Medicine Meets Virtual Reality 2000
J.D. Westwood et al. (Eds)
IOS Press, 2000

A Prototype Haptic Lumbar Puncture Simulator

Paul Gorman[1], Thomas Krummel[1], Roger Webster[2], Monica Smith[2], David Hutchens[2]

[1]*Department of Surgery*
School of Medicine
Stanford University
Stanford, CA. USA 94305-5655

[2]*Department of Computer Science*
School of Science and Mathematics
Millersville University of Pennsylvania
Millersville, PA. USA 17551

Abstract. Lumbar punctures (LP) are complex, precise procedures done to obtain cerebro-spinal fluid from a patient for diagnostic purposes. Incorrect techniques resulting from inadequate training or supervision can result in sub-optimal outcomes. As tactile feedback is crucial for a successful lumbar puncture, this procedure serves as an ideal candidate for the development of a haptic training simulator. The intent of this project is to engineer a force feedback LP simulator that provides a safe method of training students (medical students, residents, or trained physicians) for an actual LP procedure on a patient.

1. Introduction.

The lumbar puncture (LP) procedure is extremely complex and requires precision on the part of the administering physician. The lumbar needle must be inserted between the vertebral bones of the lower back and into the fluid filled spinal canal with great care. Currently, LP's are taught in medical school by the apprenticeship method, in which the student gains experience by performing the procedure on a real patient. A trained physician/teacher stands by and instructs medical students as they perform the procedure. Although many excellent physicians have learned through this method, it has drawbacks that affect both the patient and the medical student. The disadvantages for the patient are obvious. The patient is forced to absorb the errors of the medical student, which could result in unnecessary pain, tissue damage, or injury. The possibility of incorrectly performing the procedure and causing harm can be stressful for the student, and may lead to increased anxiety or error generation. Another drawback to the apprenticeship model is that the medical students must wait for the availability of a patient in need of an LP before they can attempt to improve their technique.

Researchers ([1], [2], [3]) have attempted to solve some of the problems that arise in the development of a force feedback LP simulator, though no one has developed a readily available and usable device. The intent of this project is to develop a haptic LP simulator that is effective, not cost prohibitive, relatively simple to maintain, and truly usable. Using our system, a medical student inserts an actual lumbar puncture needle through a life-size human mannequin torso (Figure 1). The needle is attached to the haptic device, which provides force feedback. The student can practice the procedure at any time without the fear and anxiety of performing an LP on a real patient. The LP procedure is a good candidate for a haptic training simulator because physicians rely almost entirely on tactile feedback to perform the LP procedure.

Figure 1. A lumbar puncture needle (attached to the haptic device) is passed through a human mannequin torso.

2. Hardware.

The haptic device used is the Sensable Technologies Phantom 1.5 Desktop unit. The Phantom provides force feedback so students can actually feel the resistant forces on a correct, and more importantly, an incorrect trajectory (i.e. collision with bone). The development computer is a Windows NT personal computer with dual 500 MHz Pentium III processors and the Wildcat 4000 OpenGL accelerator. The software should run adequately on a single 450 MHz Pentium system with moderate OpenGL graphics acceleration.

3. Modeling and Software.

The virtual needle, spinal column (from L1 to the sacrum), and spinal canal area three dimensional (3D) models are stored as virtual reality markup language (vrml) files. The models are loaded into the simulation (both in graphics and in haptics). During program debugging the vrml models of the virtual needle, spinal canal, and lumbar spine are shown to illustrate how the needle is being inserted (Figure 2). Six tissue layers are modeled: skin, dermis, subcutaneous tissue, muscle, ligamentum flavum, and the dura mater. Each layer is modeled as a thin haptic box with appropriate force vector calculations. The resistant force calculations vary depending upon the material in the layer model, the depth of insertion, and the insertion angle of the needle. The forces also change when the needle is initially inserted or punctures through the skin. If the needle contacts bone, the student experiences stiffer resistant forces. The vrml spine model is loaded into haptics as a very stiff object. At each haptic layer, the student feels the surface friction, puncture force, internal friction, and damping. These force parameters can be changed interactively via slider bars by the software developer. This has helped in program debugging to determine the appropriate forces to exert at each layer. The haptics software modules make calls to the General Haptic Software Toolkit (GHOST) development kit from Sensable Technologies. The graphics modules make calls to EAI/Sense8's WorldToolkit API of OpenGL calls.

The 3D graphic representation can also be used to replay the insertion technique, showing the medical student what he/she did during the training session. A software module records the motions of the user (positions and orientations of the Phantom encoders). After the simulated procedure is complete, the user can then play back what he/she did and review, on the monitor, what happened internally. This learning feature is not available to the student involved in the LP of an actual patient, and may help students improve their technique.

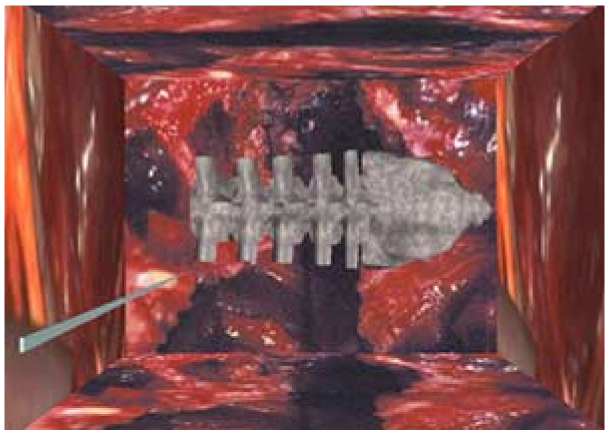

Figure 2. Graphics window showing vrml 3D-spine model (from L1 to sacrum).

4. Conclusion.

The necessity of simulating the lumbar puncture procedure is best seen in real life experiences. An Internet discussion group offers personal experiences of LPs. Glenn [5] recounts his experience of having a lumbar puncture performed on him: "I was a guinea pig for an up and coming physician's assistant student that was being taught the procedure by my former doctor." The student made an error, and Glenn "jumped 5 feet off the table; turns out she probed into my spinal chord, which immediately set my left side on fire and left it numb for hours after." Glenn's experience shows how important it is for medical students to have experience with the LP procedure before they attempt to perform it on an actual patient.

Initial work and results with the haptic LP simulator are encouraging. Actual LP needles are passed through a human mannequin torso attached to the haptic device as the graphics are displayed and updated in real-time. Although somewhat realistic tactile force feedback is provided to the learner, we are currently still experimenting with the haptic programming issues of surface friction, internal friction, damping, resistant forces, and angular collisions with our models of bone, skin, tissue, and fluid. As of yet, no scoring mechanism exists to measure and track performance for this system (currently being developed). This mechanism will keep track of the number of times and degrees to which the user diverted from the desired path. It will also record the amount of time it took to complete the procedure. A numeric score will be displayed for the user upon completion of the simulation.

Ongoing development is focused upon providing users accurate feedback and added functions to alter the virtual anatomy. The goal is to provide a valid, efficient, and safe method to learn the LP procedure. Future work on this simulator includes the ability to select different body types of the virtual patient. For example, the simulator could have an option that would allow the user to set the thickness of fatty tissue of the virtual patient, increasing the student's ability to perform the procedure on different body types. This functionality may make the simulator more versatile, allowing students to use one simulator to practice their technique on a variety of virtual patients.

Acknowledgements.

This project was funded, in part, by the National Science Foundation under grant numbers DUE-9651237 and DUE-9950742, and by the Faculty Grants Committee of Millersville University.

References.

[1] Kevin Cleary, C. Lathan. *"Surgical Simulation: Research Review, Computing Challenges, and Spine Biopsy Simulator*", Parallel Computing, 1997, pps. 1-15.

[2] Sunil Singh, M. Bostrom, D. Popa, C. Wiley, "*Design of an Interactive Lumbar Puncture Simulator with Tactile Feedback*", Proceedings of Robot and Human Communication, ROMAN '93, pps. 156-159.

[3] Sunil Singh, M. Bostrum, D. Popa, C. Wiley, *"Design of an Interactive Lumbar Puncture Simulator with Tactile Feedback*", Proceedings of IEEE International Conference on Robotics and Automation, 1994, pps.1734-1752.

[4] Paul Gorman, J. Lieser, W. Murray, R. Haluck, T. Krummel. "*Assessment and Validation of a Force Feedback Virtual Reality Based Surgical Simulator*", In the Proceedings of the Third PHANToM Users Group Workshop, Cambridge, Massachusetts, 1998.

[5] "*Puncture Experience(s).*" World Wide Web Site: http://neuro-www.mgh.harvard.edu/forum/MultipleScleros/PunctureExeriences.html.