Training with Perk Tutor improves ultrasound-guided in-plane needle insertion skill

Hillary Lia[1], Zsuzsanna Keri[1], Matthew S. Holden[1], Vinyas Harish[1], Christopher H. Mitchell[2], Tamas Ungi[1], Gabor Fichtinger[1]

[1]Laboratory for Percutaneous Surgery, School of Computing, Queen's University, Kingston, Canada

[2]Department of Anaesthesia, Sir Charles Gairdner Hospital, Perth, Australia

ABSTRACT

PURPOSE: The open-source Perk Tutor training platform has been shown to improve trainee performance in interventions that require ultrasound guidance. Our goal was to determine if needle coordination of medical trainees can be improved by training with Perk Tutor compared to training with ultrasound only.

METHODS: Twenty participants with no previous experience were randomized into two groups; the Perk Tutor group and the Control group. The Perk Tutor group had access to the 3D visualization while the Control group used ultrasound only during their training. Performance was analyzed, measured and compared by Perk Tutor with regards to four needle coordination metrics. None of the groups had access to 3D visualization during performance testing.

RESULTS: The needle tracking measurements showed, for the Perk Tutor group, lower average distance between the needle tip and ultrasound (1.2 [0.9 – 2.8] mm *vs* 2.7 [2.3 – 4.0] mm, respectively; $P = 0.023$) and lower maximum distance between the needle tip and ultrasound (2.2 [1.9 – 3.2] mm *vs* 4.6 [3.9 – 6.2] mm, respectively; $P = 0.013$). There was no significant difference in average needle to ultrasound plane angle and maximum needle to ultrasound plane distance. All participants were successful in the procedure.

CONCLUSION: The Perk Tutor group had significantly reduced distance from the needle tip to the ultrasound plane. Training with Perk Tutor can improve trainees' needle and ultrasound coordination.

KEYWORDS: Perk Tutor, 3D Slicer, SlicerIGT, PLUS Toolkit, Image-Guided Intervention, Visualization, Competency-based medical education, Ultrasound-guided needle insertion

1. PURPOSE

Real-time ultrasound guidance has become the standard of practice in a variety of needle insertion procedures including central venous catheterization, peripheral nerve blocks, and biopsies[1]. Ultrasound guidance is useful for visualization of the target and surrounding structures. Using ultrasound can reduce the number of needle adjustments and time required for needle placement[2]; however, lack of training may prevent clinicians from using the image to its potential[3].

Proper needle visualization is an essential skill to successfully perform ultrasound-guided needle insertions. This procedure can be performed as an out-of-plane approach or an in-plane approach. When performing a needle insertion using the in-plane approach, constant visualization of the needle must be maintained. A study found that most errors trainees made when performing in-plane needle insertions were failures to keep the needle in the ultrasound plane[4]. In-plane insertion technique can have a long learning curve as simultaneous coordination of the needle and ultrasound probe is required.

Currently, there is no standard method of training for ultrasound-guided needle insertion procedures. However, there is consensus that simulation-based education has a significant role in procedural skill acquisition. A group of residents were surveyed and the majority felt that procedural skills including central venous catheterization and lumbar puncture are most effectively taught with simulation[5]. Simulation-based education allows for repeated practice with no damage to a patient. Computer-assisted simulation that allows visualization of the needle tip and provides feedback to the trainee may be beneficial to develop the coordination skills required for this procedure[1].

Research about how trainees gain competence is ongoing to determine factors that contribute to the success of the procedure. For example, it has been determined that needle insertions tend to be more efficient with less needle repositioning when needle visibility is increased[6].

Several training systems for ultrasound-guided needle insertions have shown promise. A needle guidance system that displays the trajectory of the needle has been shown to improve accuracy and efficiency of ultrasound-guided needle insertions[7]. Using electromagnetic tracking of the needle to show trajectory and needle tip position helped operators maintain better needle visibility[8]. The SonixTouchGPS Ultrasound System that also shows the projected path of the needle was shown to improve performance time and accuracy of the needle placement[9]. However, it remains unclear whether using these systems can help clinicians improve their ultrasound needle visualization skills when the guidance is unavailable. A training system with needle tracking capabilities and objective needle visualization metrics may help trainees learn ultrasound guided needle placement and improve coordination.

Perk Tutor is a computerized training platform for image-guided intervention training[10], and it has been successfully used for a number of procedures[11, 12]. Perk Tutor provides real-time three-dimensional visualization of the needle relative to the ultrasound plane. It was found that Perk Tutor helped trainees reduce potential tissue damage, needle path length and needle insertion time in lumbar puncture[11]. However, there were no metrics that directly measured the needle and ultrasound coordination skills of the trainee.

Measurement of the maximum and average angle of the needle to the ultrasound plane and distance of the needle tip to the ultrasound plane (Figure 2) could be an indicator of a trainee's needle coordination competence. Our goal was to determine, using our new metrics, if the 3D visualization provided by Perk Tutor improved trainee needle and ultrasound coordination skills.

2. METHODS

Our study was performed following approval by the local Health Sciences Review Ethics board. Participants were recruited on a voluntary basis and a written informed consent form was signed by each participant prior to participation. Twenty participants from undergraduate biomedical and life science programs with no experience using ultrasound or performing in-plane needle placements were randomly assigned into two groups. The skill level of this group is representative of medical students at the beginning of their training of ultrasound-guided needle placement. The Perk Tutor group had access to the needle visualization module in Perk Tutor (Figure 1 (A)) while the Control group used ultrasound guidance only during practice of the procedure. All participants received a brief presentation about ultrasound basics and ultrasound-guided needle placement before hands-on practice. The participants practiced ultrasound-guided in-plane needle insertion five times. All participants were tested using conventional ultrasound guidance only. There was no time limit during practice and testing.

Performance of trainees was evaluated based on recorded motion of the needle and the ultrasound probe. This was a generic vascular access procedure. The trainees first identified the tube in the phantom using ultrasound. Then, the trainees inserted the needle into the tube using the ultrasound to guide the needle. Motion recording started when the needle first touched the phantom and stopped when the needle tip entered the fluid-filled tube. Success was determined by checking if fluid from the tube came through the needle at the end of the procedure.

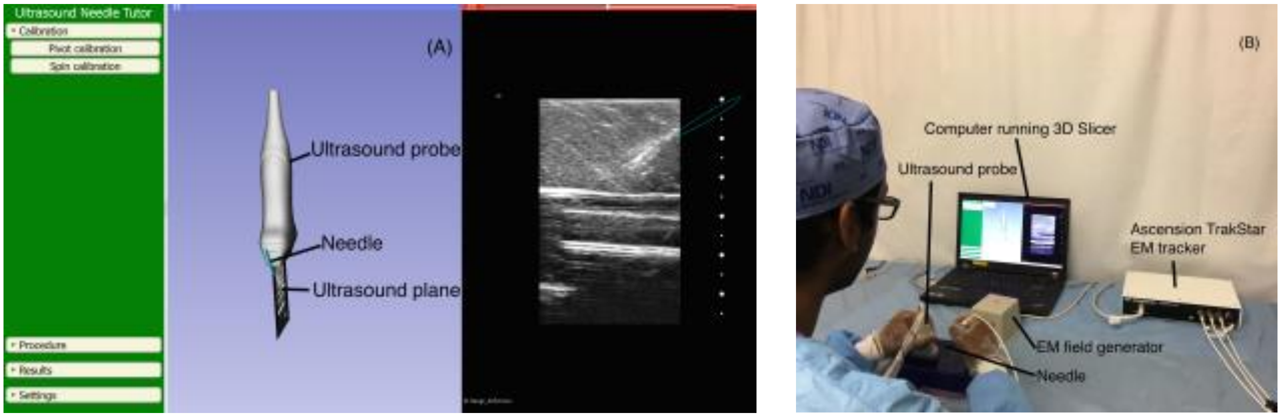


Fig. 1. (A) Screenshot of Perk Tutor 3D visualization and ultrasound image. **(B)** Experimental training setup with novice practicing an in-plane needle insertion.

Our setup of the Perk Tutor system (Figure 1 (B)) consisted of a computer running 3D Slicer (www.slicer.org) connected to an Ascension TrakStar electromagnetic tracker with three sensors (Northern Digital Inc., Waterloo, ON), a Telemed MicrUs portable ultrasound machine (Telemed Medical Systems, Milan, IT), and a Blue Phantom Vascular Training Model (CAE Healthcare Inc., Sarasota, FL). A sensor was attached to each of the needle and the ultrasound probe; one reference sensor was attached to the phantom. Tracking and imaging data were acquired and sent to 3D Slicer using the PLUS library (www.plustoolkit.org) [13]. We developed a needle coordination training interface upon the Perk Tutor platform, which displays the ultrasound image on the computer screen as well as the 3D visualization of the needle, ultrasound probe, and ultrasound plane. The four quantitative measures of needle and ultrasound coordination were integrated into Perk Tutor as custom performance metrics. Perk Tutor is not a commercial product but can be set up by technical personnel in a few hours as it is an extension of the free open-source software 3D Slicer. Set up time before each session was five minutes to start the Perk Tutor system, ensure the sensors were attached to the phantom, needle and ultrasound, and to ensure the tube inside the phantom was filled with fluid.

To compute the performance metrics, it is necessary to first calibrate the needle and ultrasound probe. We performed all calibrations using the SlicerIGT platform (www.slicerigt.org). First, we performed a pivot calibration and spin calibration to determine the position and orientation of the needle tip relative to the sensor attached to the needle. Subsequently, we performed a pointer-based calibration to determine the transformation between the ultrasound image and the sensor attached to the ultrasound probe. Using these calibrations, the angle between the needle and the ultrasound probe was computed as the complement of the angle between the needle vector and the ultrasound plane's normal vector. The distance between the needle tip and ultrasound probe was computed as the orthogonal distance from the ultrasound plane to the needle tip. These metrics were implemented in Perk Tutor and were computed off-line on the recorded needle and ultrasound trajectories.

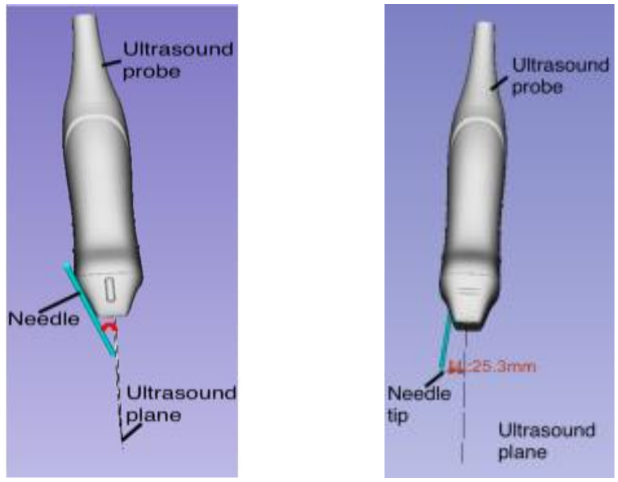
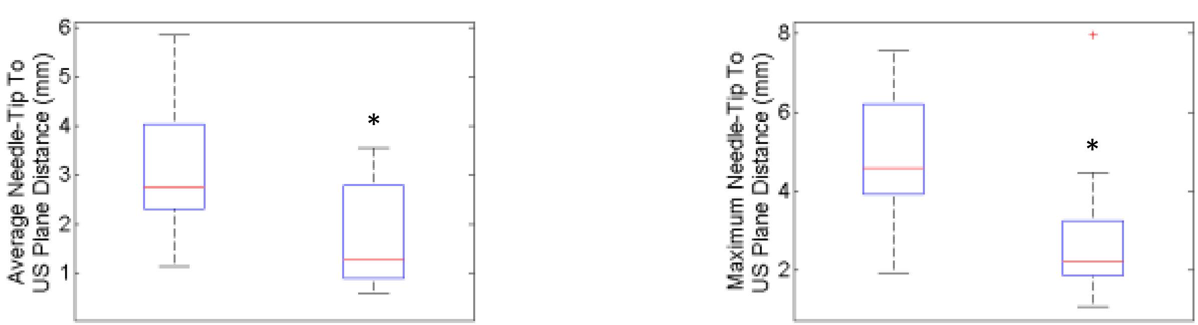


Fig. 1. Representation of measurement of coordination metrics. **(A)** Needle to ultrasound plane angle. **(B)** Needle tip to ultrasound plane distance.

The performance metrics were calculated as the primary outcomes of the study. Using the Jarque-Bera test, the performance metrics did not follow a normal distribution. Thus, they were compared using the non-parametric rank-sum test with alpha value α=0.05. There was no correction applied for multiple tests. Results are presented as median [interquartile range; IQR].

3. RESULTS

Statistical analysis of the needle trajectory showed that the median [inter-quartile range] average needle-tip to ultrasound plane distance was significantly lower (Figure 3) in the Perk Tutor group than in the Control group (1.3 [0.9 - 2.8] mm *vs* 2.7 [2.3 - 4.0] mm, respectively; *P* = 0.023). Additionally, maximum needle-tip to ultrasound plane distance was significantly lower in the Perk Tutor group than in the Control group (2.2 [1.9 - 3.2] mm *vs* 4.6 [3.9 - 6.2] mm, respectively; *P* = 0.013). Average needle to ultrasound plane angle and maximum needle to ultrasound plane angle were each not significantly lower in the Perk Tutor group than in the Control group (3.4 [2.3 - 5.5] deg *vs* 2.6 [1.9 - 3.7] deg, respectively; *P* = 0.740), and (4.5 [3.8 - 8.4] deg *vs* 6.7 [3.7 - 8.9] deg, respectively; *P* = 0.485). Both total procedure time and path length showed no significant difference between the Perk Tutor group and the Control group 13.1 [6.4 - 18.4] s *vs* 15.3 [10.7 - 17.7] s, respectively; *P* = 0.339) and (59.2 [45.0 - 72.9] mm *vs* 63.8 [59.0 - 116.5] mm). All participants were successful in the simulated intervention.



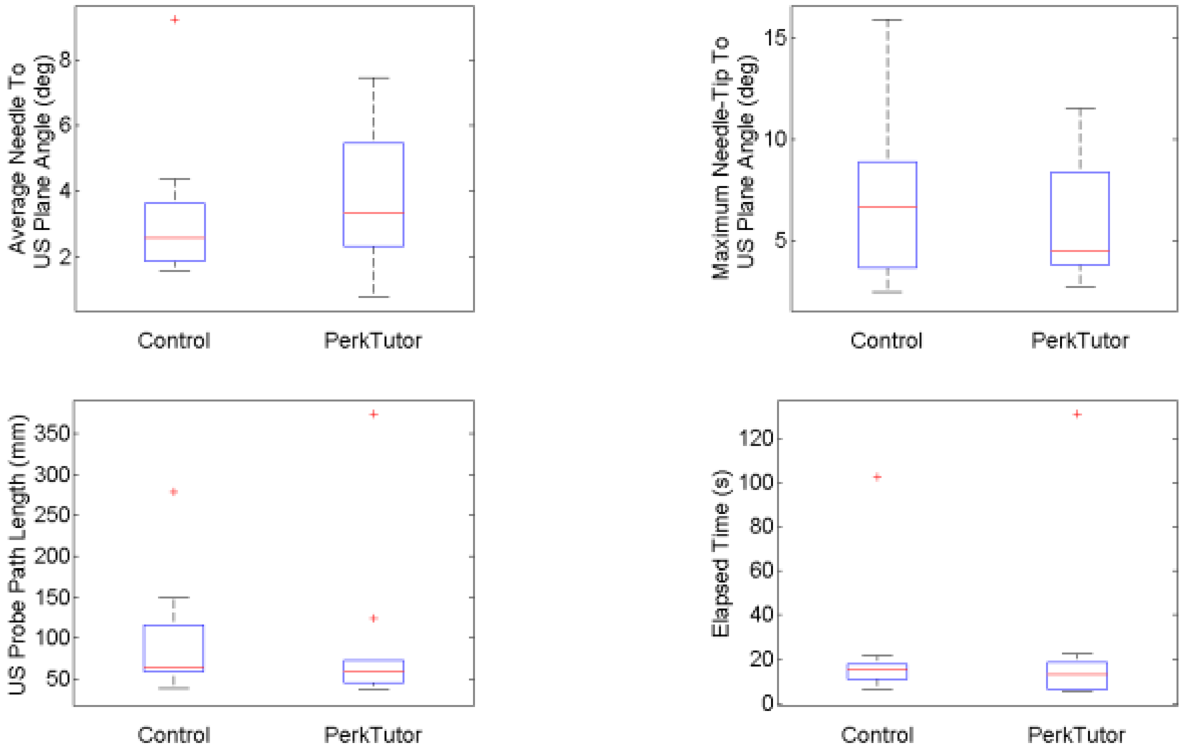


Fig. 3. Needle tip to ultrasound plane distance metrics showing a significant difference (*p<0.05) between the Control group (n=10) and the Perk Tutor group (n=10). Angle between needle and ultrasound plane metrics, total procedure time and total path length did not show a significant difference between the Control group (n=10) and the Perk Tutor group (n=10).

4. DISCUSSION

Our study shows that training with Perk Tutor improves needle and ultrasound coordination skills over traditional simulation-based training. Notably, there was no significant difference between basic efficiency metrics (i.e. time and path length) for the two groups. This demonstrates that the proposed training system specifically targets needle coordination skills and that basic efficiency metrics alone cannot necessarily capture this type of improvement.

There are some limitations to this study. We measured the distance and angle between needle and ultrasound, but these metrics are based on instructor consensus, and have not been validated against clinical performance on patients. Although it was suggested that trainees should practice ultrasound probe and needle coordination at a single location to master the technique[1], it is unclear how the skill will transfer to the clinical setting and to differing procedure sites. Furthermore, it was possible to perform a successful needle insertion without always keeping the needle in the ultrasound plane. Some trainees may have been more focused on reaching the simulated vessel with the needle tip rather than always keeping the needle in plane.

A previous study[11] has shown that training with Perk Tutor improves trainees' efficiency in ultrasound-guided needle interventions, as measured by metrics such as tissue damage and needle path length. We could identify and implement metrics that could measure needle coordination of trainees alongside these previously existing metrics. A validation study using SonixGPS, an application that displays the predicted trajectory of the needle on the ultrasound image, showed that trainees who practiced with the technology kept their needle in the ultrasound plane longer than the control group throughout the procedure[6]. However, the trainees were not evaluated using coordinated metrics. Instead, an expert timed how long the trainee kept the needle in the ultrasound plane by observing the ultrasound image. A similar system that displays the needle trajectory showed that the time required for placement and the number needle advances decrease when the guidance system was used[8]. This study also did not use calculated metrics, instead an expert used a scale to provide participants with a score from zero to three. Perk Tutor can measure the position of the needle relative to the ultrasound plane, needle placement time and number of needle readjustments. This is beneficial because it allows for objective evaluation and does not require an expert to be present for each practice for the trainee to receive feedback.

We propose that the current Perk Tutor configuration can be implemented as a training tool within the context of a larger ultrasound-guided needle intervention training curriculum. The objective metrics of performance provided by the system fit with the recent shift to competency-based medical education models. Needle and ultrasound coordination is a skill common to all ultrasound-guided needle interventions, and the new metrics for its evaluation in an in-plane approach would apply to many interventions such as nerve blocks or joint fluid aspiration. Furthermore, our system configuration is not specific to any procedure, meaning the visualization and metrics would work “out-of-the-box” on any intervention involving an in-plane needle insertion approach.

Because the system is based on the open-source Perk Tutor platform and an inexpensive hardware setup, it could be readily reproduced at other medical education centers. This would allow trainees to engage in self-guided technical skills training, without direct expert supervision. An emerging problem with competency-based medical education is the requirement of staff to review trainee performance. By automating the training process, learning can become self-directed. Furthermore, the Perk Tutor system permits custom metrics to be implemented using a single scripting tool. This would allow clinical experts to define their own metrics for assessing intervention skill and needle coordination, or composite metrics based on a combination of previously implemented metrics.

The proposed metrics need only be computed during the needle insertion phase of the intervention workflow. We envision that phase-specific metrics could be implemented for not only the needle insertion phase, but each phase within workflow. Using the workflow analysis capabilities of Perk Tutor, the system could automatically recognize each phase of the workflow, calculate the specific metrics for each phase, and compute an overall proficiency score. Such a score can be combined with clinical expertise to evaluate trainee competence.

Designing competency based medical curricula requires defined milestones for trainees and a method to measure progress at and between each milestone[14]. Perk Tutor can become a useful tool for medical educators to integrate competency based medical education quickly and easily.

5. CONCLUSION

We configured Perk Tutor for teaching the in-plane approach of ultrasound-guided needle placement and implemented four new metrics to assess needle and ultrasound coordination based upon the average and maximum distance and angle between the needle and the ultrasound plane. A study to evaluate the effectiveness of the training configuration found that Perk Tutor helps trainees reduce the average and maximum distances of the needle tip to the ultrasound plane. This demonstrates that this configuration improves trainee coordination in ultrasound-guided needle placement and the setup is feasible for training operators in ultrasound-guided needle interventions.

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