JOURNAL OF Surgical Simulation

*Journal of Surgical Simulation* (2020) **7**, 8–15
DOI: https://doi.org/10.1102/2051-7726.2020.0002

ORIGINAL ARTICLE

# Comparison of verbal, graphical and kinaesthetic cues for instructing pedicle screw cannulation angles within a virtual environment

**Stewart McLachlin,[a,b,*] Antony H. Bateman,[d,e] Albert J. Yee[d] and Cari Whyne[a,c,d]**

[a]*Orthopaedic Biomechanics Laboratory, Sunnybrook Research Institute, Toronto, Ontario, Canada;* [b]*Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, Ontario, Canada;* [c]*Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, Ontario, Canada;* [d]*Division of Orthopaedic Surgery, University of Toronto, Toronto, Ontario, Canada;* [e]*Department of Trauma and Orthopaedics, University Hospitals of Derby and Burton NHS Foundation Trust, Derby, UK*

**Corresponding author at: Mechanical and Mechatronics Engineering, Room E5 3001, University of Waterloo, 200 University Ave W, Waterloo, ON N2L 3G1, Canada. Email: stewart.mclachlin@uwaterloo.ca*

Date accepted for publication: 13 May 2020

## Abstract

**Background:** Instrumented spinal fusion surgery requires accurate angulation of surgical instruments relative to the anatomic planes for safe screw insertion into the vertebral anatomy. The visuospatial skills necessary for this surgery are developed through training and experience; however, there is a lack of available technologies to simulate this training environment. This study investigated a virtual environment to compare tool angulation performance of training and trained spine surgeons using different information delivery modalities. **Methods:** Nineteen surgeons were presented with tool angulation information using three different modalities within a custom virtual simulator (3D Slicer). In random order, angles were presented in 5° increments up to 50°, using three different methods: verbal, graphical or kinaesthetic. Participants were asked to reproduce the angles using a 25 cm probe tracked using a Leap Motion controller. The tool angle was recorded in a single plane and the absolute error was calculated from the desired angle. **Results:** Overall, there was a significant improvement in participant tool orientation accuracy with the kinaesthetic delivery method (angle error, 2.9° ± 2.2°) compared with the verbal (4.8° ± 3.9°) and graphical delivery methods (4.7° ± 4.0°). Distribution of absolute error values ranged from 0° to 21°; the largest errors were most common in the verbal delivery modality ($P < 0.05$). Angles were overestimated in 62% of tests. Participants with more surgical experience (fellowship trained) were more accurate than resident-level trainees ($P < 0.05$). **Conclusions:** Small tool orientation errors (mean, <5°) occur when surgeons reproduce specific two-dimensional tool angles; accuracy was improved with kinaesthetic training. These findings support the value of virtual simulation for technical skills development outside the operating room.

**Keywords:** *surgical training; visuospatial skills; motion tracking; virtual simulation; tool orientation*

## Introduction

Insertion of bone screws during surgery requires a physical understanding of the relationship between the orientation of the insertion instrument in the surgeon's hand and the, often obscured, underlying anatomic planes and geometry. Historically, the surgeon developed these skills through apprenticeship; mentors guided their trainees as they acquired the necessary skills in the operating room environment.[1] For visuospatial skills, such as tool orientation, a trainee surgeon would have relied on verbal, written or visual angle information to help guide the procedure. In spine surgery, technical notes and reports have described trajectory angles for safe insertion of screws, devices, and osteotomies at the different levels of the spinal column and are often posted visually within the operating room as reference.[2,3] In instances where the trainee has chosen an inappropriate tool orientation, the mentoring surgeon may guide the trainee's hand in positioning of an instrument to provide kinaesthetic feedback to aid learning.

With technological advances and improved understanding of the educational needs of trainees, the path to develop surgical skills is changing.[4–6] High-fidelity simulation tools have been developed and incorporated as part of the curricula to allow for the development of surgical skills without risk to patients.[7–10] For surgical specialities such as orthopaedics and neurosurgery, use of simulation-based training is increasing.[11–13] These tools, even in low-fidelity simulation, can enhance visuospatial skill development, especially for trainees who struggle in this area. Further, simulation offers the ability to evaluate the visuospatial abilities of trainees.[14] For visuospatial skills, trainees have most commonly been evaluated using standardized visuospatial tests, such as the mental-rotations test and others.[15,16] However, these tests do not evaluate the spatial orientation capabilities of surgical trainees to achieve a specific orientation of a tool in their hand.[17] There is currently little evidence to support the ability of spine surgeons to achieve the recommended trajectory angles (i.e. medialization in the axial plane and cephalad/caudal angulation in the sagittal plane) before pedicle screw insertion.[18]

Verbal, graphical, and kinaesthetic cues may help improve the performance of desired tool angulation, but it is not yet known if any of these information delivery modalities are more beneficial than the others. The purpose of this study was therefore to investigate the ability of training and fellowship-trained spine surgeons to estimate tool orientation for a range of pedicle cannulation angles and compare modalities for delivering this information within a virtual simulation environment. It was hypothesized that providing surgeon participants with visual prompts or kinaesthetic guidance would improve the accuracy of tool orientation.

## Methods

Study participants were recruited from the University of Toronto Department of Surgery Spine Program, including both orthopaedic spine and neurosurgery staff surgeons, clinical fellows and residents. Participants who completed spine fellowship training were considered the trained participants in the study, and orthopaedic surgical residents were considered training participants (Table 1).

The virtual simulation environment and workflow was created in the open-source medical imaging and visualization software 3D Slicer using a custom-written Python script.[19] The virtual simulation was bridged to the physical environment through the use of a Leap Motion controller (Leap Motion, San Francisco, CA, USA). Use of the Leap Motion allowed for three-dimensional (3D) tracking of a physical tool; a long wooden stick (25 cm) that could be held similar to a surgical tool used in the operating room (Fig. 1). The Leap Motion device was positioned on its side to capture a volume of space along a flat table surface. The custom

**Table 1.** Participant demographics and average cannulation error for modality of information delivery for all tests (± standard deviation)

| Group | No. | Highest training level achieved | Verbal error | Graphical error | Kinaesthetic error |
|---|---|---|---|---|---|
| Training | 1 | PGY-1 | 2.4 ± 1.8 | 4.1 ± 2.6 | 2.9 ± 2.1 |
| Training | 2 | PGY-1 | 6.5 ± 1.6 | 1.6 ± 1.8 | 2.4 ± 1.1 |
| Training | 3 | PGY-2 | 4.5 ± 3.8 | 2.3 ± 2.1 | 4.2 ± 2.5 |
| Training | 4 | PGY-2 | 5.3 ± 2.8 | 7.1 ± 4.4 | 3.9 ± 3.5 |
| Training | 5 | PGY-2 | 3.6 ± 2.2 | 6.4 ± 5.1 | 3.4 ± 1.8 |
| Training | 6 | PGY-3 | 3.6 ± 3.1 | 5.4 ± 5.5 | 4.4 ± 3.2 |
| Training | 7 | PGY-3 | 4.7 ± 3.7 | 7.9 ± 4.8 | 3.3 ± 2.4 |
| Training | 8 | PGY-4 | 5.1 ± 3.7 | 4.4 ± 3.1 | 4.5 ± 2.0 |
| Training | 9 | PGY-4 | 6.6 ± 6.6 | 5.0 ± 3.0 | 3.3 ± 1.9 |
| Training | 10 | PGY-4 | 6.1 ± 5.0 | 6.2 ± 5.7 | 1.4 ± 2.2 |
| Training | 11 | PGY-4 | 7.4 ± 2.9 | 6.6 ± 3.9 | 2.8 ± 2.2 |
| Trained | 12 | Fellowship | 7.9 ± 6.0 | 4.0 ± 3.7 | 1.9 ± 1.4 |
| Trained | 13 | Fellowship | 3.6 ± 3.8 | 3.0 ± 2.5 | 1.7 ± 1.6 |
| Trained | 14 | Fellowship | 5.1 ± 4.9 | 4.2 ± 3.4 | 3.3 ± 2.7 |
| Trained | 15 | Fellowship | 3.2 ± 3.6 | 3.9 ± 2.3 | 3.2 ± 2.0 |
| Trained | 16 | Fellowship | 3.7 ± 2.8 | 3.6 ± 3.6 | 1.1 ± 1.0 |
| Trained | 17 | Fellowship | 3.5 ± 2.8 | 4.1 ± 1.5 | 2.5 ± 1.6 |
| Trained | 18 | Fellowship | 5.5 ± 3.2 | 3.8 ± 4.6 | 2.3 ± 1.6 |
| Trained | 19 | Fellowship | 2.8 ± 3.2 | 6.1 ± 6.6 | 2.7 ± 2.4 |

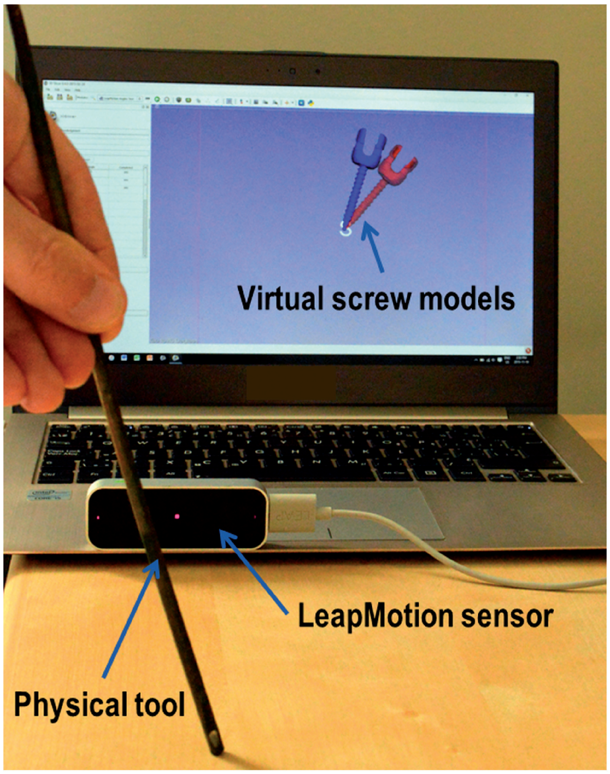



**Figure 1.** The Leap Motion sensor tracks the 3D orientation of the physical tool. The yaw planar angle (parallel to the sensor) was then applied to the virtual onscreen model in 3D Slicer software.

software recorded the real-time orientation of the tool pressed to the table based on the three angles of yaw, pitch and roll along with the location of the tool tip position at 100 Hz in the fixed reference frame of the Leap sensor.

At the start of the test, the participant was familiarized with the combined physical/virtual environment with a virtual pedicle screw model on screen that responded to the physical tool movements of the participants. The software applied only the yaw and pitch angular trajectories to a virtual pedicle screw model, where translation of the virtual model was fixed to reduce visuospatial complexity and stutter for the onscreen representation. Participants were informed that the physical tool was required to start in a vertical position and angle instructions considered as a single planar angle (yaw) measured from the vertical axis as the tool was moved towards the participant. This approach was chosen to simulate the operating room procedure for pedicle screw insertion, where the surgeon would initially identify the entry point and then angle the probe towards themselves based on the pedicle orientation. For further clarification between the virtual and physical environments, a visual notification was used to provide limited information about the detected tool position, whether it was visible (blue), not visible (red), or in the neutral 0° position (green). Colours were shown by changing a fiducial marker in the centre of the screen.

Participants completed the actual test in the second step of the workflow. The test consisted of a range of angles in 5° increments between 5° and 50° given in a random order such that all angles were completed for each of the three angle information presentation modalities. The angles were presented as (1) verbally from the examiner, with onscreen text (Fig. 2), (2) as an onscreen graphic depicting the required angle (Fig. 3), or (3) kinaesthetically (Fig. 4). The kinaesthetic option displayed both the real-time tool position and target position on screen as a virtual pedicle screw model. The user was then able to move the tool position to the correct target position in both the virtual and physical space, informed by a colour change of the tool position model. The user was then required to return to the neutral position before having to repeat this same position without visual assistance. Participants confirmed angle acceptance verbally with the examiner. Between each test. the participant was required to return to the neutral position before the next angle prompt was shown. In total, each participant completed 30 angle tests.

The final step displayed the target angle for all 30 tests with the actual angle achieved. The absolute difference between the target and actual angles were used as the outcome measure for the participant evaluation. Differences were compared between the different angle presentation modalities. Participants were also compared based on the level of surgical experience (resident level versus fellowship trained).

### Statistical analysis

Statistical analysis was performed using an analysis of variance with Tukey's honest significant difference post-hoc comparison as well as a Moses test of extreme reactions ($\alpha = 0.05$) using R statistical software (version 3.1.3; R Core Development Team, Vienna, Austria).

## Results

Nineteen surgeons participated in the test. There were 8 participants in the fellowship-trained group and 11 in the resident-level training group (Table 1). On average, the entire test was completed in approximately 5 min, with each orientation request taking about 5–10 s to locate each angle.

Evaluating all participants and angle presentation modalities, there was an average angle discrepancy of 4.1° ± 3.6°. Error values between 1° and 3° were most frequent. There was an improvement in participant tool orientation

| Verbal delivery cues | Representation in virtual environment |
|---|---|
| • The participant was asked verbally by the examiner to "move the tool to XX degrees"<br>• Text appeared in the virtual environment to confirm the desired angle |  |

**Figure 2.** Details on the verbal method of cannulation angle delivery.

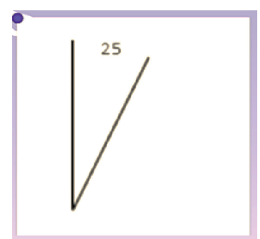
| Graphical delivery cues | Representation in virtual environment |
|---|---|
| • The image in the virtual environment updated to show a true graphical representation of the desired angle |  |

**Figure 3.** Details on the graphical method of cannulation angle delivery.

accuracy (Fig. 5) with the kinaesthetic delivery method (angle error, 2.9° ± 2.2°) compared with the verbal (4.8° ± 3.9°) and graphical cues (4.7° ± 4.0°) ($P < 0.05$). Distribution of absolute error values ranged from 0° to 21°, with extreme errors most likely in the verbal only modality ($P < 0.05$). In general, participant's accuracy did not improve over the course of the 30 angle tests completed in random order. Tool angles were overestimated in 62% of tests. Participants with more surgical experience (fellowship trained) were more accurate on average (Fig. 6) than resident-level trainees ($P < 0.05$).

## Discussion

This study evaluated a simulated environment that merged a physical and virtual spatial relationship to assess a surgeon's ability to achieve a desired tool orientation based on the information delivery method. Overall, surgeon participants were able to achieve the desired tool orientation with an average error of approximately 4° across all tests combined. Comparison of the modalities showed that the most effective information delivery method was the kinaesthetic modality, which provided some visuospatial guidance to the surgeon before the actual blinded test. For verbal and graphical delivery methods, there was a significant increase in orientation error of almost 2° compared with the kinaesthetic delivery mode. Although the simulation had only a short delay between angle re-creation time points in the kinaesthetic delivery, these results suggest that there is an element of visuospatial muscle memory that could benefit surgical procedures such as pedicle screw insertion that rely on these skills.

With only verbal delivery of the desired angle, there was an increased likelihood of an extreme error value compared with the other delivery methods. This suggests that visual cues can improve performance in visuospatial tasks (although some large errors did still occur across all participants and delivery modes). Although the simulated task was relatively simple, the commonality of these seemingly random error outliers may be linked to evidence supporting use of surgical navigation to reduce the likelihood of significant deviations from the optimal trajectory in procedures such as pedicle screw insertion.[20] Even in cases where surgical navigation is used, the surgeon must still rely on their visuospatial abilities to recognize the difference between an appropriate and error-prone tool orientation, often linked to the technical skill of the surgeon.[1,21]

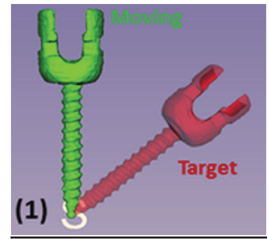
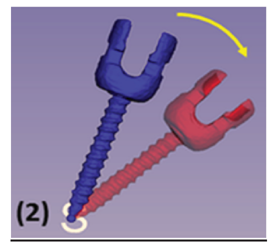
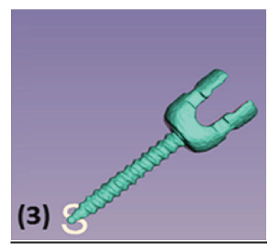
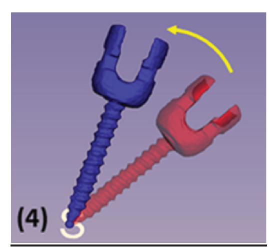
| Kinaesthetic delivery cues | Representation in virtual environment |
|---|---|
| • **Step 1:** the virtual environment updated to show the live "moving" position of the tool and the fixed "target" position of the desired angle<br>• The "moving" model was green when in the reference position |  |
| • **Step 2:** the participant moved the tool towards the target orientation angle<br>• The "moving" model colour changed to dark blue |  |
| • **Step 3:** once the participant reached the desired orientation angle with the "moving" model, it changed colour to teal when it was on top of the "target" model for 2 s |  |
| • **Step 4:** the participant returned the tool to the reference position for 1 s |  |
| • **Step 5:** the virtual environment updated to remove both the "moving" and "target" models from the screen<br>• The participant then attempted to move the tool to the same orientation angle as the previous guided step |  |

**Figure 4.** Details on the kinaesthetic method of cannulation angle delivery.

Within orthopaedics, surgeons routinely use visual inspection of joint angles as a diagnostic tool. This ability has been shown to improve with training and experience. However, the accuracy in performing these tasks, even by experienced surgeons, has been called into question.[22] In this study, the more experienced group of surgeons (fellowship trained) were able to more accurately achieve the desired tool orientation than the resident-level group. This suggests that these visuospatial skills can be learned over time and may be amenable to training. Furthermore, this represents an

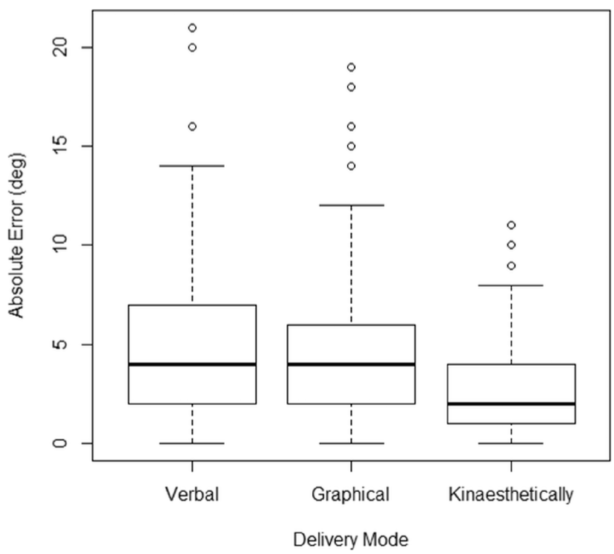



**Figure 5.** Absolute error (degrees) of the tool orientation angle versus the angle delivery information mode. The kinaesthetic delivery mode had a smaller error ($P < 0.05$) than the verbal and graphical angle presentation modalities.

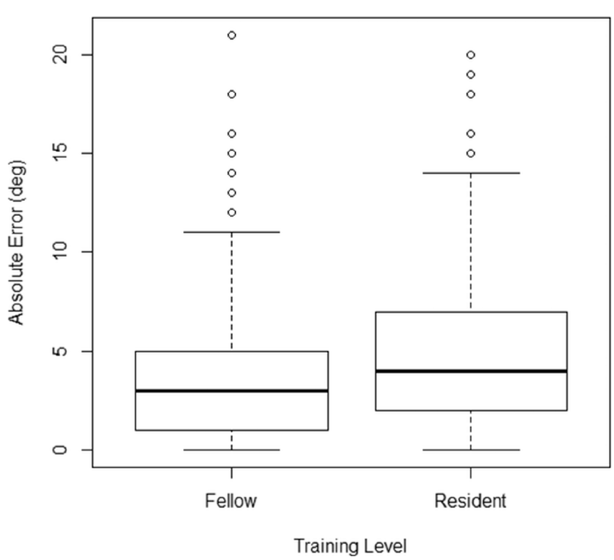



**Figure 6.** Absolute error (degrees) of the tool orientation angle versus the surgical training level of the participants. The fellow group had a smaller error ($P < 0.05$) than the resident level group.

important potential application for the developed interactive module on the open-source 3D Slicer software platform, providing an opportunity to gain these visuospatial skills through simulation.

There is increasing demand for surgical simulation tools to train surgeons in critical operating room tasks whilst minimizing risk to patients.[11–13] Recent work has established the potential benefits of simulators for training surgeons; they appear to enhance performance without risk to patients by removing the early stages of learning and complex skill development from the operating room. In several studies, such simulators have been shown to improve task performance among trainees.[23,24] It has also been shown that both low- and high-fidelity simulation can lead to transfer of skills, with a balance that must be achieved between fidelity and the cost and accessibility of the simulator.[25] Despite this work, the authors are not aware of any studies to date that evaluate the mode of information delivery within a surgical simulation environment. Outside orthopaedics, a recent study by Naidu et al.[26] asked 106 doctors and midwives attending a perineal trauma conference to cut a simulated episiotomy at 60°. They found that only 15% of participants were in the range 58°–62° with 44% less than 55° and 18% greater than 65°. The authors concluded that the delegates were poor at estimating the appropriate angle and suggested the need for further structured training.

There are some relevant limitations of this study. First, the delivered angle information and required tool orientation was assessed in only a single plane. In reality, the process of selecting the correct trajectory of a surgical tool requires multi-planar angle selection. Although the simulation platform was capable of these measurements, it was felt that initial assessment of the delivery modality was best accomplished within a single plane. It is anticipated that errors in tool orientation are likely greater with the increased complexity of multi-planar orientation, but this also likely requires multiple sensors or more sophisticated equipment for accurate measurements than was used in the current study. Further, the simulation platform delivered information on a 2D computer screen, making no use of 3D or stereoscopic visual input systems. The subsequent angle reproduction with the tool in the 3D physical environment potentially allows for stereoscopic visual clues to be utilized; however, the effectiveness of this additional visuospatial information is unknown.

From a translational perspective, although tool angle trajectory is an important part of pedicle screw insertion, other factors, such as entry point selection and haptic feedback during probe advancement, are also important. These were not simulated in the present study. Other potentially relevant factors that may affect tool positioning performance include, but are not limited to, age, handedness, caffeine consumption, sleep and experience with other simulation tools and environments. Lastly, there was only a brief delay between the kinaesthetic delivery and the actual blinded test. Further work will be required to establish whether the same accuracy improvement exists if the productive motor task is required at a delayed interval.

Overall, this study found that a kinaesthetic information delivery modality was optimal for surgeon participants to reproduce desired tool orientation angles within an interactive simulated environment. These results help to further support the development and use of virtual training simulators with motion tracking to acquire and maintain critical technical skills needed for safe surgical operations. Towards improving clinical practice, enhanced tool positioning performance for pedicle screw insertion gained through kinaesthetic training could potentially reduce the amount of intraoperative imaging and radiation exposure to the patient needed for safe implant insertion.

## Conflicts of interest

None declared.

## References

1. Reznick RK. Teaching and testing technical skills. Am J Surg 1993; 165: 358–361. https://doi.org/10.1016/S0002-9610(05)80843-8.
2. Zindrick MR, Wiltse LL, Doornik A, Widell EH, Knight GW, Patwardhan AG, et al. Analysis of the morphometric characteristics of the thoracic and lumbar pedicles. Spine (Phila Pa 1976) 1987; 12: 160–166. https://doi.org/10.1097/00007632-198703000-00012.
3. Saillant G. Anatomical study of the vertebral pedicles. Surgical application]. Rev Chir orthopédique réparatrice l'appareil Mot 1976; 62: 151–160 [in French].
4. Nousiainen MT, McQueen SA, Ferguson P, Alman B, Kraemer W, Safir O, et al. Simulation for teaching orthopaedic residents in a competency-based curriculum: do the benefits justify the increased costs?. Clin Orthopaed Relat Res 2016; 474: 935–944. https://doi.org/10.1007/s11999-015-4512-6.
5. Dwyer T, Wadey V, Archibald D, Kraemer W, Shantz JS, Townley J, et al. Cognitive and psychomotor entrustable professional activities: can simulators help assess competency in trainees? Clin Orthop Relat Res 2016; 474: 926–934. https://doi.org/10.1007/s11999-015-4553-x.
6. Kaufman HH, Wiegand RL, Tunick RH. Teaching surgeons to operate—principles of psychomotor skills training. Acta Neurochir (Wien) 1987; 87: 1–7. https://doi.org/10.1007/BF02076007.
7. Rambani R, Ward J, Viant W. Desktop-based computer-assisted orthopedic training system for spinal surgery. J Surg Educ 2014; 71: 805–809. https://doi.org/10.1016/j.jsurg.2014.04.012.
8. Mattei TA, Frank C, Bailey J, Lesle E, Macuk A, Lesniak M, et al. Design of a synthetic simulator for pediatric lumbar spine pathologies. J Neurosurg Pediatr 2013; 12: 192–201. https://doi.org/10.3171/2013.4.PEDS12540.
9. Kellermann K, Salah Z, Mönch J, Franke J, Rose G, Preim B. Improved spine surgery and intervention with virtual training and augmented reality. In: International Workshop on Digital Engineering. 2011, p. 8–15. Available from: http://wwwisg.cs.uni-magdeburg.de/visualisierung/wiki/data/media/files/surgery_simulation_training/kellermann_2011_iwde.pdf.
10. Klein S, Whyne CM, Rush R, Ginsberg HJ. CT-based patient-specific simulation software for pedicle screw insertion. J Spinal Disord Tech 2009; 22: 502–506. https://doi.org/10.1097/BSD.0b013e31819877fd.
11. Atesok K, Mabrey JD, Jazrawi LM, Egol KA. Surgical simulation in orthopaedic skills training. J Am Acad Orthop Surg 2012; 20: 410–422. https://doi.org/10.5435/JAAOS-20-07-410.
12. Sturm LP, Windsor JA, Cosman PH, Cregan P, Hewett PJ, Maddern GJ. A systematic review of skills transfer after surgical simulation training. Ann Surg 2008; 248: 166–179. https://doi.org/10.1097/SLA.0b013e318176bf24.
13. Arnold P, Bohm P. Simulation and resident education in spinal neurosurgery. Surg Neurol Int 2015; 6: 33. https://doi.org/10.4103/2152-7806.152146.
14. Gallagher AG, Satava RM, Shorten GD. Measuring surgical skill: a rapidly evolving scientific methodology. Surg Endosc 2013; 27: 1451–1455. https://doi.org/10.1007/s00464-013-2786-x.
15. Wanzel KR, Hamstra SJ, Anastakis DJ, Matsumoto ED, Cusimano MD. Effect of visual-spatial ability on learning of spatially-complex surgical skills. Lancet 2002; 359: 230–231. https://doi.org/10.1016/S0140-6736(02)07441-X.
16. Lufler RS, Zumwalt AC, Romney CA, Hoagland TM. Effect of visual-spatial ability on medical students' performance in a gross anatomy course. Anat Sci Educ 2012; 5: 3–9. https://doi.org/10.1002/ase.264.
17. Anastakis DJ, Hamstra SJ, Matsumoto ED. Visual-spatial abilities in surgical training. Am J Surg 2000; 179: 469–471. https://doi.org/10.1016/S0002-9610(00)00397-4.
18. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement in vivo. Spine 1990; 15: 11–14. https://doi.org/10.1097/00007632-199001000-00004.
19. Fedorov A, Beichel R, Kalpathy-Cramer J, Finet J, Fillion-Robin JC, et al. 3D Slicer as an image computing platform for the Quantitative Imaging Network. Magn Reson Imaging 2012; 30: 1323–1341. https://doi.org/10.1016/j.mri.2012.05.001.
20. Flynn JM, Sakai DS. Improving safety in spinal deformity surgery: advances in navigation and neurologic monitoring. Eur Spine J 2013; 22: 131–137. https://doi.org/10.1007/s00586-012-2360-6.
21. Reznick RK, MacRae H. Teaching surgical skills—changes in the wind. N Engl J Med 2006; 355: 2664–2669. https://doi.org/10.1056/NEJMra054785.

22. Luria S, Apt E, Kandel L, Bdolah-Abram T, Zinger G. Visual estimation of pro-supination angle is superior to wrist or elbow angles. Phys Sport 2015; 43: 155–160. https://doi.org/10.1080/00913847.2015.1037230.
23. Xiang L, Zhou Y, Wang H, Zhang H, Song G, Zhao Y, et al. Significance of preoperative planning simulator for junior surgeons' training of pedicle screw insertion. Clin Spine Surg 2015; 28: E25–E29. https://doi.org/10.1097/BSD.0000000000000138.
24. Luciano CJ, Banerjee PP, Sorenson JM, Foley KT, Ansari SA, Rizzi S, et al. Percutaneous spinal fixation simulation with virtual reality and haptics. Neurosurgery 2013; 72(suppl 1): A89–A96. https://doi.org/10.1227/NEU.0b013e3182750a8d.
25. Norman G, Dore K, Grierson L. The minimal relationship between simulation fidelity and transfer of learning. Med Educ 2012; 46: 636–647. https://doi.org/10.1111/j.1365-2923.2012.04243.x.
26. Naidu M, Kapoor DS, Evans S, Vinayakarao L, Thakar R, Sultan AH. Cutting an episiotomy at 60 degrees: how good are we? Int Urogynecol J 2015; 26: 813–816. https://doi.org/10.1007/s00192-015-2625-9.