training requires close supervision and evaluation. Technical competence of surgical learners is evaluated by the mentor and has always been subjective [10]. Typically, qualitative rather than quantitative evaluations are performed in traditional surgical training.
Based on the most recent trends in surgery, distance learning represents a very attractive medium for training of new as well as continuing medical education (CME) for seasoned surgeons in

- **Traditional Surgical Procedures**. Traditional surgery typically involves 20 to 80 cm long incisions into a patient's body in order to examine or treat a certain organ or tissue [10].
- **Laparoscopy Procedures.** Laparoscopy (minimal invasive surgery) is a relatively new surgical technique that enables major abdominal procedures with only four to five 1 cm long incisions into the patient's abdomen. The surgeon passes the video imaging scopes and surgical instruments into the abdominal cavity and completes the procedure while monitoring

the operation on a display. The advantages of laparoscopy include: a) less postoperative pain, b) earlier patient's recovery and hospital discharge, c) reduced costs, d) earlier return to work or normal activity, and e) fewer complications [10].

- **Robotic Telesurgery.** In 2001 the first telesurgical operation (called the "Lindbergh Operation") was performed at a distance of 4,000 miles by a surgeon in New York, USA on a patient in Strasbourg, France. Using a satellite link to control remotely a surgical robot, the surgeon successfully removed the patient's gallbladder. This first telesurgery operation has demonstrated an enormous potential to expand the availability of surgical expertise to patients worldwide. On the other side, it has also clearly indicated that telesurgical technology needed to be improved with respect to tactile feedback, instrumentation, telecommunication speed and availability [12]. In addition, new challenges in telesurgery have been discovered in the domains of education, liability, legislation, health insurance, and costs.

Laparoscopy and robotic telesurgery require skills that are very different from the skills required in traditional surgical procedures. Surgeons accustomed to using the sense of touch have to learn to perform surgery using a video monitor instead of direct vision, how to compensate for reduced depth perception, and how to distinguish nearly identical-looking objects.

INFORMATION TECHNOLOGY IN SURGICAL EDUCATION

Information technology has become a critical component of initial and continuing medical education (CME) as well as daily surgeons' practice. According to a survey done by American College of Physicians [1], approximately 20% of physicians use computers for education. 41% of them prefer electronic formats (primarily, the Internet), 32% non-electronic, and 27% rated them the same. Electronic educational formats are preferred among physicians younger than 40. Although live meetings and courses still dominate CME, online education continues to grow in popularity. Traditional face-to-face courses and conferences accounted for 76% of the CME activities presented by the American Surgical Association (ACCME) accredited providers [2] in 2003, which is a decrease from 82% in 2002. Internet CME accounted for 12.5% in 2003, an increase of 92% since 2002. Table 1 presents the number of physicians who have participated in Internet-based CME since 1998.

Table 1. The number of physicians who participated in Internet-based CME

Year	1998	1999	2000	2001	2002	2003
Physicians	37,879	79,556	181,922	230,055	329,110	577,903

Online learning has changed medical education. The Internet has become an important force in how surgeons acquire knowledge, hands-on experience, and deliver care. A shift to increased use of online learning points to new demands for learners and providers. *Practice-based learning and improvement (PBLI)* has become increasingly important for surgery, and education providers need to introduce online tools for hands-on training and development of practical surgical skills into their programs.

The key steps in developing an effective surgical education Web site are as follows[3]:

- Perform a needs analysis and specify goals and objectives;
- Determine technical resources and requirements;

- Evaluate and use preexisting technologies;
- Secure commitment from all stakeholders;
- Identify and address potential barriers to implementation;
- Develop the course content and design the Web site combining multimedia, simulation, hyperlinks, and online communication;
- Encourage active learning (self-assessment, reflection, self–directed learning, problem-based learning, learner interaction, and feedback);
- Evaluate learners and courses;
- Pilot the Web site before full implementation;
- Monitor and maintain the Web site by resolving technical problems and updating content.

DISTANCE LEARNING SOLUTIONS FOR SURGEONS

Effective surgery education in a distance learning environment combines: 1) Virtual-reality simulators that represent real-time execution of various surgical procedures; 2) Broadband distance learning infrastructure that enables remote access to the learning environment.

1. Virtual-Reality Simulators

According to the relatively recent research conducted by Yale University and Queen's University Belfast [8], surgeons who trained on computer simulators performed the operation 29% faster and made seven times fewer errors. This research has also shown that all the participating surgeons, the beginners and even those with more than seven years experience, demonstrated a "significantly improved" performance with the added experience of training on the virtual reality simulator. The conclusion was that surgical simulators could be used both for initial training of new surgeons, and in CME programs for experienced surgeons, similar to the use of flight simulators for new and experienced airline pilots (to develop and/or maintain their flying skills). Virtual-reality surgical simulators provide numerous advantages over the traditional surgical education, as follows:

- No risk or inconvenience (pain, injury, side effects, etc.) to the patient, because no patient is involved in simulation.
- Simulation can be repeated unlimited number of times, any time and anywhere. The marginal increase of education costs with the increased simulation (training) time is negligible, as compared to the costs of the equivalent increase of the equivalent, traditional surgical training time.
- The overhead (in terms of time and resources) is minimal, since the learner does not need to wait for the operating room, for specific patients, specimens or instruments. In addition, the learner does not need to waste any time on the preparation procedures that are unavoidable in a real operating room environment.
- In simulation, the learner can gain experience in treating very rare and complex cases, while in traditional surgical education it may not be possible at all due to the low probability that such cases will be available at that time.
- Simulation environment is very similar to laparoscopy procedures, which provides the learner with hands-on experience in monitoring the operation on the screen, and controlling the manipulation of each surgical instrument that is positioned within the patient's body.
- Simulation-based surgical education programs may provide more uniform curricula, while at the same time the learners will gain hands-on experience with a very broad scope of medical cases and procedures.

Using virtual-reality simulation in surgical education, the following objectives can be achieved:

- **Accurate examination of specified medical cases/pathologies.** The learner's performance should be evaluated based on the accuracy of the diagnosis for the examined case, the preciseness of the learner's dexterity with instruments and the timeliness of the examination. Any "tissue damage" (in the simulated surgical environment) or other wrong or imprecise instrument manipulation should reduce the overall performance score.
- **Mastery of the specified surgical techniques or procedures.** The learner's performance should be evaluated using a checklist that includes all steps in the specified surgical technique or procedure, and the "weighted" scores associated with each step. A weight should be assigned to each step according to the importance of the step for the overall technique or procedure.
- **Automated, virtual-reality feedback to the learner.** Similar to traditional tests, where a learner can see the correct test results upon his/her taking the test, the learner using a virtual-reality simulator should be able to review how well he/she has performed the specified task (examination, technique or procedure), and what elements have been done incorrectly or not done at all. The simulator should also provide a review of the correct way to perform the specified task, and notify the learner whether he/she has completed the procedure in a timely manner.
- **Progress report.** The learner should be able to review his/her progress report for each simulation attempt, with a comparison to previous attempts, as well as with comparison to other learners in the program. Based on these progress reports, a comprehensive learner history log is created and updated automatically with each simulation attempt. This log should contain the number of successful attempts of specific surgical tasks, the number of hours spent in simulation training, and the most recent training date and time.

A virtual-reality surgical simulation system integrates the following:

- A high-resolution 3D graphics computer with a real-time visual simulation program (combining complex modeling systems and algorithms) – The learner can select different surgical procedures that he/she wants to practice from a remote location, while the simulator "leads" the learner through various scenarios that may occur during a surgery based on the decisions and actions that the learner makes throughout the process.
- Input peripherals to control the simulation – Similar to the corresponding real operating room scenario, the learner at a remote location uses specific surgical instruments and virtual-reality devices that serve as input peripherals to control the simulated surgical procedure.
- Output peripherals to display the outcomes of the simulation (based on advanced, high-resolution 3D computer graphics technologies) – Like in the corresponding real operating room scenario, the learner at a remote location monitors on the display the appearance and reactions of the simulated "patient's" body or a specific organ to the decisions and actions that the learner makes during the simulated surgical procedure.

1.a Modeling Systems and Algorithms

A critical component of surgical simulators is the surgeon's perception of the patient on the operating table. In general, surgical simulators should include

- Three-dimensional (3D) models of all human organs, displayed in the size and shape that corresponds to a specified patient's body measures;

- A 3D model of the overall human body, displayed in the size and shape that corresponds to a specified patient's body measures;
- Algorithms and programs that enable different presentations of human organs (from different angles, from inside or outside, with a different level of detail, etc.);
- Algorithms and programs that model the real-life reactions of organs to the interventions by various surgical instruments

Real-time, elastically deformable virtual organs and soft tissue [4, 6] represent a basis for haptic (tactile) surgical simulators. Although many techniques have been proposed for deformable object animation [4], so far only few have provided the performance necessary for real-time applications. For example, still in research is an eye simulator [6], which runs on a Windows XP workstation with a 1.0 GHz Pentium processor (or higher) and an OpenGL graphics accelerator (e.g. Nvidia Geforce). The simulator reads the learner's motions with instruments on the simulated "eye" model, modifies the shape and the reactions of the model accordingly, sends the updated graphical presentation of the eye to the display, and at the same time collects various metrics (learner's name, updated number of simulation attempts, time spent on the specified surgical procedure, instrument movements, tissue tears, and severe tear errors).

1.b Surgical Instruments and Virtual-Reality Devices

In order to control the simulation, surgical instruments and motion-tracking "virtual gloves" (5DT DataGlove) are used as an input system by surgeons in training [7]. This system records laparoscopic motions of the surgeon for learning and evaluation of his/her surgical skills.

1.c Computer Graphics Technologies

Surgical simulators rely heavily on realistic 3D imagery representing the patient's organ or tissue being "treated" in virtual reality by the learner. Most recent surgical simulators [5] were developed using MUopenGL toolkit (an object-oriented applications programming interface that calls OpenGL graphics library), running on a dual Pentium processor workstation with an Nvidia OpenGL graphics accelerator and Windows XP operating system.

2. Broadband Distance Learning Infrastructure

For successful implementation of surgical distance-learning programs, several critical requirements need to be fulfilled [11]:

- **Broadband Internet access to all learners.** The majority of applications require interactive, multimedia content to be transferred between each learner and the university's distance learning servers. The minimum data rate should be 384 Kbps.
- **University Local Area Network (LAN).** A 100BASE-T Ethernet is recommended assuming combined voice, text, graphics and video data transfer among a large number of workstations. This LAN would ensure net data rates of up to 10 MBps.
- **Large database systems.** In general, multimedia applications demand very large (order of several GBytes) memory space. In simulation-based surgical education, the resolution of the graphical content needs to be relatively high (640 x 480 x 24-bit, or at least 320 x 240 x 24-bit) in order to ensure the accuracy of the surgical training.

VIRTUAL SURGICAL UNIVERSITIES

In the last decade, numerous schools of medicine have introduced surgical tutorials, tests and case studies in an electronic form, either on the Internet or on CDs. However, only in the last couple of years have some surgical education programs started to use virtual-reality simulation of various surgical procedures. One of the leaders in online laparoscopy training is WebSurg [14], a virtual surgical university accessible from anywhere in the world through the Internet. The WebSurg project was launched at the European Institute of TeleSurgery (EITS) in Strasbourg, France, in collaboration with University of Virginia. The goal of this project is to provide online training in laparoscopic surgery worldwide, including diagnosis, standards of pre- and post-operative patient care, and practical surgical procedures.

Millersville and Penn State Universities have teamed up to develop a software suite for training and testing of surgical skills using a virtual reality surgical simulator with a sensitive touch (haptic) feedback and realistic 3D imagery. University of California has also developed a virtual surgical simulator for training perceptual motor skills, spatial skills, and critical steps of surgical procedures, with the goal to eliminate laparoscopy-caused injuries that presently occur at a relatively high rate (2.2%) if procedures are performed by inexperienced laparoscopic surgeons.

CONCLUSIONS

This paper highlights the most recent trends and challenges related to distance learning of surgery. In addition to general distance learning concepts, infrastructure and practices, surgery education requires specific technological provisions in order to ensure the mandatory level of quality. These provisions include: a) a broadband Internet access; b) a diverse set of simulators for various surgical disciplines (e.g. abdominal, endocrine, urological surgery); c) high-resolution, 3D workstations with large memory space and high processing power; d) virtual-reality input peripherals; e) a comprehensive feedback and skills evaluation system.

So far, virtual reality surgical simulators have not been widely used in schools of medicine, but it is only a matter of time when they will be adopted as effective practical training tools for surgeons. After using these simulators in training, surgeons will be more efficient, accurate and thorough when operating on real patients. In addition, they will make less mistakes and injuries to the patients, and the overall examination time will be shorter.

Future trends in the area of distance learning programs for surgery include the following:

a) Integration of individual, specialized research projects into a comprehensive, world-wide, virtual knowledge base for various areas of surgery and telesurgery, consisting of virtual-reality simulators, text documents, videos, case studies, expert surgeons' opinions, and relevant references. For example, a learner may decide to attend an online course in Emergency Surgery, where a suite of online, virtual-reality simulators will be available to practice the following procedures: peritonitis, appendectomy, small bowel obstruction and perforated ulcer.

b) Building a comprehensive virtual knowledge base for rare medical cases collected around the world, along with recommended surgical procedures – Among major advantages of simulators in general is their ability to generate rare scenarios and cases of the simulated phenomenon or process. Likewise, surgical simulators will enable learners to practice unlimited number of times certain rare procedures and scenarios that they may never have a chance to do in traditional training, in a real operating room.

c) Further technological advances in the area of virtual-reality simulators for hands-on training in all surgical fields – Current technological efforts are focused on increase in the processing power, increase in memory space and efficient access to critical data, improvement in algorithms for 3D manipulation, deformable object modeling and evaluation of surgical procedures performed on the simulator.

d) Building a worldwide surgical community, which will accelerate the accumulation and sharing of the latest surgical breakthroughs and technological advances throughout the world.

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