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Comparison of human cadaveric and meat-based models for teaching ultrasound-guided regional anaesthesia: a randomised controlled trial

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Summary

The aim of this prospective, blinded, randomised controlled study was to compare novices' acquisition of the technical skills of ultrasound-guided regional anaesthesia using either a meat phantom model or fresh-frozen human cadavers. The primary outcome was the time taken to successfully perform an ultrasound-guided sciatic nerve block on a cadaver; secondary outcomes were the cumulative score of errors, and best image quality of the sciatic nerve achieved. After training, the median (IQR [range]) time taken to perform the block was 311(164-390 [68-600]) s in the meat model trained group and 210 (174-354 [85-600]) s in the fresh-frozen cadaver trained group (p = 0.24). Participants made a median (IQR [range]) of 18 (14-33 [8-55]) and 15 (12-22 [8-44]) in the two groups respectively (p = 0.39). The image quality score was also not different, with a median (IQR [range]) of 62.5 (59.4-65.6 [25-100])% versus 62.5 (62.5-75 [25-87.5]) % respectively (p = 0.58). The training and deliberate feedback improved all participants' block performance, the median (IQR [range]) times being 310 (206-532 [110-600]) s before and 240 (174-354 [85-600]) s after training (p = 0.02). We conclude that novices taught ultrasound scanning and needle-guidance skills using an inexpensive and easily constructed meat model perform similarly to those trained on a cadaveric model.

Introduction

The use of ultrasound is an accepted standard when performing peripheral nerve blocks, with evidence for improved efficacy [1,2] and safety [3,4]. The evidence for teaching the skills and knowledge necessary to be competent and safe in ultrasound-guided regional anaesthesia is limited, despite clinical acceptance of the technique. There is considerable on-going effort in examining the different components of the ultrasound-guided regional anaesthesia curriculum. In some instances, teaching methods have been used without fully researching their effectiveness [5].

One area of uncertainty is choice of the best model or phantom to teach ultrasound-guided regional anaesthesia technical skills. The rationale for training using in vitro models is to provide novices with a safe medium to correct errors, gain motor skills, and allow time to develop proficiency before undertaking procedures on patients. A wide variety of these phantoms have been used and described [6], including water, tofu, beef gravy, gelatin, elastomeric rubber, turkey, beef, pork, and human cadavers. The last-named model may also be fresh (unembalmed), fresh-frozen (unembalmed, stored frozen at -20℃ and thawed before to use), or embalmed with different preservative solutions. Each of these models have advantages and disadvantages in terms of fidelity, cost and availability [6].

One determining factor in choosing an in vitro model is the fidelity of needle visibility under ultrasound. Wiesmann and colleagues found that needle visibility was artefactually superior in porcine and turkey meat models versus in vivo visibility [7]. Conversely, the needle tip and needle shaft visibility was similar for cadavers and the human control. A concern is that novices training on meat models as opposed to cadaver models, may form an unjustified confidence in their needle skills. This could cause them to be unprepared for their initial nerve block performance on patients.

Proponents of using cadavers for training cite the high face validity due to correct anatomy, fascial feedback during needle insertion, ergonomics, and as an invaluable opportunity for teaching [8]. Attendance at a cadaver workshop is a compulsory component of the current European Diploma of Regional Anaesthesia [9]. The main criticism of cadavers is feasibility, as they require a dedicated and accredited facility with technical expertise to prepare, and are thus expensive. Access to cadaveric tissue is also not equitable across countries. Nonetheless, if studies on training on cadavers were to provide evidence of improved ultrasound-guided regional anaesthesia performance, then the investment could be justifiable.

We designed this study to determine if there was any advantage in using fresh-frozen human cadavers compared to a simple and inexpensive porcine meat model (with embedded bovine tendon), when training novices to performing ultrasound-guided sciatic nerve blocks. The hypothesis was that the time taken to perform the task of placing a needle tip in the 12 and 6 o'clock positions (respectively corresponding to immediately above and below the target) and injecting 0.5 ml of 0.9% saline around the sciatic nerve in a fresh-frozen cadaver would be at least 60 s faster if the novice had been trained on the fresh-frozen cadaver.

Methods

This study was approved by the Macquarie University Human Research Ethics Committee (Medical Sciences; 5201400737), and registered with the Australian and New Zealand Clinical Trials Registry (ANZCTR12614000343606). The study was performed in the Surgical Skills, Simulation and Anatomy Laboratory, Faculty of Medicine and Health Sciences, Macquarie University, in May 2015.

This study was a prospective, parallel-group, equal allocation, blinded, randomised control trial. The study flowchart is described in Figure 1: participants were recruited and randomised, viewed a training video on performing a mid-femoral sciatic nerve block, performed a baseline sciatic block, underwent ultrasound-guided regional anaesthesia skills training using their allocated models, and performed a final sciatic block. No interaction was allowed between participants throughout the study.

Eligible participants were university students in medicine, nursing, and allied health/physical therapy. Students with any previous training, observation, or performance in ultrasound-guided procedures were ineligible. Radiography students were specifically excluded. After giving written informed consent, participants were randomised within blocks of gender into the meat model, or fresh-frozen upper limb cadaveric model, using a computerised number generator.

All participants then viewed a 10 minute training video introducing ultrasound physics and transducer movements relevant to ultrasound-guided regional anaesthesia. The sonoanatomy of the sciatic nerve was explained with a human model, before the mid-femoral sciatic nerve block was demonstrated using a short axis, in-plane approach. Correct block technique was emphasised including maintaining needle tip visibility during advancement, and appropriate spread of injectate around the sciatic nerve.

The meat training model used in this study was a porcine phantom with embedded bovine tendon, as described by Xu and colleagues [10]. A solid metal skewer was used to create a tunnel 2 cm below the surface, through which the tendon was inserted. Under ultrasound, the tendon appears similar to a hyperechoic peripheral nerve, while the surrounding porcine meat contains fascial layers and mimics human muscle echogenicity [6]. The meat model setup and resultant sonographic view are illustrated in Figure 2.

The cadaveric training model was a disarticulated fresh-frozen cadaveric upper limb. The median and ulnar nerves of the forearm were used as target nerves at a location 2cm below the skin surface. In both models, the target depth was identical to mimic a superficial target. The easier needle guidance task and easier sonoanatomy than the examination task station allowed training to concentrate on learning fundamental aspects of ultrasound-guided regional anaesthesia skills.

Each participant was allowed 30 attempts to practice on his/her allocated models. Each received one-on-one training by experienced consultant regional anaesthetists. The feedback was individualised, and provided after each attempt. This technique is called deliberate practice [11,12]. Teachers were instructed to train participants to successfully perform a short axis, in-plane ultrasound-guided nerve block using their respective models.

A total of 45 minutes was allowed for training, including a 10 minute rest period to minimise fatigue. GE NextGen Logiq e machines with high frequency 5-13MHz linear transducers were used at all training stations (GE Healthcare, Buckinghamshire, UK). Figure 3 shows a cadaver group participant undergoing skills training.

For the cadaveric sciatic nerve block examination, a disarticulated lower limb from a fresh-frozen cadaver was placed prone on an examination table in a separate room from the training stations. The target was standardised as the mid-femoral sciatic nerve in the posterior thigh, at a depth of 4 cm from the skin. This was chosen as a difficult task, with significant anisotropy, and required the participant to insert the block needle distant to the ultrasound transducer to optimise in-plane needle visibility.

Each participant was supervised by an experienced consultant regional anaesthetist who had not been involved in the training and who was unaware of group allocation. Each participant was instructed to obtain the best short axis view of the mid-femoral sciatic nerve target, then insert the block needle in-plane to deposit 0.5ml of 0.9% saline at the 12 o'clock and 6 o'clock position relative to the nerve. Appropriate hydrodissection of injectate was confirmed by the supervising anaesthetist. If not, the attempt was repeated until the task was correctly performed. The time required to successfully perform the task was recorded by a research assistant. A maximum of 600 s was allowed.

Identical 21- gauge facet-bevelled, non-echogenic nerve block needles were used for both training and examination (Stimuplex A, B Braun, Melsungen, Germany). A SonoSite M-

Turbo machine with high frequency 6-13MHz linear transducer was used, and the depth, gain, and nerve preset was locked (SonoSite Inc, Bothell, WA). Ultrasound images were continuously recorded on a laptop computer using video capture software (Elgato Systems, San Francisco, CA). The participant's hand and transducer movements were concurrently recorded by a video camera on a tripod. Figure 4 shows the examination station setup.

Videos were taken of each participant's baseline attempt before training, and their final examined attempt after training. Baseline and final videos were then edited and presented in a random order to two regional anaesthetists ('assessors') who had not previously been involved in the study, and who were blinded to group allocation (Y.C.L., H.A.). Both assessors independently scored all videos using the assessment sheet (Appendix 1).

The primary outcome was the time taken to correctly complete the task, defined as the time from picking up the transducer to successful deposition of injectate above and below the sciatic nerve. Our secondary outcomes were errors detected during the ultrasound-guided regional anaesthesia procedure and the worst image quality of the sciatic nerve; these were scored by the assessors using the assessment sheet. Seven individual errors were described: unstable hand grip on the transducer; number of needle passes; hand swapping during the procedure; advancement without needle tip visualisation; unstable transducer movements causing loss of nerve imaging; unstable needle movements causing loss of needle image; and intraneural injection. Each assessor counted and recorded each instance of error. The image quality score was defined as the worst image of the sciatic nerve at the time of injection, scored numerically (1 = unsatisfactory, 2 = poor, 3 = satisfactory, 4 = outstanding).

Our sample size calculation was based on previously published work with an identical primary outcome [13]. In that study of novices performing 30 sciatic nerve blocks on a fresh-frozen cadaver, aiming to place a needle at the 12 and 6 o'clock positions and injecting 1ml of saline, the mean (SD) time taken was 125.5 (71) s. Data indicate that there was no statistically significant reduction in time taken for the task with repetition. Thus a minimum sample size of 23 participants in each of the meat and cadaver groups will provide power of 80% and a two-tailed significance level of 0.05. If the sample size were increased to 30 participants in each group, power would be 90%; therefore we aimed to recruit 60 participants in case of drop-out.

The cumulative error and image quality scores for each video were calculated by averaging both assessors' scores. Image quality was first converted into a percentage of maximum score (necessary for analysis by ANOVA, higher scores equating to better image quality. The inter-rater variability of scoring procedural errors and the image quality score between the two assessors was tested by Cronbach's alpha. The time taken to successfully complete the task between groups, and from baseline to final exam, was assessed using repeated measures mixed ANOVA. Repeated measures mixed ANOVA between groups and from baseline to final results, was also used to test each secondary outcome of cumulative error and image quality scores. Differences in time taken from baseline to final examination, for all participants, were assessed using paired t-tests. Comparisons between groups at final examination for individual errors were assessed using two-sample t-tests.

All raw results were tested with Shapiro-Wilk's test and were found to be non-normally distributed. Data were thus treated with a natural log transformation before analysis. Statistical analysis was performed using SPSS Statistics version 23 (SPSS Inc, Chicago, IL). Statistical significance of all analyses was determined by a two-tailed p value < 0.05.

Results

Fifty-seven participants were recruited. Cronbach's alpha for assessors' inter-rater consistency was 0.87 for the cumulative error score, and 0.58 for the image quality score.

In the primary outcome of time taken to successfully complete the mid-femoral sciatic blocks, at baseline testing the meat model group took a median (IQR [range]) of 340 (217-599 [110-600]) s whilst the fresh-frozen cadaver model group took 284 (189-390 [110-600]) s. At the final exam, the meat model group took 311 (164-390 [68-600]) s while the fresh-frozen cadaver model group took 210 (174-354 [85-600]) s. There was no statistically significant difference within groups or between either group (p = 0.24). This is reported in Table 1 and Figure 5a.

At the baseline attempt, the meat model group had a median (IQR [range) of 22 (14-34 [4-88]) errors, compared with 17 (11-29 [7-49]) in the fresh-frozen cadaver group. After training, this improved to 18 (14-33 [8-55]) versus 15 (12-22 [8-44]) errors respectively. However, this was not statistically significant (p = 0.39). Individual error and cumulative error scores are reported in Table 1, and graphically in Fig. 5b.

Similarly, for the image quality score, at baseline the meat model group scored 56.3 (37.5-75 [25-87.5])% versus 62.5 (37.5-62.5 [25-87.5])% in the fresh-frozen cadaver group. At final exam, the respective scores were 62.5 (59.4-65.6 [25-100])% and 62.5% (62.5-75 [25-87.5] %. The difference was not significant (p = 0.58) (Table 1, Fig. 5c).

Combined together, participants showed a statistically significant improvement in time taken, from a median (IQR [range]) of 310 (206-532 [110-600]) s to 240 (174-364 [68-600]) s (p = 0.02).

Discussion

This study shows that training novices with either a simple meat model or fresh-frozen cadaveric model improves performance of an ultrasound-guided sciatic nerve block procedure. However, training on the more expensive, resource-intensive fresh-frozen cadaver model was no better than on the meat model, with time taken to successfully perform the block, number of errors made, and image quality scores all not significantly different between groups.

The direct implication of our results is that the meat model used in this study can be used to teach novices in early scanning and needle handling skills relevant for ultrasound-guided regional anaesthesia. Training on cadaveric models offers no advantage. This is beneficial for departments designing an appropriate ultrasound-guided regional anaesthesia curriculum for anaesthesia trainees, as the meat model has excellent feasibility: it is cheap, does not entail ethical concerns, can be constructed with minimal preparation, is easily disposed of after use, and does not require a specialised anatomy laboratory.

All biological tissue based models have a limited lifespan (one to two days). Fresh-frozen cadavers can be subjected to only a limited number of cycles of thawing and freezing before tissue decomposition occurs, and over time, injectate boluses around target nerves leads to further loss of anatomical fidelity. While the lifespan of the porcine model it after a training workshop is economically viable.

The choice of meat model deserves mention. Many types of phantoms have been used for teaching and in research; each has its advantages and disadvantages [6]. We chose the porcine model with embedded bovine tendon as the best compromise between fidelity to fresh-frozen cadaveric sonoanatomy (Figs. 2 and 4), and feasibility. Face validity is compromised by the loss of the normal relationships between nerves and fascial planes, blood vessels and bone. Needle visibility is falsely superior, but spread of injectate is similar [7]. Nonetheless, this study shows that the meat model can be used to teach ultrasound-guided regional anaesthesia skills as adequately as a fresh-frozen cadaver model.

In contrast, the use of cadavers is supported by the correct anatomical relationships within them; they most closely replicate the clinical experience when practicing procedural skills. Participants reported high satisfaction and improved confidence, and felt strongly that cadavers added educational value in teaching airway and critical care skills [14-16], central venous access [17], and ultrasound-guided regional anaesthesia [18]. Unfortunately most studies did not have objective endpoints, or lacked a control arm to compare against cadaver training. In one rare randomised controlled study, multiple surgical procedures were taught using either a bench model, a cadaver, or by didactic teaching. There was no difference in learning outcomes between the bench or cadaver models, and both were found to be superior to didactic teaching alone [19].

Other studies have been performed comparing different models, but not involving cadavers. Researchers have compared training using bench models of differing fidelity for epidural blocks [20], transforaminal injections [21], and ureteroscopy skills [22]. These studies also found no difference in outcomes. The common methodological aspect of all these studies, including ours, was close supervision or directed feedback of novices by experienced supervisors. It is possible that the quality of teaching delivered by an expert faculty has greater impact than any effect from using different models [23,24].

Although there is little evidence to justify the use of cadavers, it is popular with learners; 98% of participants in one cadaver ultrasound-guided regional anaesthesia course found it of educational benefit, and 84% subsequently believed the course provided confidence to help integrate ultrasound into their regional anaesthesia practice [18]. This high satisfaction rate reported by participants is probably related to the uniqueness of this type of teaching. Factors that foster this receptive teaching environment include: high inherent face validity of cadavers; the novelty of practicing on cadavers; the novelty of attending a specialised laboratory; the small size of groups; and the high ratio of instructors to participants.

Learning ultrasound-guided regional anaesthesia skills is nonetheless difficult for novices. In our secondary outcome of errors committed, participants in this study were committing a median (range) 16 (6 - 49) errors at the final examination. The most frequent types of error include multiple needle passes, unstable needle movements causing loss of visibility, and advancing without visualising the needle tip. These are similar to findings in other studies [25].

We found that training significantly shortened the time taken to successfully perform the sciatic nerve block. In the study by Barrington and colleagues [13], 28 attempts were required for novices to gain competence (defined as the ability to correctly visualise the needle with appropriate transducer movements). We have shown that, after 30 training attempts, novices can place boluses of injectate above and below a deep target nerve, mimicking the successful insertion of an ultrasound-guided nerve block.

Our study has several limitations. Inspection of the raw results from all three outcomes (Figures 5a, 5b, 5c) suggested an uneven distribution of participants' initial skill levels despite randomisation. An examination of individual participants' performance revealed five participants (three male, two female), all in the meat model group, whose performance fell within the lowest quartile for at least two outcomes. This suggests poor aptitude for ultrasound-guided technical skills despite training.. Nonetheless, if these participants had been distributed evenly into both groups, the performance difference between meat and fresh-frozen cadaver models would have decreased, and the comparative analysis would remain non-significant.

Interpretation of our secondary outcome of image quality is limited by poor inter-assessor consistency; therefore, this endpoint is not as reliable as the errors score. We also tested one specific meat model, and our data should not be translated to other models without further research. Lastly, while we assessed ultrasound-guided regional anaesthesia technical skills, other important aspects such as sonoanatomical knowledge or non-technical skills were not assessed in this study [26].

In conclusion, this randomised controlled study has found that teaching ultrasound-guided regional anaesthesia skills to novices using a fresh-frozen cadaver offers no better performance than a meat model. Skills learnt on the porcine meat model were transferable to a cadaver block. Participants' performance improved after training with directed feedback irrespective of the model used for training. The purpose and utility of cadaver-based teaching in ultrasound-guided regional anaesthesia require clarification.

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Appendix 1 Assessors' guide and description of errors

Instructions to participant (state this prior to each attempt):

Please perform an in-plane needle insertion in the model and inject 0.5ml of saline immediately next to the sciatic nerve, at both the 6 o'clock and 12 o'clock positions.

(Show supplied sonogram images of needle shaft, tip end points at 6 o'clock and 12 o'clock)

Error definitions

Error 1. Unstable hand grip once needling starts.

Not anchoring hand/fingers on model to stabilise the transducer at least 75% of time. Count each instance

Error 2. Number of needle passes.

Defined as advancement of needle >2cm through tissue, or interruption in fluid motion followed by a change in direction either as withdrawal >2cm, angle change >30 degrees. Perfect attempt = 2 passes, one each at the 6 o'clock and 12 o'clock positions

Error 3. Hand fatigue.

Defined as swapping hands on transducer during procedure, or lifting transducer off skin surface. Count number of instances.

Error 4. Advancing needle without visualising the tip.

Defined as advancing the needle despite the tip not seen on ultrasound. Count number of instances.

Error 5. Unstable transducer movements causing loss of needle image OR sciatic nerve image.

Defined as unintentional transducer movement resulting in loss of the nerve target and/or needle. Count number of instances.

Error 6. Unstable needle movements causing loss of needle image.

Defined as unintentional needle movement resulting in loss of needle visibility (ie. Ultrasound image is stationary, but needle moved out of the scanning plane). Count number of instances.

Error 7. Intraneural needle passes OR intraneural injection.

Defined as needle passing through, or seen to be inside, the sciatic nerve. Swelling of nerve on test injection. Count number of instances.

Image quality score

Worst sciatic nerve sonoanatomy image when injecting.

4 = Outstanding. Unequivocal and clearly defined nerve border.

3 = Satisfactory. Unequivocal but incompletely defined nerve border.

2 = Poor. Equivocal and poorly defined nerve border.

1 = Unsatisfactory. Nerve not defined

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Table 1 Time taken for successful block insertion, error rates, and image quality score, at baseline and final examination. P values given are for the between-group comparison at the final exam. Values are median (IQR [range]) or proportion.

	Meat model group	Fresh-frozen cadaver model	

	n=28		group n=29		p value
	Baseline	Final exam	Baseline	Final exam	
Time taken; s	340 (217-599 [110-600])	311 (164-390 [68-600])	284 (189-390 [110-600])	210 (174-354 [85-600])	0.37
Error 1	1.0 (1.0-1.9 [0-8.5])	0.8 (0-1 [0-6])	1.0 (1.0-1.0 [0-6])	0.5 (0-1 [0-2.5])	0.38
Error 2	7.0 (4.1-10.1 [2.5-38.5])	6.3 (4.5-8.8 [3.5-12])	6.5 (4.3-12.0 [2.5-24.0])	5.5 (4.5-7.0 [2.5-16.5])	0.41
Error 3	0.5 (0.1-1.9 [0-14])	0 (0-1 [0-16])	0.5 (0.0-1.3 [0-8])	0 (0-1.5 [0-6])	0.93
Error 4	4.5 (3.0-7.9 [0-38.5])	3.5 (2.1-4.5 [0.5-9])	5.0 (2.5-9.3 [1-16])	3.5 (2.0-4.5 [1-8])	0.74
Error 5	2.3 (1.0-4.4 [0-18])	2.0 (0.1-3.5 [0-13])	1.5 (0.5-3.0 [0-11])	1.0 (0.5-2.5 [0-9.5])	0.24
Error 6	3.5 (1.6-4.5 [0-11.5])	5.0 (2.1-7.0 [0.5-9])	3.0 (1.5-4.0 [0.5-14.5])	4.0 (2.8-6.0 [1.5-11.0])	0.82
Error 7	0 (0-0.5 [0-3])	0 (0-0 [0-2])	0 (0-0 [0-1.5])	0 (0-0.3 [0-1.5])	0.31
Cumulative error score	22.3 (13.9-33.8 [3.5-87.5])	17.3 (11.3-28.9 [6.5-49])	17.5 (13.8-32.8 [7.5-54.5])	14.5 (12-22 [8-41.5])	0.39
Image quality score (%)	56.3 (37.5-75 [25-87.5])	62.5 (37.5-62.5 [25-87.5])	62.5 (59.4-65.6 [25-100])	62.5 (62.5-75 [25-87.5])	0.50

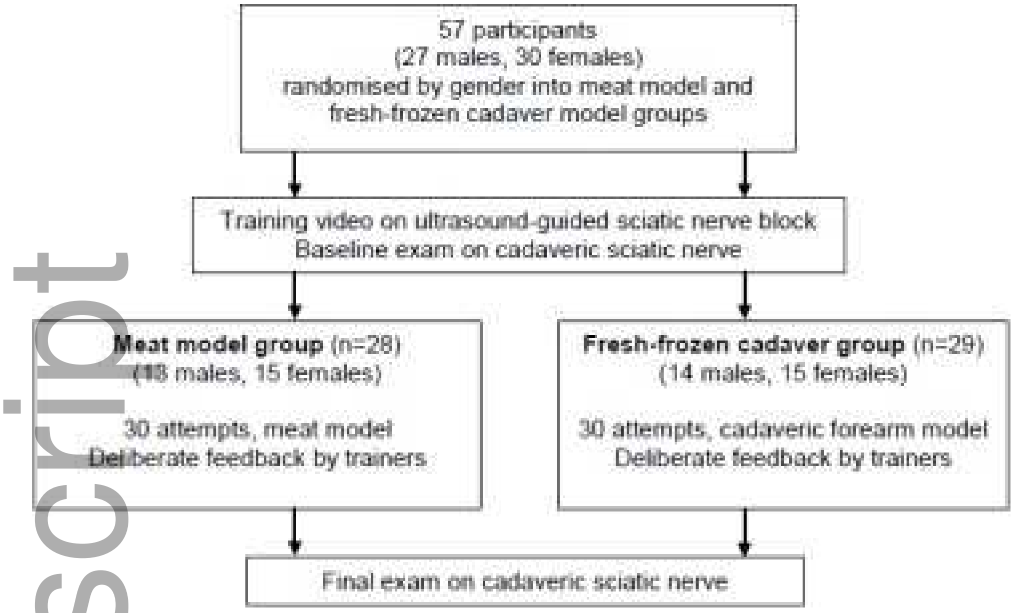
Figure 1 Flow of participants through study, and randomisation into the meat model and fresh-frozen cadaver model groups.

Figure 2 Porcine meat model with embedded bovine tendon (circled, with arrow), and corresponding ultrasound image obtained.

Figure 3 Photograph of a skills training station setup, demonstrating a participant in the cadaver group practising on a forearm nerve target.

Figure 4 Photograph of the mid-femoral sciatic nerve examination station, and corresponding sonogram of the sciatic nerve target in the lower limb of the fresh-frozen cadaver.

Figure 5 Comparison of outcomes between meat model (☐) and cadaver model (◩) groups at baseline and final mid-femoral sciatic nerve attempts. Top figure: time taken for task; middle panel, cumulative error score; bottom figure, image quality score. Boxes denote median and IQR; whiskers show range.



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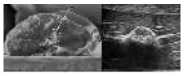

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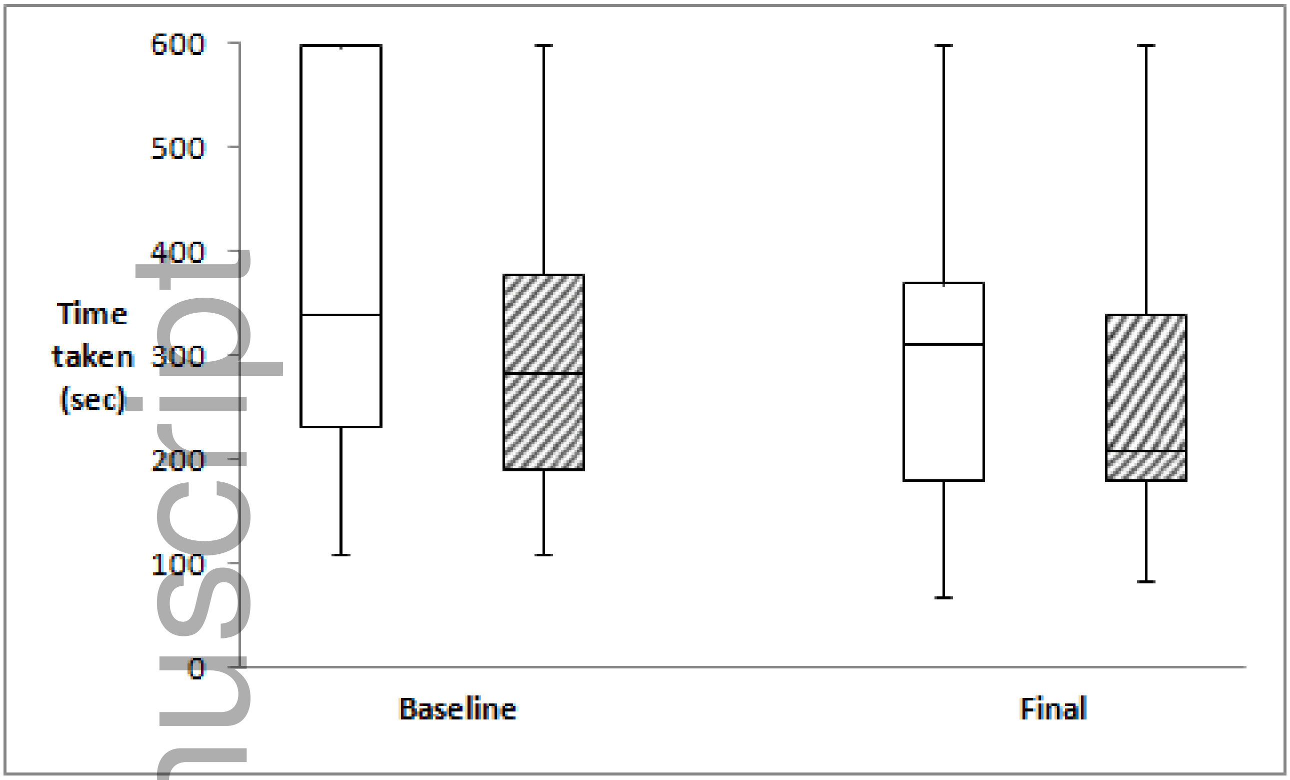

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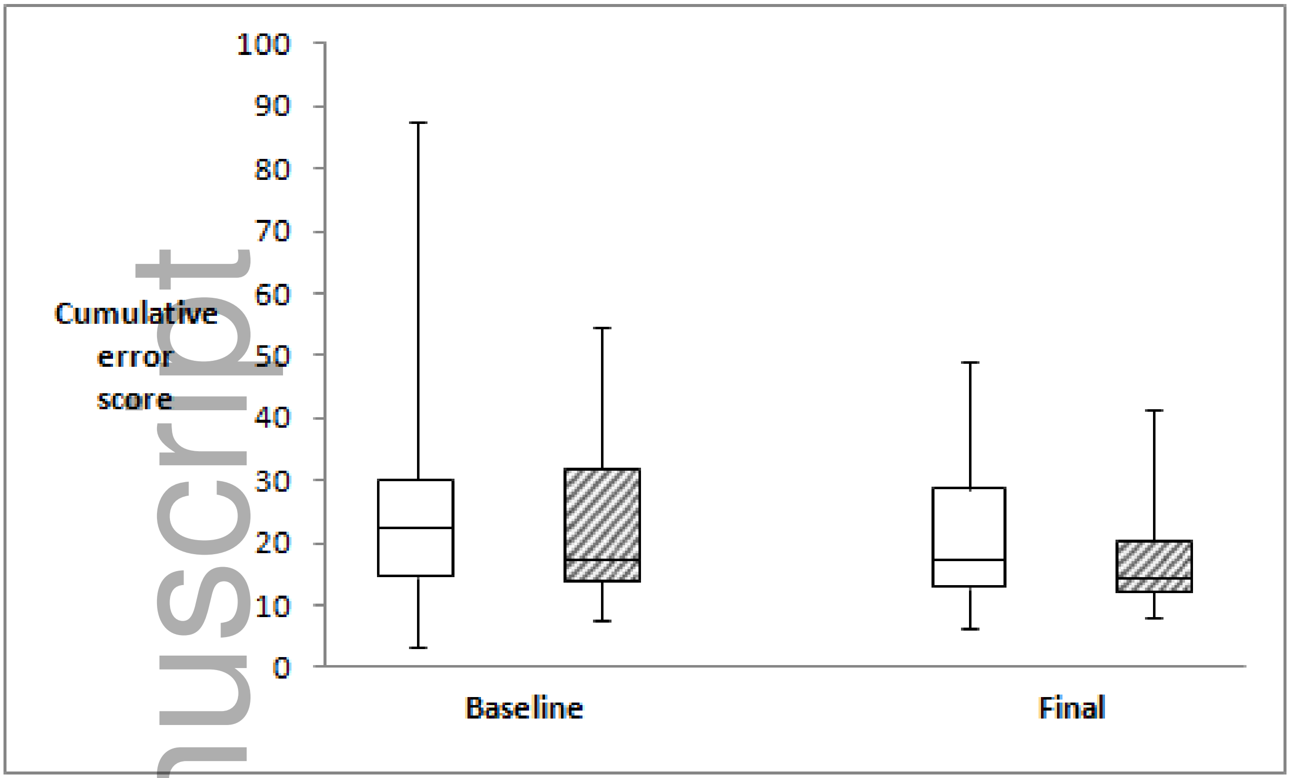

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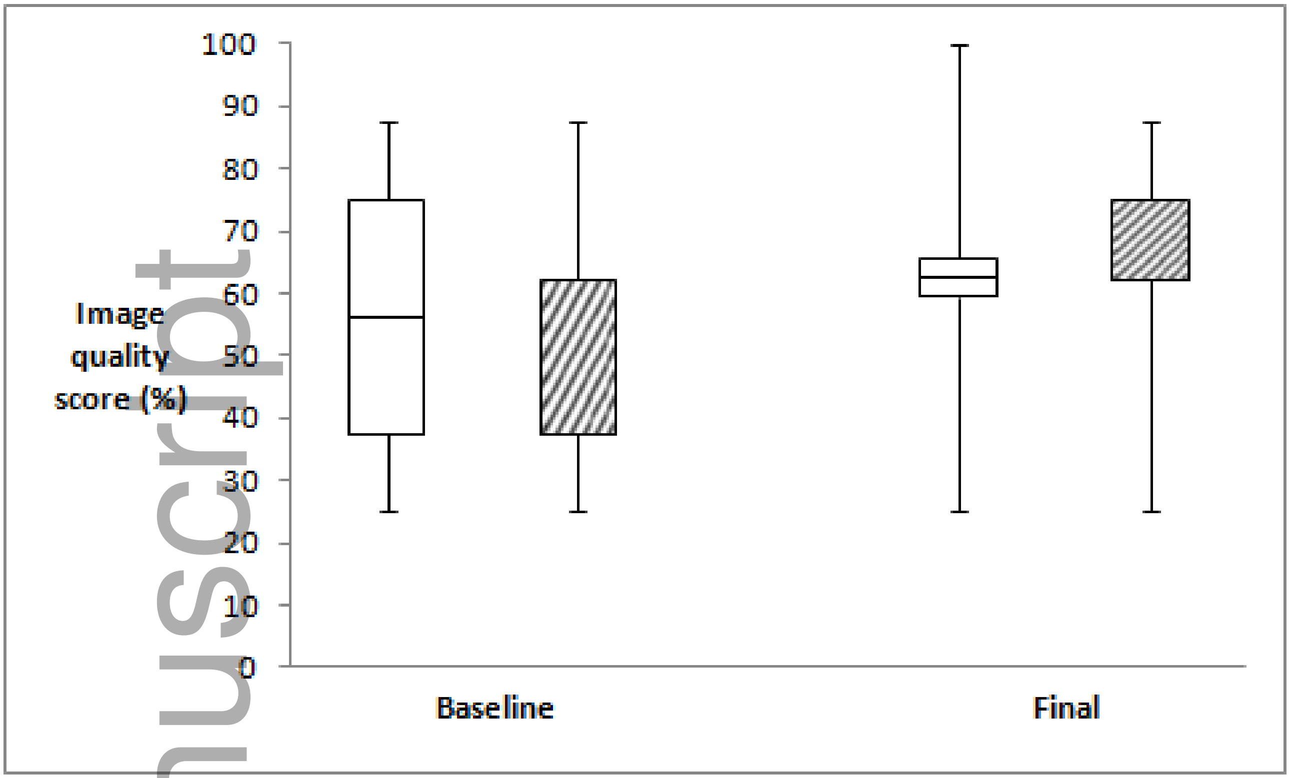

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