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Research Article

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How Should Beginners Learn Ultrasound In-Plane Needle Techniques? A Randomized Comparison between Directed- and Self-Learning

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Abstract

Background: With ultrasound (US) guidance, the in-plane (IP) technique allows operators to track the needle in real time during its advancement towards the target nerve. While mastery of the IP technique is instrumental to the success (and safety) of peripheral nerve blocks, the optimal learning strategy for beginners has not been elucidated. In this randomized trial, using phantom gel models, we compared control-, self- and directed-learning for the acquisition of IP needle skills. We hypothesized that, compared to the 2 other groups, directed-learning would require a shorter performance time and fewer needle passes to complete the post-test.

Methods: Thirty novice operators (experience level<30 US-guided procedures in the 6 months prior to the study) were randomized to 1of 3 groups. In the control group, subjects underwent pre- and post-testing with no training in between. In the self-learning group, subjects underwent 1 hour of independent learning (needling of a practice phantom model) between the pre- and post-tests. In the directed-learning group, 1 hour of learning through coaching and feedback was provided between the pre- and post-tests. Pre-tests and post-tests, which were identical, consisted of needling sonographic targets of varying sizes and depths, which were embedded in a test phantom model. The primary outcomes encompassed performance time and number of needle passes; secondary outcomes included the presence or frequency of 8 quality-compromising behaviors. All study variables were assessed by a blinded observer.

Results: Compared to the pre-tests, post-test performance times improved similarly in all 3 groups. However only subjects randomized to directed-learning showed a reduction in the number of needle passes as well as improvement in several quality-compromising behaviors.

Conclusion: A directed-learning session, integrating coaching and feedback, is pedagogically more productive than self-learning for beginners aiming to acquire US IP technique. Further trials are required to determine the IP technique learning curve for novice operators.

Keywords: Ultrasound; Learning; In-plane technique; Deliberate practice; Randomized trial; Skills

Introduction

Ultrasonography (US) has revolutionized the practice of Regional Anesthesia by enabling operators to visualize the nerve and block needle [1]. More specifically, the in-plane (IP) technique allows anesthesiologists to continuously track the needle in real time during its advancement towards the target nerve. While mastery of the IP technique is instrumental to the success (and safety) of peripheral nerve blocks, the optimal learning strategy for beginners has not been elucidated. To date, two important learning models have been identified: the discovery model (self-learning), whereby the learner discovers and amalgamates information by himself [2], and the deliberate practice model (directed-learning), whereby an instructor provides feedback and coaching to the learner [3]. Because of its simplicity, self-learning is most commonly used [4]; however, directed learning may be pedagogically more productive [5].

Although deliberate practice models have been described for Regional Anesthesia [6,7], a direct comparison between directed and self-learning has not been carried out. Thus, in this randomized trial, using phantom models, we compared self- and directed learning for the acquisition of IP needle skills in novice operators. We also included a third (control) group to account for the learning effect associated with repeated testing (pre-test and post-test). We hypothesized that, compared to its control and self-learning counterparts, the directed-learning group would require a shorter performance time and fewer needle passes to complete the post-test.

Methods

After obtaining ethics committee approval (McGill University Health Center, Montreal, Canada), as well as written and informed consent, 30 novice operators were enrolled in the study protocol. A novice operator was defined as a Fellow, resident or medical student who had performed <30 US-guided procedures in the 6 months prior to recruitment. Exclusion criteria included prior training on an US phantom model. Using sealed envelopes and a computer-generated sequence of random numbers, participants were randomly allocated to a control (CT), self-learning (SL) or directed-learning (DL) group. The Zonare Z.one Ultra sp US machine, L14-5w linear array probe (Zonare Medical Systems, Mountain View, CA), 90 mm, 22-gauge block needles

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(Terumo Corporation, Tokyo, Japan) and test phantom models were identical in all 3 groups.

Test and practice phantom models were constructed by inserting wooden pegs of various diameters and lengths into a wooden base. The test models consisted of 3 sets of wooden pegs grouped by diameter (6 mm, 4 mm and 2 mm) and positioned in order of decreasing length (Figure 1A). The latter was calculated to ensure that the top of the pegs were at 2, 4 and 6 cm below the gel surface. An additional 6 mm of depth was added to compensate for compression of the gel medium by the US probe. To facilitate identification of the 2 mm-set, 6 mm marker pegs were placed at both ends of the wooden base. These pegs were not considered US targets. In the practice phantom model (SL and DL groups), the pegs were positioned differently and grouped by length (target depth). Furthermore an additional 12 mm diameter target was added. Thus the practice model displayed 3 sets (2, 4 and 6 cm in depth) and 4 targets of different diameters per set (Figure 1B).

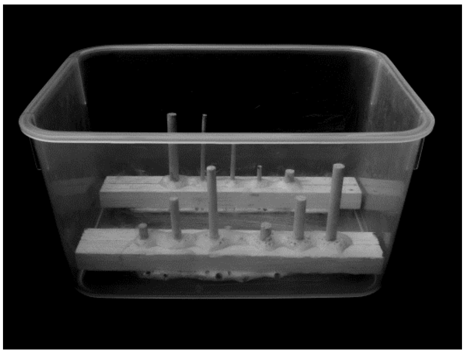

Figure 1A: Test phantom model before the addition of gel medium.

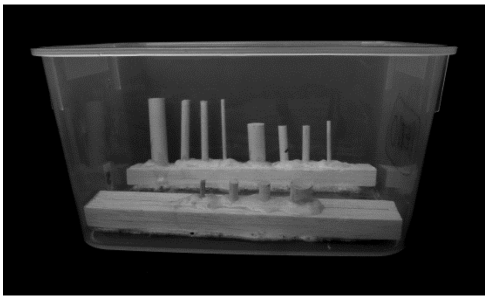

Figure 1B: Practice phantom model before the addition of gel medium.

After the pegs had been secured to the wooden base, the latter was bonded to the bottom of a 2.6 liter plastic container using polyurethane glue. Each container was then filled with a water mixture containing 182 grams of agar gelatin powder, 150 mL of orange colored Metamucil (Procter and Gamble, Toronto, Canada) and 15 mL of chlorhexidine solution. Metamucil served as a US speckling agent and also served to opacify the gel. Chlorhexidine was added as a preservative. Care was taken to remove all undissolved material and air bubbles prior to cooling the mixture. In the resulting phantom model, the top of the wooden pegs appeared as distinct linear targets (Figure 2). Prior to use, the surface of the model was covered with a thin layer of water to optimize imaging and minimize needle tracks.

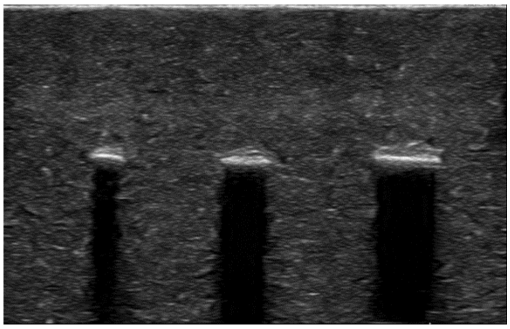

Figure 2: Long axis sonographic view of the practice gel phantom model. The 2 mm-, 4 mm- and 6 mm-targets from the first set (depth=2 cm) can be visualized. The 12 mm-target from the same set is located outside the visual field.

Participants in all 3 groups underwent an identical pre- and post-test. The latter was administered 1 hour after the pre-test (CT group), or 1 hour after the learning session (SL and DL groups). Before the pre-test, all subjects were asked to read the study protocol. All questions were answered to ensure that they understood the test procedure as well as the outcomes that would be measured. Furthermore an IP needle placement was demonstrated and an empty copy of the test model (Figure 1A) was made available throughout the test period to facilitate understanding of the target layout. Participants were asked to complete each of the targets in sequence (from the 6 mm- to the 2 mm-set), moving to the next group only when the needle had been successfully placed in direct contact with the top of each of the 3 wooden pegs (Figure 3). An assessor, who was blinded to group allocation, was present during the pre/posttest periods but only interacted with the participants to confirm the successful completion of each set.

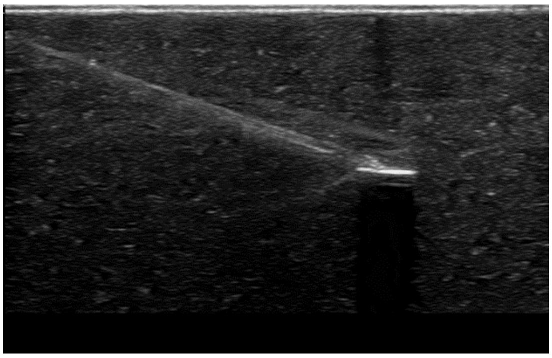

Figure 3: Short axis sonographic view of the test phantom model, demonstrating an in-plane needle placement on the 6 mm-target (depth= 2 cm).

After the pre-test, subjects allocated to the CT group were simply asked to wait 1 hour without further practice/teaching intervention. In contrast, subjects randomized to the SL group were left alone in a room for 1 hour, given a practice phantom model and asked to perform 3 in-plane needle placements on each of the 12 targets. Subjects allocated to the DL group performed a similar number of needle placements

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during an identical period of time using the same practice phantom model. However, they were provided with coaching and feedback by an instructor (experienced operator who had performed over 250 US-guided nerve blocks). The latter addressed basic issues; such as alignment of the needle and visual axis [8] and ability to troubleshoot an off-course needle. Furthermore he also provided feedback on quality-compromising behaviors (Table 1).

Name	Description	Outcome type
QCB1	Advancement of needle while not visualized	Count
QCB2	Malposition of target on screen	Count
QCB3	Poor probe handling or ineffective probe movement	Yes/No
QCB4	Awkward needle holding	Yes/No
QCB5	Watching hands or needle instead of target	Yes/No
QCB6	Fatigue	Yes/No
QCB7	Failure to correlate sidedness of screen and probe	Count
QCB8	Inappropriate needle insertion site	Count

Table 1: Quality-compromising behaviors (QCBs) (Adapted from Sites et al. [10]).

After completion of the allocated learning intervention, subjects underwent a post-test, which was identical to the pre-test. During both tests, the performance time and number of passes constituted the primary outcomes. Performance time was measured from the moment the probe was first placed on the phantom model, until the last set of targets was successfully completed. A pilot study involving 10 experienced operators (staff anesthesiologists and regional anesthesia Fellows who have performed >200 US-guided procedures in the last 6 months), found a mean performance time of 345 ± 95.8 seconds for completion of the test phantom model. Based on this information, we decided that 16 minutes (960 seconds), i.e., a value 50% greater than 3 standard deviations beyond the average expert performance time, would be the maximum allowable time for beginners to complete the test. Study participants who were unable to complete all 3 target sets within 16 minutes were deemed to have failed and their performance time was fixed at 960 second for the purpose of analysis. The number of passes was determined by looking at the US screen as well as the participant's hand movements. One needle pass was defined as an advancement that was preceded by a withdrawal of more than 1 cm [9]. Secondary outcomes included quality-compromising behaviors, which we adapted from a previous study by Sites et al. [10]. They were recorded as a binary outcome (yes/no), or as a count (number of instances) (Table 1). To ensure consistency, the same blinded observer recorded all primary and secondary outcomes.

Statistical analysis

We hypothesized that the DL group would require a shorter performance time and fewer needle passes to complete the post-test. Based on the performance time (345 ± 95.8 seconds) displayed by expert operators in the pilot study, 10 subjects per group were required to detect a 40%-difference (effect size 0.68) in performance time using the One-Way ANOVA test with an alpha type error of 0.05 and a power of 80%. Statistical analysis was performed using SPSS version 20 statistical software (IBM Armonk, NY). The One-Way ANOVA, Kruskal-Walis and chi-square tests were used to compare data across groups and all P values were adjusted for multiple comparisons. Pre- and post-test data were analyzed using the paired t-test, Wicoxon's signed ranks or Mc Nemar's tests. All P values presented are 2-sided and those inferior to 0.05 were considered significant.

Results

Thirty novice operators were recruited over a period of 2 months. There were no intergroup differences in terms of demographic variables (Table 2). Performance time, number of passes and success rates are presented in Table 3. The performance time and success rates for the pre- and post-tests were similar. However, the number of passes in the post-test was significantly decreased in the DL group compared to the CT and SL groups (P=0.011 and P=0.025, respectively), as were the number of QCB1 events (P=0.005 and P=0.027, respectively) and QCB8 events (P=0.002 and P<0.001, respectively).

	Control	Self-learning	Directed Learning	P value
Sex (Male/Female)	6/4	6/4	4/6	0.727
Age Mean (SD)	29.0	25.3	28.3	0.514
Level of trainee (medical student/resident/fellow)	4/4/2	7/3/0	6/3/1	0.600
Number of in-plane blocks in last 6 months Mean (SD)	4 (8)	1 (2)	2 (6)	0.530

Table 2: Demographic data; SD: Standard Deviation.

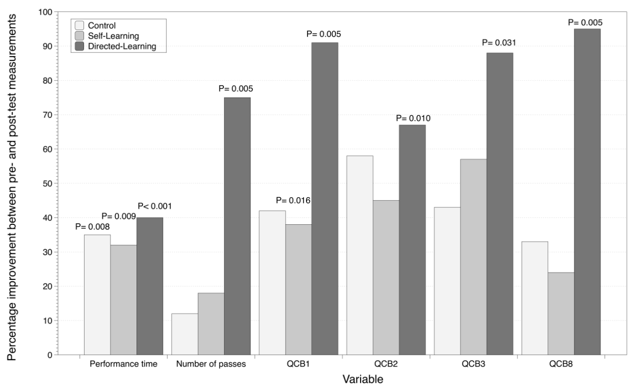

Figure 4: Percentage change in mean value (performance time, number of passes, (QCB1, QCB2 and QCB8) or proportion (QCB3), reflecting the magnitude of improvement between pre- and post-test measurements. Significant P values (paired analysis for pre- and post-test data) are indicated. QCB1: advancement of needle while not visualized; QCB2: malposition of target on screen; QCB3: poor probe handling or ineffective probe movement; QCB8: inappropriate needle insertion site; QCB = Quality-Compromising Behavior.

Results of paired analysis of pre- and post-test variables are presented in Table 4. Compared to the pre-test, the post-test displayed a decreased performance time (all groups), fewer needle passes (DL group) as well as improvement in QCB1 (SL and DL groups) and

QCBs 2, 3 and 8 (DL group). Figure 4 illustrates the proportional improvement between pre- and post-tests for these significant variables.

		Control	Self-learning	Directed Learning	P value
Total performance time Mean (SD)	Pre-test	711.0247.5	713.0193.3	716.3215.5	0.999
	Post-test	463.6219.0	486.6211.1	431.4116.1	0.837
Total number of passes Mean (SD)	Pre-test	58 (32)	61(42)	77(40)	0.501
	Post-test	51(48)	50 (26)	19 (5)	0.006*
Successful performance n/total	Pre-test	7/10	10/10	7/10	0.195
	Post-test	9/10	9/10	10/10	>0.999
*Directed learning vs. self-learning P=0.025, directed learning vs. control P=0.011.					

Table 3: Performance time, number of needle passes and success according to group allocation. SD: Standard Deviation.

Variable		Control	Self-learning	Directed Learning
Total performance time (seconds) Mean (SD)	Pre-test/Post-test	711(247)/463(219)	713(193)/486(211)	716(215)/431(116)
	P value	0.008	0.009	<0.001
Total number of passes Mean (SD)	Pre-test/Post-test	58(32)/51(48)	61(42)/50(26)	77(40)/19(5)
	P value	0.496	0.361	0.005
QCB1 Mean (SD)	Pre-test/Post-test	18.8(17.2)/10.8(11.1)	15.2(12.7)/9.4(8.5)	21.6(20.6)/1.9(1.5)
	P value	0.082	0.016	0.005
QCB2 Mean (SD)	Pre-test/Post-test	2.6(2.5)/1.1(1.5)	2.2(1.8)/1.2(1.9)	3.9(2.7)/1.3(1.4)
	P value	0.156	0.188	0.010
QCB3 Proportion (%)	Pre-test/Post-test	70/40	70/30	80/10
	P value	0.250	0.375	0.031
QCB4 Proportion (%)	Pre-test/Post-test	60/50	50/50	70/10
	P value	>0.999	>0.999	0.063
QCB5 Proportion (%)	Pre-test/Post-test	90/90	50/30	50/30
	P value	>0.999	0.687	>0.999
QCB6 Proportion (%)	Pre-test/Post-test	70/50	30/40	50/10
	P value	0.500	>0.999	0.125
QCB7 Mean (SD)	Pre-test/Post-test	0.9(1.3)/0.3(0.7)	0.6(1.3)/0(0)	0.1(0.3)/0.1(0.3)
	P value	0.313	0.250	>0.999
QCB8 Mean (SD)	Pre-test/Post-test	24.3(28.1)/16.4(26)	18(14.5)/13.6(12.4)	16.7(18.5)/0.9(1.1)
	P value	0.250	0.496	0.005

Table 4: Paired analysis of pre- and post-test variables. SD: Standard Deviation.

Discussion

In this randomized trial, using phantom models, we compared CT, SL and DL for the acquisition of IP needle skills in novice operators. The performance time and number of passes were selected as primary outcomes because these variables would reflect an improvement in technical ability. Our results show that the performance times similarly decreased in all 3 groups. However the CT and SL groups showed no improvement in the number of passes between the pre- and post-test. In contrast, subjects randomized to DL required markedly fewer passes to complete the post-test than the pre-test. These findings suggest that CT and SL subjects were able to complete the required tasks faster, but not necessarily "better", whereas those in the DL group achieved both. Clinically, a reduction in needle passes may be as important as a decrease in performance time because it could translate into less patient discomfort as well as a decreased risk of needle trauma and vascular puncture. Our findings echo the results of Sites et al [6] who observed rapid improvement of US needling skills when feedback was provided between trials on a phantom model.

Because our protocol compared CT, SL and DL in vitro, the choice of phantom models requires discussion. Several permutations of US phantom models have been previously described [11], essentially they differ both by the embedded targets and the sonographic medium. In our study, the agar gelatin mixture was used because of its low cost and durability. This permitted the fabrication of multiple copies of both test and practice models; in turn, their continuous rotation (after each participant) allowed us to minimize the presence of residual needle tracks, which required 1-2 hours to completely dissipate. Furthermore damaged gel surfaces could be easily repaired by heating the model in a microwave oven. In our protocol, the wooden pegs provided reliable US targets; moreover varying their size and length enabled the creation of multiple configurations in a relatively compact space (plastic container). Extreme caution was taken to ensure that SL and DL subjects would not improve their post-test performance simply by having practiced on the test model itself: that is why the hour-long SL and DL practice session took place on a different (practice) phantom model which displayed different target groupings as well as an additional 12 mm-target.

The QCBs used in our trial were adapted from a previous study by Sites et al. [10]. Quality-compromising behaviors have also been employed in studies investigating the learning curves of skills required for US-guided Regional Anesthesia [7,12]. For the purpose of our trial, we identified 8 behaviors that were applicable to tasks performed on the test phantom models: we used them as outcomes as well as key topics addressed by the instructor during the DL training. Out of these 8 QCBs, QCB1 (needle advancement without visualization) has been identified as the most in common mistake seen in novice operators [10]. In fact, our study reveals that subjects in all 3 groups repeatedly exhibited QCB1 during the pre-test. In the post-test, only DL subjects were able to curtail this behavior.

Our protocol contains some limitations. Firstly, we elected to train and test our study subjects using gel models, which are considered low fidelity. Cadaveric models might have simulated real patients more accurately. However, despite their higher fidelity, the access and storage conditions required by cadavers would severely limit their widespread implementation in common learning settings (classroom, hospital or medical conference). Secondly, we chose to study the IP technique because the ability to visualize the needle constitutes one of the most important technical skills in Regional Anesthesia [1]. Thus our findings may not apply to other US techniques such as the out-of-plane needling technique. Thirdly, we limited SL and DL to an hour-long session. We cannot rule out the possibility that SL might have compared favorably to DL had a longer period of independent technical discovery (SL) been allowed. However our results do suggest that, when novice operators are faced with a limited learning session (1 hour), DL provides better pedagogical efficiency. Finally, because of the punctual nature of our study intervention, no conclusions can be drawn regarding the learning curve of US IP technique for novice operators.

In conclusion, a directed-learning session, integrating coaching and feedback, is pedagogically more productive than self-learning for beginners aiming to acquire US IP technique. Further trials are required to determine the IP technique learning curve for novice operators.

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