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Virtual Reality simulator’s effectiveness on the spine procedure education for trainee: a randomized controlled trial

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Running Title: Virtual Reality Simulator for Procedures

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Clinical trial registration number: NCT05029219
Virtual Reality simulator’s effectiveness on the spine procedure education for trainee: a randomized controlled trial

Running Title: Virtual Reality Simulator for Procedures
Abstract

Background: Since the onset of the coronavirus disease 2019 pandemic, virtual simulation has emerged as an alternative to traditional teaching methods as it can be employed within the recently established contact-minimizing guidelines. This prospective education study aimed to develop a virtual reality simulator for a lumbar transforaminal epidural block and to demonstrate its efficacy.

Methods: We developed a virtual reality simulator using patient image data processing, virtual x-ray generation, spatial registration, and virtual reality technology. For a realistic virtual environment, a procedure room, surgical table, C-arm, and monitor were created. Using the virtual C-arm, X-ray images of the patient’s anatomy, the needle, and indicator were obtained in real time. After simulation, trainees could get feedback from adjusting the visibility of the structures (such as skin and bones). The training of lumbar transforaminal epidural block using the simulator was evaluated in 20 inexperienced trainees. Trainees’ procedural time, rating score, number of C-arm taken, and overall satisfaction were recorded as primary outcomes.

Results: The group using the simulator showed a higher global rating score ($p = 0.014$), reduced procedural time ($p = 0.025$), reduced number of C-arm uses ($p = 0.001$), and higher overall satisfaction score ($p = 0.007$).

Conclusions: We created an accessible and effective virtual reality simulator that can be used to teach a lumbar transforaminal epidural block, without radiation exposure, for inexperienced trainees. The results of this study indicate that the proposed simulator will prove to be a useful aid for teaching a lumbar transforaminal epidural block.

Keywords: Operative Surgical Procedure; Spine procedure; Simulation training; Transforaminal epidural block; Virtual reality; Virtual reality simulator
Introduction

Traditionally, training using cadavers was often the preferred method of teaching spine-related procedures [1]. Practicing various techniques on cadavers provided an opportunity for inexperienced doctors to gain procedural experience without putting the patient at risk [2]. However, because at least one trainee, one radiographer, and one skilled person are required for training to be conducted on a cadaver, overcrowding cannot be avoided [3]. Therefore, cadaver training for procedures has dwindled under the currently implemented social distancing measures in the face of the coronavirus disease 2019 (COVID-19) pandemic [4]. One perspective is that the pandemic has acted as a catalyst to facilitate a paradigm shift in traditional education methods; it is expected that traditional methods will eventually be replaced by alternatives such as online education, 3D printing, multimedia resources, and virtual/augmented reality [5,6].

Recently, virtual reality simulators (VRS) have been developed for application in various medical fields such as pain modulation and rehabilitation, and for providing instruction during surgical procedures [7-9]. Regarding its use for teaching C-arm guided spine procedures, the advantages of VRS over cadaver training is that it can allow trainees to avoid the radiation exposure [7-12]. The advantages of VRS over traditional hands-on-training is that it can minimize the number of patients for the learning curve of trainees [13,14].

To the best of our knowledge, no previous VRS has been developed for the training of C-arm-guided spine procedures. The development of such a simulator requires not only virtual reality (VR) technology but also technologies such as medical image processing, virtual X-ray generation, and spatial registration technology.

In this study, we created this simulator for educational purpose of spine procedures and hypothesize the simulator would affect the learning efficacy, procedure time, and radiation exposures of inexperienced trainees compared to the commonly performed learning. Therefore,
we investigated our VRS system’s application on a lumbar transforaminal epidural block (LTFEB) by assessing its efficacy to educate inexperienced trainees.
Materials and Methods

Simulator development

3D polygonized model preparation

An anonymized lumbar computerized tomography (CT) data file was obtained from an anonymized data server of the OOO in digital imaging and communication in medicine format. A 3D polygonized model was generated using 3D Slicer (version 4.10.2; http://www.slicer.org) to obtain an optimized 3D model of the spine. Regarding the vertebrae, 3D models were obtained separately for the five lumbar vertebrae, sacrum, and pelvic bones. In addition, the shapes of the intervertebral discs between the bones were obtained. The vertebrae had approximately 60,000 to 120,000 polygons per bone; however, there were concerns about performance degradation when used directly in the program. Therefore, we reduced the number of polygons to 5% for each bone using MeshMixer (version 3.5; Autodesk Inc., San Rafael, CA, USA).

DICOM data manipulation

For DICOM file management in a virtual space, we built a program that could read and write DICOM files in UNITY software (version 4.2; Unity Technologies, San Francisco, California, USA) environment. We applied the Grassroots DICOM (GDCM) (version 3.0; http://gdcm.sourceforge.net) library in Visual Studio 2019 (version 16.10.3; Microsoft, Redmond, Washington, USA) and UNITY using CMake (version 3.119.1; Kitware, Inc., Clifton Park, New York, USA) and Simplified Wrapper and Interface Generator (version 4.0.2; http://www.swig.org/).

After we set the GDCM, DICOM data were read as binary data and were classified into tags such as image type (Tag# 0008,0008), image orientation (Tag# 0020, 0037), instance number (Tag# 0020, 0013), image position (Tag# 0020, 0032), pixel spacing (Tag# 0028, 0030), windows center (Tag# 0028,1050), windows width (Tag# 0028,1051), rescale intercept (Tag# 0028, 1052), rescale slope
(Tag# 0028, 1053), and pixel data (Tag# 7FE0,0010), and stored in separate series of arrays.

By adjusting the arrayed pixel data values with the rescale intercept and rescale slope values, the Hounsfield unit (HU) values of each image were obtained. We generated CT images by assembling the pixel colors through adjustment of the obtained HU values based on the windows center and windows width values. The four spatial coordinates of each image were stored and arranged in another array for subsequent virtual X-ray generation. The images were classified as axial, coronal, or sagittal using the image orientation value. They were then positioned in the virtual space by referencing the image position and pixel spacing values (Fig. 1A). When only HU values between 300 and 2,000 were visualized and the remaining values were applied with transparent materials, a 3D bone-like image was obtained (Fig. 1B).

**Virtual C-arm development**

First, for a realistic simulation, a 3D C-arm polygon model was created. Then, the C-shaped part, where the X-ray generator and detector were attached for height adjustment, was enabled for rotation, tilting, and vertical movement. The entire C-arm was enabled for parallel movement in all four directions. A generator that produced X-rays and a detector that detected them were placed in the virtual space. The detector points were set to be able to be divided by the desired resolution (x * y) between the corner points. The virtual X-rays were generated from the generator, to each divided point in the detector, as shown in Fig. 2A. Using the ratio of the dot product of each X-ray with the reference point of the obtained images, the point of the CT slice images where the collision occurred was calculated. After the corresponding HU values were obtained, the sum of the values was calculated. By dividing this value by the total number of CT slices, X-ray absorption was calculated, and virtual X-ray images were obtained by arranging them sequentially after converting the values into pixel values (Fig. 2B).
Simulation programming

The simulation program for the user movement and the C-arm procedure performance was designed most compatible with the Oculus Quest 2 (Meta Platforms, Menlo Park, California, USA). However, the simulation was programmed to be compatible with other VR devices using the XR Interaction Toolkit.

To ensure a realistic virtual environment, such as the place where actual procedures are performed, the procedure room, surgical table, C-arm, and monitor were created as 3D models and placed in an appropriate virtual space. The procedure room was set so that the position of the patient could be changed and the learner could perform the procedure on their desired side. The surgical table was divided into several parts to have functions such as height adjustment; the C-arm was also divided into several parts for rotation, tilt, height adjustment, and movement.

The monitor was designed to arrange the real-time X-ray image on the left and the stored image on the right (Fig. 3A). For the trainee’s convenience, two sets of virtual arrows were placed next to the bed so that the C-arm and bed could easily be adjusted (Fig. 3B). The arrows were placed next to the C-arm and the surgical table, where they could be easily accessed by the trainees (Fig. 3C). The table on which the needle and indicators were placed was also situated near the surgical table for the trainee’s convenience (Fig. 3D).

The primary axis of the left controller was designed to easily control the rotation and tilt of the C-arm and was programmed to shoot and save the virtual C-arm, through the primary/secondary button. On the other hand, the primary axis of the right controller was programmed to enable the learner to freely move, and the primary/secondary buttons were programmed to finely move forward and backward when the needle was inserted. Both the controller’s grip and trigger buttons were set to pick up/grab tools and execute functions.
For the performance and convenience of the simulation, the previously obtained 3D polygonised model and a 3D bone-like image consisting of CT image slices (Fig. 4A and 4D) were placed in the same spatial position in the virtual simulation space (Fig. 4B and E). Subsequently, the CT image slices were made invisible (Fig. 4C and F). The 3D data of the body contour was also displayed in the correct spatial position (Fig. 4G).

An indicator and needle were created to simulate the procedure. The indicators were created as general bar-type and laser pointer-type (Fig. 5A). The laser pointer-type indicator allowed rays to be emitted and when it touched the skin, a red sphere appeared on the C-arm (Fig. 5B). After being presented with the red sphere, the position could be finely adjusted using virtual arrow buttons (Fig. 5C). When the general bar-shaped indicator, needle, and sphere collided with X-rays, a value of 2,000 (based on the HU) was added to make it appear as if metal material appeared on the C-arm (Fig. 5D).

Because it was difficult to support a mesh collider with more than 255 polygons in UNITY, a pelvis and body composed of less than 200 polygons each were separately constructed for efficiency, and collision with a needle- or laser pointer-type indicator was examined (Fig. 6A). When the tip of the needle made contact with the skin, a function to fine-tune the entry point of the needle through the virtual arrow button was implemented to enable precise manipulation (Fig. 6B). Once the needle started to enter the skin, it was made not possible to adjust the insertion point. Then, the needle could be advanced while finely adjusting the angle of the portion outside of the skin (Fig. 6C). The position of the needle tip was calculated as the part of the specific CT slice that was touched. When the HU value of that part was 300 or higher, it was judged that the needle had touched the bone and further advancement of the needle was restricted, and the trainee received feedback in the form of a vibration. The trainee was able to perform the procedure by checking the position of the spine and needle through the virtual C-arm. After all the procedures were
completed, the results screen was configured so that the procedural outcomes could be verified (Fig. 6D and Supplementary Video). The VRS program could help trainees to learn LTFEB by making skin and bones invisible as well as allowing 3D visualization from multiple directions. This allowed the trainee to better learn the spatial positional relationship between the anatomy and the needle. They were trained to perform needle placement in the posterior to the vertebral body and just antero-lateral to the superior articular process.

**Evaluation of the simulator**

**Participants**

The study protocol was reviewed and approved by the Institutional Review Board of our institution. This study was conducted in accordance with the ethical principles of the Helsinki Declaration-2013 and followed good clinical practice guidelines. The study was registered at ClinicalTrial.gov (NCT00000000). The results of 20 first- or second-year residents undergoing anesthesiology and pain medicine training with no experience in C-arm-guided spine procedures were included; those already familiar with the procedures were excluded from the study. All participants were randomly allocated to one of two groups: a VRS group (Group V, n = 10) and a control group (Group C, n = 10). Before group allocation, envelopes containing the group information were numbered sequentially and sealed. The sealed envelopes were opened by an investigator unaware of the trainees’ assessments. Written consent was obtained from all participants.

**Curriculum and tests**

The entire curriculum flow is summarized in Fig. 7. First, the following data was gathered for all participants: gender, age, years of residency training, and their previous experience with
performing, observing, and assisting C-arm guided spinal procedures. Subsequently, participants watched a five-minute video of one of the authors performing a LTFEB, single vertebra level, and unilateral procedure, under C-arm guidance. The audio that played with the video was based on Furman [15]'s book, which described the fundamentals of the C-arm, the direction of the X-ray beam, the relative positions of the needle and beam during the procedure, the anatomical structure of the lumbar spine, and the method for performing the LTFEB.

After receiving a basic introduction, all participants were instructed to perform a LTFEB (lumbar 4-5, left) on the phantom as a pre-test. The phantom was prepared according to a previous study [16]. The parameters included in every assessment were the checklist score, global rating score, procedure duration (seconds), number of C-arm taken, and satisfaction score (0 – 5). Participants in the VRS group (Group V) were individually trained for approximately one hour using a VR headset and an Oculus program. Participants in the control group (Group C) were provided with video material and Furman [15]'s book, which had been provided to all participants in advance so that they could review it and individually study for approximately one hour. The post-test was conducted in the same way as the pre-test, after all the training courses were completed. Every performance was assessed by physicians with expertise in the field of pain assessment and were unaware of the group assignment.

**Outcome measures**

The primary outcome was change in the checklist score (post-test vs pre-test) to evaluate proficiency in performing C-arm-guided LTFEB, which has been previously utilized in several studies [16-18]. The checklist score [17], which validated the evaluation of LTFEB, consisted of seven task-specific questions, and each question was scored as either ‘yes’ or ‘no’ (Appendix 1). The global rating scale [17,19] consisted of 7 questions, and each question was scored out of a total
score of 5 points (Appendix2). Additionally, the procedural time and the number of C-arm shots were evaluated, and the procedure time was defined as the time from when the first X-ray image was taken, until administration of the injectate was completed. For the participant satisfaction evaluation, questions were asked after all the courses were completed, and they were asked to give an answer ranging from 1 to 5 (1 = unsatisfactory, 5 = satisfactory).

**Statistical analysis**

Based on a related previous study [17], the checklist score was different by 5 between the control group participating in the didactic session and the low-fidelity group educated with plastic spine covered by foam. Assuming that the median checklist score is the same as the mean checklist score, we conservatively predicted half of this difference as the average difference of our study. The value obtained by dividing the interquartile range by 1.35 was assumed to be the standard deviation. The number of samples was calculated based on the larger standard deviation of 1.5 among the test group and the control group. When the power was 0.9 and the significance level was 0.05, the required target number of subjects calculated by the G.power 3.1.9.7 program was 9 per group [20]. Considering the 10% dropout rate, 10 patients per group was deemed to be the required sample size. Continuous variables are presented as median and interquartile range, depending on normality. Categorical demographic variables are reported as numbers. For continuous variables, comparisons of patient characteristics between the groups were made using the Mann–Whitney U test. Categorical demographic data were analyzed using Pearson’s chi-square test or Fisher’s exact test. The Mann–Whitney U test was performed to test the difference in absolute values pre-test and post-test between groups for primary and secondary outcomes, and to test the difference between groups and the degree of change of each outcome. To test the differences between before and after education within the group, the Wilcoxon signed-rank test was
performed. Statistical significance was set at $p < 0.05$. All data were analyzed using SPSS Statistics for Windows (Version 24.0, IBM Corp., Armonk, NY).
Results

Overall, 20 residents participated in the study. Demographic data are presented in Table 1. There were no statistically significant differences between the two groups in any demographic parameters.

Fig. 8 shows the mean value of the checklist and global rating score. The mean post-test scores increased in both groups with respect to the pre-test scores. However, compared to group C, group V showed a more significant improvement in the global rating score.

The checklist score increased in both groups compared to the pre-test training score (group V, \( p = 0.004 \); group C, \( p = 0.041 \)). There was no significant difference in the degree of change in the checklist score before and after training between the groups. However, compared with group C, the global rating score increased significantly after training in group V compared to that before training (\( p = 0.014 \)). In both groups, the global rating score increased after training compared to that before training (group V, \( p = 0.005 \); group C, \( p = 0.027 \)). The time taken to complete the procedure (\( p = 0.025 \)) and the total number of C-arm taken (\( p = 0.001 \)) was significantly lower in group V compared to that in group C after training. The procedure duration and number of X-ray images taken decreased at the post-test compared to those at the pre-test in all participants. The participants in group V showed a higher overall satisfaction score than those in group C (\( p = 0.007 \)).
Discussion

In the present study, we developed a virtual simulator for spine procedures and evaluated its effectiveness in training inexperienced trainees. To our knowledge, the simulator is the first VRS developed directly by a physician with long-term experience in applied pain medicine. The virtual simulator group for LTFEB improved the global rating score and global rating score compared to the commonly performed learning. In addition, procedure time and the number of C-arm taken of the virtual simulator group were shorter than those of the commonly performed learning group.

The generation of a virtual X-ray image has also been attempted in various fields [20-23]. However, we could not find any previous study that implemented a simulation using an actual C-arm. Because other studies are limited and present only one view, such as an anteroposterior [22,23] or lateral view [22], or an image according to a specific angle, the image generated by the C-arm is more relevant. Even if X-ray images are generated at a specific angle, the image changes greatly depending on the positional relationship between the generator, detector, and target objects, including the procedure instruments [21]. We could not find any previous simulations that properly reflected this context [22,23]. In addition, virtual X-ray images had to be provided in real time to enable simulation of the procedure in a virtual space. However, using DICOM data directly in the virtual space, without optimization programming techniques, is difficult and can limit some of its applications [24]. Although it could have been performed through a large-scale, long-term project using multiple technicians, it is usually difficult to secure a large budget for an educational endeavor. In addition, commercially produced software may result in increased production costs, which would limit access to trainees.

An open-source program designed for UNITY to freely read, write, and edit DICOM data in VR is currently unavailable; as such, we have created a program to visualize DICOM data in a virtual
space and directly manipulate it [24,25]. The program we developed can build a simulation for actual patients in a short time. Therefore, it can also be applied to the pre-procedure planning/simulation, and act as a real-time intraoperative guide. In addition, it can be applied to research settings and facilitate simulations in various other medical fields.

Compared with other simulators, the simulator used in this study has the advantage of being developed by a doctor who performs and teaches the procedure [24,26]. Although there have been many advances in attempts to reproduce reality using VR, this is still a challenging task due to limitations in the performance and pricing of equipment. It is difficult to reproduce actual tactile sensation or implement very fine movements. Therefore, to overcome these limitations and to effectively use VR for education, it is essential that users be able to directly experience and repeat the process of modifying the method according to their needs. For example, in this simulator, training to understand 3D structures from 2D X-ray images is imperative. Therefore, to strengthen the purpose of and to reproduce the actual procedure, fine movement control should be implemented only for appropriate parts of the simulation, and vibration should be replaced with tactile feedback. In addition, a verification process is needed to provide support while maximizing learning effectiveness. Therefore, only a person familiar with the actual procedure was able to develop such a simulator.

Another significant strength of our simulator is that it avoids the risk of radiation exposure, in contrast to training using cadavers and phantoms [11,12,16]. The author [16] previously suggested that a spine procedure could be taught effectively and inexpensively by making a lumbar spine phantom using 3D printing. However, education using phantoms cannot avoid radiation exposure. Although Hashemi et al [27] insisted that ultrasound-guided LTFEB was accurate and feasible in a clinical setting, it is not recommended by the 2021 American Society of Interventional Pain Physicians guidelines [28].
We expected that when inexperienced residents trained for a LTFEB with our simulator, it would be possible to learn the procedure more efficiently than when training with an alternative. Accordingly, we found that the global rating score increased significantly and there was a significant decrease in the procedure time and the number of C-arms in group V compared with those in group C. We attribute this result to the access a trainee had to the program and the fact that they could repeatedly refine their technique by practicing a LTFEB through our simulator. If inexperienced trainees have repeatedly practiced, it can be expected that they will gradually become proficient in the procedure. The ability to check the 3D structure of the vertebra and to confirm the relative position of the needle tip at the end of the procedure are features that cannot be replicated, even in a clinical setting with an actual patient.

The degree of change in the checklist score before and after education was not significantly different between the groups. Presumably, because the checklist score was a binary answer for each evaluation item, it was difficult to subdivide the proficiency level. In addition, several limitations within our simulator could be attributed to the fact that the checklist score for group V was not greatly improved compared with group C. We have not been able to completely resolve the inherent limitations of VRS, such as dizziness and tactile reproducibility. In addition, the CT data from patients available for use was usually not high-density CT data, but more commonly CT images of the spine. Therefore, it was difficult to achieve high resolution and image quality of the virtual X-rays, and image quality may have affected the efficiency of the learning process.

This study had several limitations. First, since the phantom was used to evaluate the proficiency of the procedure, there was inevitably a gap between the context and the clinical situation when performing the technique on an actual patient. Second, we could not blind the subjects because we had to compare VRS with traditional educational methods. Therefore, our approach can be criticized for not comparing VRS and traditional methods under equal and unbiased conditions.
Third, because the created VRS could only provide the learning of the procedure method, there was a limitation in providing the learning about the predictable side effects such as vessel or nerve injury. Fourth, only LTFEB was trained in this study. However, the created simulator can be used to simulate any other C-arm guided procedures using CT data from relevant patients. Therefore, we expect further studies to evaluate the effectiveness of this simulator on the learning of other procedures.

Herein we describe a new simulator that enables inexperienced trainees to effectively learn a LTFEB without radiation exposure and confirm the educational efficacy of the simulator. The virtual simulator for LTFEB improved the learning efficacy of inexperienced trainees compared to the commonly performed learning. The virtual simulators in various spine procedures are needed to be investigated as a remote-accessible alternative to educate early-career trainees.
References


Table 1. Participants’ demographics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Group V (n = 10)</th>
<th>Group C (n = 10)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex, male/female</td>
<td>6/4</td>
<td>5/5</td>
<td>&gt;0.999</td>
</tr>
<tr>
<td>Resident training year, ½</td>
<td>5/5</td>
<td>6/4</td>
<td>&gt;0.999</td>
</tr>
<tr>
<td>Age, years</td>
<td>26.5 [25.3, 28.0]</td>
<td>27.5 [25.0, 30.8]</td>
<td>0.853</td>
</tr>
<tr>
<td>Prior observation</td>
<td>0.0 [0.0, 0.0]</td>
<td>0.0 [0.0, 0.0]</td>
<td>&gt;0.999</td>
</tr>
<tr>
<td>Prior assistance</td>
<td>0.0 [0.0, 0.0]</td>
<td>0.0 [0.0, 0.0]</td>
<td>&gt;0.999</td>
</tr>
<tr>
<td>Prior performance</td>
<td>0.0 [0.0, 0.0]</td>
<td>0.0 [0.0, 0.8]</td>
<td>0.796</td>
</tr>
</tbody>
</table>

Data are shown as the number of participants or median (interquartile range). Group C indicates the group of participants educated without the VRS. Group V indicates the group of participants who were educated with the VRS. The p-value indicates the results of the Mann-Whitney U test.
Figure 1. DICOM data manipulation. **A.** Axial, coronal, and sagittal computed tomography images positioned in the virtual space. **B.** 3D bone-like image were obtained by visualizing only HU values between 300 and 2,000.
**Figure 2.** Virtual C-arm development.  
**A.** The virtual X-rays were generated from the generator to each divided point in the detector (resolution $10 \times 10$ displayed for understanding).  
**B.** Virtual X-ray image was obtained by calculating the degree of absorption for each virtual X-ray (resolution $256 \times 256$).
Figure 3. The virtual simulator room.  A. The monitor displaying the real-time X-ray image on the left and the stored image on the right.  B. Virtual arrows placed for the C-arm and surgical table movement.  C. The C-arm and surgical table with virtual arrows.  D. Overall view of the room.
Figure 4. The obtained 3D polygonized model and a 3D bone-like image consisted of CT image slices placed in the virtual simulation space.  

A, D. 3D bone-like image obtained by visualizing only HU values between 300 and 2,000.  

B, E. Spatial position matched 3D bone-like image and the 3D polygonized model.  

C, F. 3D polygonized model.  

G. 3D polygonized model with skin contour displayed.
Figure 5. The indicator and needle used for simulation of the procedure.  

A. * General bar-type indicator, † Laser pointer-type indicator, ‡ Needle for the procedure.  
B. † A red sphere generated by the laser pointer-type indicator.  
C. Virtual arrow buttons for the fine adjustment of the red sphere.  
D. The indicators and needle appeared like metal material on the virtual X-ray.
Figure 6. Simulation programming.  

A. Virtual colliders of pelvis and body composed of less than 200 polygons.  
B. The virtual arrows for fine adjustment of the needle entry point.  
C. The virtual arrows for fine adjustment of the needle angles.  
D. The result display providing feedback.
Figure 7. Study design.
Figure 8. Changes in mean checklist and global rating scores in both groups.

Group V indicated the group of participants who were educated with the VRS. * indicates $p < 0.05$, within the group comparison based on the results of the Mann-Whitney U test; † indicates $p < 0.05$, between group comparison based on the results of the Wilcoxon signed rank test.
**Supplementary Legends**

Supplementary Video. The virtual C-arm, patient X-ray images, needle, and indicator were all operable in real time.

Appendix 1. Checklist score

Appendix 2. Global rating scale
## Appendix 1
Skill acquisition check list

Identification number: __________________ Supervisor: ________________

**Instruction:**
Selective transforaminal epidural nerve block

<table>
<thead>
<tr>
<th>Evaluation Item</th>
<th>Unable to perform</th>
<th>Incorrectly performed</th>
<th>Properly performed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TASK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Needle approach from posterolateral to the appropriate level</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2. Confirm the appropriate point of the needle tip. (Just below the pedicle)</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3. Needle passing adjacent to these structure at the appropriate level. (Just antero-lateral to the superior articular process)</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4. Confirm the appropriate depth of the needle tip. (Posterior to the vertebral body)</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5. Knowing and performing the proper sequence as well as knowledge of the quantity of the solution to be injected. (Contrast media, drug)</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6. At least two images were checked for appropriate locations.</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7. Proper positioning of self and the monitor and successful performance of the procedure.</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Total points: 1.
2.
3.
## Appendix 2

### Overall rating scale

<table>
<thead>
<tr>
<th>Identification number: ________________</th>
<th>Supervisor: ____________</th>
</tr>
</thead>
</table>

**Please rate the subject skill using the following scale.** (1. Selective transforaminal epidural nerve block, 2. Lumbar medial branch block, 3. Lumbar sympathetic nerve block)

<table>
<thead>
<tr>
<th>Operation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needles cannot be seen. Frequent use of unnecessary force when advancing the needle</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Occasionally, the needle goes out. Carefully observe the needle position.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Minimize damage to surrounding tissues. Consistent and careful handling of the needle</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time and movement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A lot of unnecessary movement</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Unnecessary movement, but more time-efficient</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>No unnecessary movement and time</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Needle insertion</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires repeated attempts to insert the needle</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sometimes awkward but can insert a needle in the first few attempts</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Needles can be inserted naturally without awkwardness</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiation device Operation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiographic images are often off-center to the target Inadequate angle adjustment during the procedure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The radiographic image usually points to the center of the target. Good angle adjustment during the procedure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Radiographic images always point to the center of the target and the needle. Proper adjustment of the appropriate angle continuously during the procedure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use of assistants</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failing to seek assistance from an assistant or reposition the imaging device</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Usually with the help of an experienced assistant</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Assisted by an assistant with the most appropriate strategy for the procedure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedure and progression</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stops frequently, or requires an examiner's advice or help</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Demonstrates the ability to perform surgical procedures with relatively steady progression</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Clearly shows natural progression and procedural steps from start to finish.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedure-related knowledge</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of knowledge. Most processes require specific instructions.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Knowing the important contents of the procedure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Familiarity with all aspects of the procedure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
The possible score is 7-35 points.