Augmented Reality Needle Guidance Improves Facet Joint Injection Training

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ABSTRACT

PURPOSE: The purpose of this study was to determine if medical trainees would benefit from augmented reality image overlay and laser guidance in learning how to set the correct orientation of a needle for percutaneous facet joint injection. METHODS: A total of 28 medical students were randomized into two groups: (1) The Overlay group received a training session of four insertions with image and laser guidance followed by two insertions with laser overlay only; (2) The Control group was trained by carrying out six freehand insertions. After the training session, needle trajectories of two facet joint injections without any guidance were recorded by an electromagnetic tracker and were analyzed. Number of successful needle placements, distance covered by needle tip inside the phantom and procedural time were measured to evaluate performance. RESULTS: Number of successful placements was significantly higher in the Overlay group compared to the Control group (85.7% vs. 57.1%, p = 0.038). Procedure time and distance covered inside phantom have both been found to be less in the Overlay group, although not significantly. CONCLUSION: Training with augmented reality image overlay and laser guidance improves the accuracy of facet joint injections in medical students learning image-guided facet joint needle placement.

Keywords: Enhanced reality, Surgical simulation, Surgical modeling

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1. INTRODUCTION

1.1 Surgical simulation

Surgical simulation offers a safe environment within which learners can repeatedly practice a range of skills without endangering patients. Simulation-based educational programs are being widely implemented in medical training due to increased patient awareness regarding medical errors and patient safety, funding restrictions, and cuts in the maximum residency hours[1]. Simulation also allows the evaluation of the trainees' skills before they are allowed to perform certain surgical procedures on real patients.

1.2 Augmented reality

Augmented reality (AR) is the supplementation of the physical environment with computer-generated imagery. AR is most commonly used in the medical field for providing guidance to improve the precision of surgical techniques. The variety of technologies keeps growing to support various situations in the operating room with helpful visual information from the enhanced visibility of a tumor to textual patient history. AR usually requires expensive equipment; therefore, it is still unlikely that it will become part of widely spread surgical protocols. As an alternative, it might be used in medical training centers to support trainees in their early phase of education. The longer term benefit of AR enhanced training on surgical skills is a field that still leaves much space for research.

1.3 The simulated surgical procedure

Lumbar facet joint degeneration is a condition tied to degeneration of the intervertebral discs, and is considered a significant source of back pain. While MR imaging is widely employed in the evaluation of disc degeneration, there currently is no consensus on how best to evaluate lumbar facet joint arthrosis radiographically[2]. The difficulty in diagnosing facet-mediated pain leaves controlled, diagnostic nerve blocks as the only means of making a diagnosis[3]. One way these blocks can be accomplished is by intra-articular injection of an anesthetic agent. This percutaneous procedure requires precise placement of the needle tip into the facet joint, prior to the injection of the anesthetic agent. Surface landmarks can be used to identify the appropriate skin puncture site, but determining the entry angle of the needle and maintaining that angle during the insertion of the needle is a challenge for new learners. AR image overlay and laser guidance may be options for helping students learn the correct needle trajectory. In the current common clinical practice, operators perform image guided facet joint injections by looking at the CT image of the target area, and mentally translate this image to the physical position of the target area in the patient. AR image overlay provides trainees with the visual result of this translation. We hypothesize, that having access to the image overlay and laser guidance in the training phase, helps trainees visualize their target when they face the real clinical environment, where the image is at a different physical location compared to the patient.

1.4 Objectives

The purpose of this study was to determine if medical trainees would benefit from image overlay AR and laser guidance in learning the correct orientation of a needle for simulated percutaneous facet joint injection. Therefore, we have trained one group of volunteers with image overlay, and a control group with conventional method. After the training session, their performances have been evaluated on simulated facet joint injection procedures.

2. METHODS

2.1 Study subjects

Medical students, inexperienced in image-guided or intra-articular needle insertions, were trained during our experiments, and their performance was assessed after training. Signed consent of voluntary enrollment was obtained from each student, and the study protocol was approved by the Queen’s University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board.

2.2 Tools used in the study

Experiments were carried out using the PerkStation[4] hardware and software system. This training suite comprises of an AR image overlay system, two laser planes for laser guidance, and a platform for phantoms to perform surgical procedures on. The target phantom was made of a hard plastic model of two vertebras with a facet joint between them, placed in soft plastic gel, which mimicked soft tissue. An additional firm layer of gel was molded on the upper surface of the soft tissue layer in place of the skin. The phantom, except for the bone part, was transparent. The side facing the trainee was covered to mimic a live scenario, while the opposite side was left open for the observer to be able to see the needle position within the phantom. The distance from the surface of the skin to the entrance of the facet joint was 37mm.

The same needle was used in all experiments. It was equipped with an electromagnetic position sensor, which was tracked by a NDI Aurora (Northern Digital Inc., Waterloo, ON, Canada) electromagnetic measurement system. The position and orientation of the needle was recorded into files in XML format at a rate of 10 samples/s. The observer of the experiment also annotated the recordings by manually pressing buttons on the recording software interface for each surgical gesture (entering the phantom, insertion, retraction, angle adjustment, releasing the needle) to facilitate the evaluation process (Figure 1).

2.3 Software used in the study

Needle tracking was implemented by two software layers. IGSTK was used to read the input from the tracker hardware, and broadcast the position and orientation of the needle sensor on the computer network. IGSTK provides an abstraction over different hardware, and implements a uniform communication protocol for other applications[5]. The output of IGSTK was read by the OpenIGTLink module of 3D Slicer, which provides a framework for calibration and visualization of tracked tools[6]. 3D Slicer is a free, open source software package designed for the analysis of medical image data. Real time text annotations were inserted into the recorded needle trajectories by a 3D Slicer software module, developed by our group for this experiment.

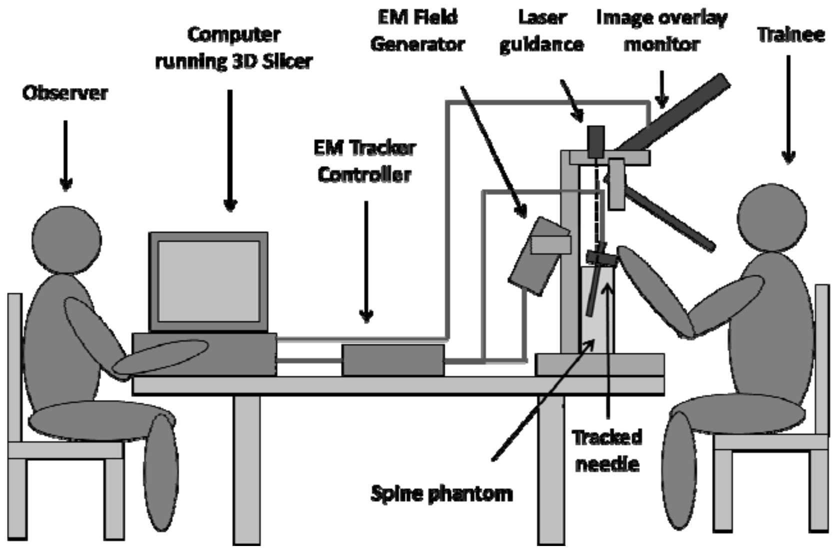

Figure 1. Experiment setup of the Perk Station with electromagnetic needle tracking.

To evaluate the recordings, a new software module (PerkProcedureEvaluator) was developed for 3D Slicer. After reading the XML files, the evaluator module can measure the time spent on each surgical gesture and the path length of the needle tip when the needle was inside the phantom. A 3D display with the virtual model of the needle, the phantom, and the CT scan of the phantom ensures that gestures are annotated correctly (Figure 2). Since electromagnetic position tracking has an uncertainty comparable in magnitude to the target area, we evaluated success of the injection by visual inspection of the phantom, and not from the recorded tracking information.

2.4 Study protocol

Enrolled trainee subjects were instructed on the procedure of facet joint injection, the anatomy, and the simulation environment to be used. They could take as much time as they required to perform the injections. The primary goal of the procedure was instructed to be the successful placement of the needle tip into the facet joint, with minimal potential soft tissue damage.

During each insertion, once the trainees felt that the needle was in the correct position, they were given feedback on the success or failure of the insertion. This was given in place of a confirmation image of the real clinical environment.

A total of 28 volunteers were randomized into two groups of 14: (1) The Overlay group received a training session of four insertions with image and laser overlay followed by two insertions with laser overlay only; (2) The Control group was trained by six freehand insertions. After the training session, the skills in both groups were evaluated by two freehand (without image overlay or laser guidance) needle insertions.

2.5 Statistical methods

The number of successful needle placements into the facet joint was evaluated visually by the observer during the needle insertion procedures, and statistically compared between the two groups using the Mann-Whitney test. Procedure time and distance covered by the needle tip inside the phantom during the last needle insertion was analyzed by independent sample T-test.

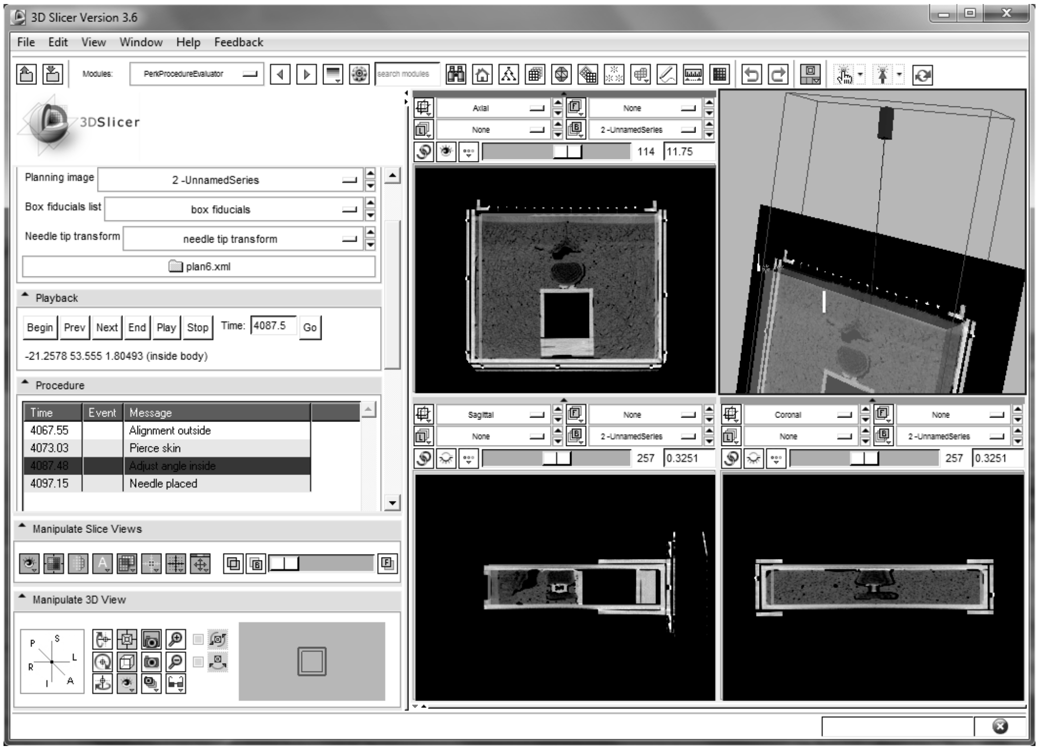

Figure 2. Software module (PerkProcedureEvaluator) running in 3D Slicer to evaluate recorded surgical gestures.

3. RESULTS

The number of successful placements was significantly higher in the Overlay group, compared to the Control group (85.7% vs. 57.1%, p=0.038). See Figure 3 for the number of subjects in each group who successfully inserted 2, 1, and 0 needles, out of 2 attempts in the assessment session.

Total procedure time, time spent inside the phantom, and distance covered inside the phantom are shown for each group in Table 1, along with the results of the statistical comparison between groups. Neither total procedure time, nor time spent inside the phantom was found to be different between the two groups. The distance covered by needle tip, which would be the analogue of potential soft tissue damage in a real patient, was mildly reduced in the Overlay group (207.1 ±175.8 vs. 297.8 ±227.9, p=0.24).

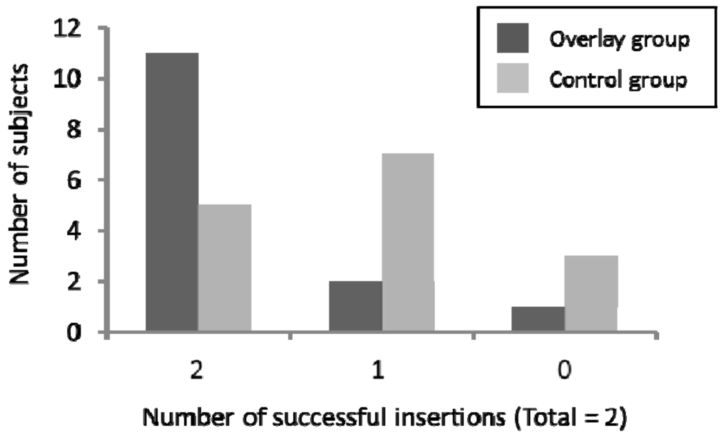

Figure 3. Number of subjects, who successfully inserted 2, 1 or 0 needles, out of 2 attempts in the assessment session, in both Overlay (dark gray, n=14) and Control (light gray, n=14) groups.

Parameter	Overlay Group (n = 14)	Control Group (n = 14)	Student's T-test
Total procedure time (s ±SD)	48.9 ±44.4	53.9 ±44.3	p = 0.76
Time spent inside phantom (s ±SD)	29.2 ±24.7	31.3 ±22.4	p = 0.80
Distance covered inside phantom (mm ±SD)	207.1 ±175.8	297.8 ±227.9	p = 0.24

Table 1. Time and covered distance parameters measured automatically on procedure recordings.

4. DISCUSSION

The main finding of the this experiment is that trainees who were provided with AR image overlay and laser guidance in their early phase of training performed with more success on the simulated freehand needle insertions than those trained with the conventional freehand method. Therefore, it is likely that this augmented reality training method would decrease the amount of practice required for medical students to become eligible for real patient procedures, or to master a new surgical technique.

Time required to perform the procedure, and time spent with the needle inside the phantom until the final needle position was reached did not differ significantly between the two experiment groups. However, the amount of needle motion by participants in the Overlay group is considerably less than what we observed in the Control group. This, and our visual observations suggest that image overlay and laser guidance enables more straightforward gestures, while the freehand method requires more probing with the needle to find the target joint. Apparently, this beneficial skill is retained in the trainees even when the guidance is taken away from them and they face the conventional freehand method. In this way, AR provides additional value in the training process over the benefits of classical simulation, which only mimics the clinical environment in terms of needle guidance.

Simulation improves training efficiency by allowing the trainee to practice as much as necessary to achieve an acceptable level of performance[7]. However, one of the main challenges in the implementation of simulation training is the lack of standardization, which prevents reliable comparison between the findings of different research centers. Current methods and equipment vary between training facilities. Standardization will also allow the use of simulation laboratories to evaluate competency, and can thus be employed for assessment purposes. By developing the Perk Station in the public domain, we have attempted to contribute to this standardization process. All the software used in this experiment is open-source, and the mechanical design of the Perk Station has previously been published[4]. This allows the research community to freely reproduce or modify it, so that they may compare their methods with ours, or even to develop their own ideas using the current Perk Station as a base.

Feedback during training is one of the main motivators of performance improvement. Objective feedback is also important in surgical education[8]. Reviews show that there is a higher level of mastery for computer-assisted learning when external feedback is used to teach technical surgical skills[9]. Therefore, it is important to develop metrics for surgical dexterity, and preferably use the same definitions across different simulators or institutions. However, it is important to recognize that simulation-based learning should be considered an addition to traditional operating room learning, and not a replacement[10].

The significance level of our statistical results might be improved in the future by involving more participants in our studies. Different measurement methods may also be implemented for the software module for evaluation. The recorded needle trajectories and event annotations enable reloading the experiments by the software and exploration of the data at any time in the future.

5. CONCLUSION

Training with augmented reality image overlay and laser guidance improves the accuracy of needle placement for medical students learning the correct orientation of a needle for percutaneous facet joint injection. Simulation enhanced with augmented reality can potentially improve the quality of conventional surgical procedures performed without additional guidance.

6. ACKNOWLEDGMENTS

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