SIMULATION-BASED MILITARY REGIONAL ANESTHESIA TRAINING SYSTEM

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ABSTRCT

Deployed American troops suffering injuries to the extremities are best treated with regional anesthesia, which renders only a portion of the body, such as a limb, insensate. However, it is possible for long-lasting damage to occur when regional anesthesia is improperly applied. Though nerve block procedures present fairly low risk in a hospital setting, the same may not be true on the battlefield—where severe trauma cases are prevalent and fellowship trained pain management specialists are not always available. There is a need for all military anesthesiologists to undergo training for the administration of peripheral nerve blocks, yet currently no suitable mass training curriculum or training system exists. The training system must be accurate, intuitive, and convenient. Under contract with the Telemedicine & Advanced Technology Research Center (TATRC), Energid Technologies is developing such a training system. It includes instructional content in a standard, configurable framework, and immersive simulation of procedures to reinforce the instructional content.

1. INTRODUCTION

The majority of casualties in recent military operations were superficial wounds or wounds to the extremities (Trunkey, 1983; Rush et al., 2007). This was partly due to the advent of body armor—which reliably protects soldiers' vital organs but leaves their limbs exposed. These types of wounds are well suited to treatment using regional anesthesia, with brings with it a host of advantages over general anesthesia. As such, regional anesthesia management (such as administering peripheral nerve blocks) has become a critical part of combat casualty care. Unfortunately, adequate training for such procedures is currently lacking.

Over the past decade, the utilization of peripheral nerve blocks for both intraoperative and postoperative analgesia, or pain control, has become increasingly popular. A peripheral nerve block renders a portion of the body, typically a limb, insensate and weak for a temporary period of time, which allows for 'painless surgery' and an extended period of pain relief afterward. Nerve blocks have been associated with faster hospital discharge in the ambulatory surgery setting, a reduction in the postoperative usage of parenteral narcotics, and a potential improvement in patient functional recovery. The placement of an indwelling perineural or peripheral nerve catheter and continuous infusion of local anesthetics through the catheter allows for further extension of the pain-free period, and has been successfully employed in both inpatient and outpatient settings.

Though nerve block procedures present a fairly low risk in a hospital setting, the same may not be true on the battlefield—where severe trauma cases are prevalent and properly trained pain management specialists are at a premium. In fact, although anesthesia residents are required to complete a minimal number of regional anesthesia procedures in order to qualify for board certification, there is no "certificate of regional anesthesia" to prove competency. There is a need for all military anesthesiologists to undergo such training, yet, currently no suitable curriculum or training system exists.

What is needed is a training system that teaches all aspects of regional anesthesia. A system that not only includes didactic content and an instructional framework, but also allows the anesthesiologist to practice in a virtual environment—with visual, haptic, and auditory feedback. And since the trainer needs to be accessible to all applicable medical personnel (wherever they might be stationed), it should be small, rugged and portable.

The virtual regional anesthesiology training simulation system described in this paper is a cutting-edge anesthesiology simulator and training system. It can be used for numerous training applications, such as training anesthesiology residents, practice with new technology or instruments, rehearsing anesthetic emergencies, and possibly future testing, certification, or recertification of anesthesiologists (Meislin, et al., 1997).

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We have been developing a realistic regional anesthesia training simulator. The main goal of our regional anesthesia training simulator is to create a natural, immersive virtual environment unlike any developed before, incorporating haptic, visual and auditory feedback. Both stimulator-based and ultrasound imaging guided regional anesthesia procedures are simulated in the training system. The innovative devices capable of generating haptic feedback during needle insertion, needle injection and palpation can be applied through a modular design for various procedures and curriculums. The simulation system provides initial training for students, as well as continuity training for seasoned anesthesiologists requiring ongoing training for procedures that require significant technical skill. Our design is configured using the Extensible Markup Language (XML). Each of the modules and systems shown in Fig. 1 can be exchanged through XML. The design is well suited to interface with SCORM-compliant contents (Sharable Content Object Reference Model at www.adlnet.gov/scorm/index.cfm).

Fig. 1: Core training modules and systems.

2. CORE TRAINING MODULES

Energid's regional anesthesia simulation (RAS) system includes four core training modules:

1) Didactic Trainer,
2) Anatomy Viewer,
3) Technique Trainer, and
4) Scenario-Based Trainer.

These four components will together provide trainers with a comprehensive and effective training for teaching nerve block procedures.

2.1 Didactic Trainer

The design of this module is centered on a SCORM - compliant core for authoring and delivering training content. The interactive SCORM-compliant didactic instructional trainer facilitates the development of reusable learning content within a common technical framework. The instructional narrative component of the training system will graphically, textually, and verbally describe the procedure from beginning to end. Students are able to cycle through the pages describing the block. Fig. 2 below shows an example of the introductory content for an femoral nerve block procedure.

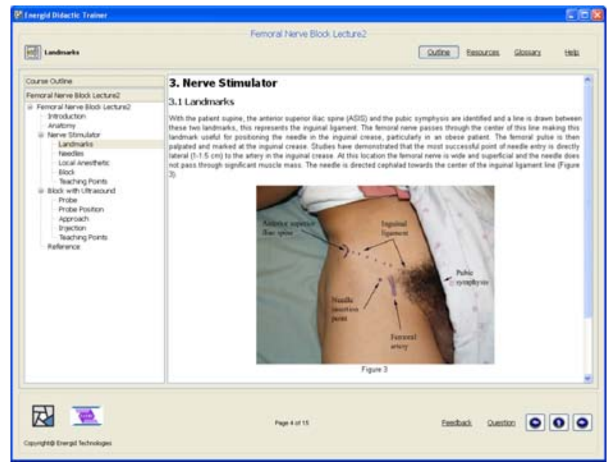


Fig. 2: Didactic Instructional Trainer; an interactive user interface for an anesthesia procedure.

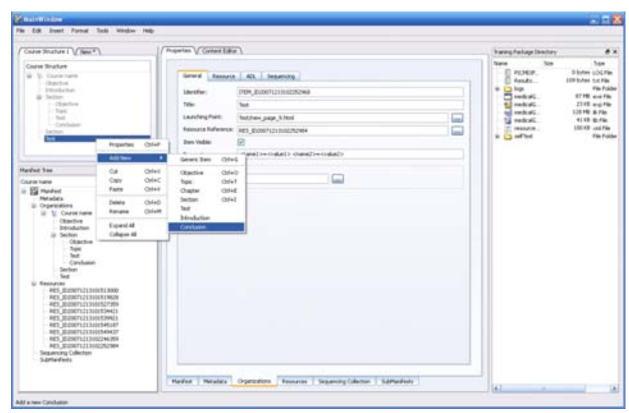


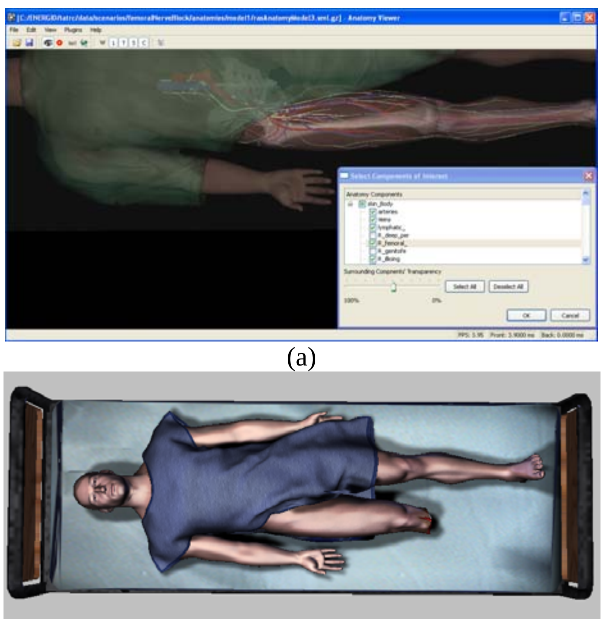
Fig. 3: SCORM-based authoring tool.

Energid has developed a SCORM Authoring tool to compose training packages in the form of a Reusable Learning Object (RLO). This tool can currently be used to create and edit SCORM packages where training contents consists of HTML text, images, and video clips.

We create an ***easy-to-use approach*** that allows the Medical Content Authors (MCAs) with little or advanced knowledge on the SCORM to author RLOs. Our approach is a content-based method in which the user first focuses on developing course content and structure using a wizard-like GUI (Graphic User Interface). The subsequent optional steps are creating and organizing resources (e.g. html files, images, videos etc.) that support the content and structure. We also support course structure templates and HTML templates for rapid training package development. Once the MCA selects a course template, the wizard allows the user to select a predefined HTML template that represents the presentation of a training page. A GUI will display the selected course structure (see Fig. 3) and allow the MCA to edit the content and structure. This will be done using a Resource Editor and Activity Editor.

2.2 Anatomy Trainer

The anatomy viewer allows trainees to explore richly detailed anatomy in a 3D graphical environment while selecting anatomical features of interest for visual enhancement. Users can view anatomical structures from any perspective, and create ‘flythroughs’. The Anatomy Selector Dialog traverses the model and creates a tree of anatomy components (see Fig. 4). The user may select a group of anatomical features (e.g. the nervous system) or sub-regions for display. A transparency level can be specified for non-selected components which helps highlight the structure of interest. The Anatomy Viewer also allows the user to zoom in and zoom out of the 3D model and adjust the 3D model’s position and view angle.



(a)

(b)

Fig. 4: Anatomy Viewer. (a) A 3D patient model shown with a transparency level specified by the user through the anatomy selector and (b) a patient model with a mangled lower extremity.

2.3 Technique Trainer

The technique trainer is used to practice specific techniques within the simulator. The user can select a particular technique within the selected procedure. One component of the trainer, for example with the Magneto-Rheological (MR) - fluid based haptic device (discussed in section 3.1), allows for simulated practice of specific operative techniques, specifically needle insertion and syringe injection (Lim, 2008). An additional embedded in our trainer is the performance measurement that assesses the user’s Task Performance Levels (TPLs). Fig. 5 shows the needle insertion trainer session through the technique trainer GUI.

Fig. 5: Technique Trainer.

2.4 Scenario-Based Trainer

Scenario-based simulation has the potential to revolutionize surgical training. Training with scenarios will result in better performance than general training in a variety of manual skills (Noble, 1970). Another obvious supporting argument for scenario-based training is the issue of developing surgical judgment, that is, clinical decision making. Energid’s scenario-based trainer takes students through an entire simulated procedure from start to finish, allowing for multiple paths to completion with both common and rare complications built in. The authoring tool also allows for creation of new scenarios. Decision making is scored providing direct feedback to students about the appropriateness of their choices. Fig. 6 presents the scenario-based trainer GUI design. The GUI design include better training content outline, image scaling, vital sign display and Q&A selection and display.

Fig. 6: Scenario-Based Trainer.

3. NOVEL SKILL TRAINERS

The Energid RAS trainer includes innovative devices capable of generating haptic feedback during needle insertion, injection and palpation through MR fluid control and tactile display systems - controllable actuator arrays - enhanced with the development of modular software and algorithms, configurable procedures and scenarios, and integrated training modules. Anesthesiologists will hold and manipulate tools, interact visually with the virtual patient model and simulated ultrasound images, and interact verbally with patients, just as they would in a real procedure.

3.1 MR Haptic Device

MR fluid is a type of controllable "smart material" whose rheological properties may be rapidly varied by the application of a magnetic field (Magneto-Rheological Technology at http://www.lord.com). This interesting property has brought the possibility to use the MR fluid to develop haptic devices (Scilingo, et al., 2003; Li, et al., 2004; Liu, et al., 2006).

In this research, we develop a pair of MR fluid based haptic systems for simulating needle insertion and syringe injection procedures. We use the essential characteristic of MR fluid, a controllable yield strength (changeable in milliseconds under a magnetic field), to impose simulated forces on a nerve block needle used in regional anesthesia procedures. We employ our customized needle tracking algorithm to determine the position and orientation of the needle.

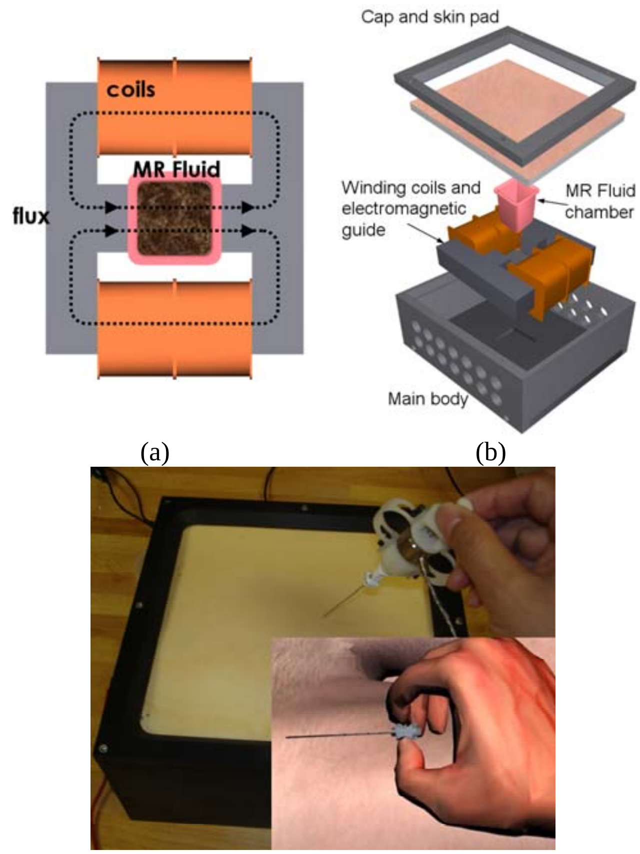
- *MR fluid-based Needle Insertion Haptic Device*

The haptic system for needle insertion consists of an electromagnetic field winding and an MR fluid chamber. (see Fig. 7) By controlling the magnetic field strength inside of the MR fluid chamber, the viscosity of the MR fluid can be changed in such a way that the needle resistive force is created mimicking the actual muscle/tissue viscosity of the human body. Hence, the controllable haptic feedback is generated in the system. The performance of the MR fluid haptic system may be determined by the MR fluid (the base density and viscosity) and winding unit (the strength of magnetic field).

- *MR fluid-based Syringe Injection Haptic Device*

Anesthesiologists normally rely on a subjective evaluation of possible abnormal resistance to injection while performing a nerve block. A greater force required to perform the injection is believed to associate with intraneural injection. Therefore, simulation of the syringe injection process with controllable pressure is crucial to nerve block procedures in order to properly train pain management specialists.

For simulation of the syringe injection process, a regular syringe is filled with MR fluid. By controlling the intensity of the electromagnetic field composing an electromagnetic field winding the viscosity of the MR fluid can be controlled in a way that mimics syringe injection force. The needle injection flow speed is determined by the regional anesthesia procedure being simulated and the tissue models involved in the procedure.



(c)

Fig. 7: MR fluid-based needle insertion Haptic device; (a) An illustration of the flux flow, (b) the exploded system components, (c) the MR haptic device with a force sensor.

3.2 Tactile Palpation Device

The tactile understanding of anatomy is of enormous importance during nerve block procedures. This calls for the development of a novel tactile feedback technology to locate anatomic structures with palpation. A well-designed palpation haptic device can improve the trainee's interactive perception of the patient's anatomy structure. Energid's tactile palpation device aims to achieve high fidelity tactile feedback through a configurable platform.

Devices for tactile display systems we are developing employ arrays of independently controllable actuator elements that are able to exert forces in normal direction to the user's skin surface. By adequate control of the actuators, an impression, similar to the direct touch of an object, can be artificially generated.

As shown in Fig. 8, the main components in this system are a high-density pin array, a deformable skin layer to mimic virtual human model, a positioning system, and an actuator to reconfigure skin profiles by precisely controlling the pin array. The advantage of this design is that it can mimic touch sensing of virtual objects in a high resolution, high fidelity and high force level that conventional haptic systems lack.

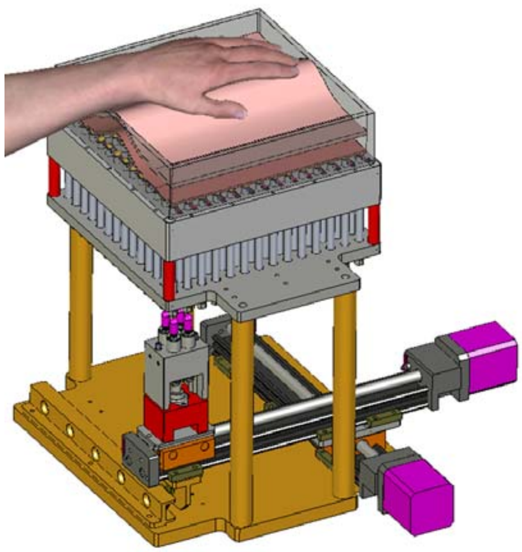


Fig. 8: A prototype design of a tactile palpation device.

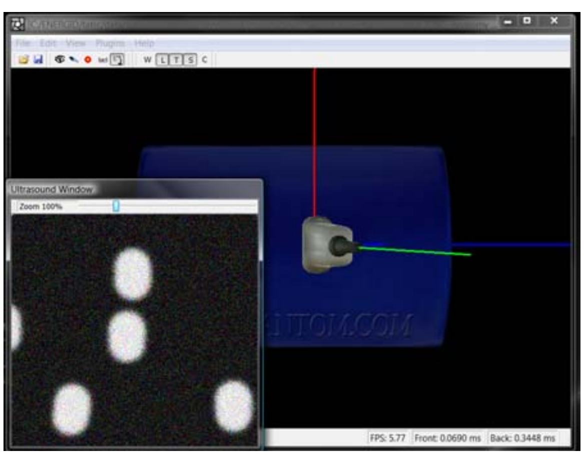


Fig. 9: A synthetic ultrasound image

3.3 Simulated Ultrasound Image Guided Nerve Block

With the aim of verifying the block and increasing the corresponding success rate, the use of ultrasound (US) has produced a significant improvement of nerve detection under direct visualization (Peterson, et al., 2002). Flexible and real-time image acquisition requires that ultrasound imaging be able to translate and rotate without restriction. One of the important objectives of the anesthesia training system is to provide virtual ultrasound images from the transducers at arbitrary locations and angles. We employ an interactive clipping plane algorithm to create dynamic cross sections of anatomy structures on the ultrasound scan plane with a synthetic noise processor and Blob analysis algorithm (see Fig. 9). The simulated ultrasound image is rendered graphically on the display based on the probe position and angle.

4. RESULTS

Energid's regional anesthesia simulation system delivers the total integrated spectrum of medical training modalities, including didactic instructional course, anatomy viewer, technique trainer, and scenario-based trainer. Our system modules have achieved reusability and interoperability by the SCORM specification. The SCORM-compliant didactic trainer browses didactic curriculum which embed text, images, and video clips. The SCORM-based authoring tool allows instructor to develop and edit training contents.

Energid develop a pair of MR fluid based haptic systems for providing accurate haptic feedback for needle insertion and needle injection. The MR haptic systems will provide accurate haptic feedback and help the trainee effectively learn the psychomotor skills necessary for regional anesthesia procedures. A novel tactile palpation device will provide touch sensing of virtual objects in a high resolution, high fidelity and high force level that conventional haptic systems lack. The use of ultrasound guidance offers significant benefits to perform regional nerve blocks. The simulated ultrasound image guides simulation is integrated into our comprehensive training system. A schematic illustration of the RAS system for the nerve block is shown in Fig. 10 below.

5. CONCLUSIONS

Energid Technologies made great strides toward our goal of creating a comprehensive, state-of-the-art regional anesthesia simulation system. Through a modular design and innovative components, such as the anesthesia training modules, the palpation haptic feedback device, the MR-fluid based needle insertion devices, and the simulated ultrasound image-guided training module, our system will support multiple training procedures and will be particularly beneficial to battlefield regional anesthesia training. The RAS training system uses a natural, immersive virtual environment, incorporating haptic, visual and auditory feedback in the simulation.

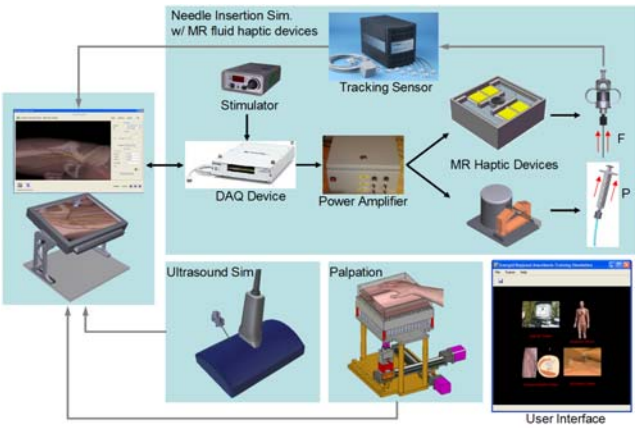


Fig. 10: An illustration of system integration.

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