South Afr J Anaesth Analg. 2023;29(1):18-22
https://doi.org/10.36303/SAJAA.2839

South Afr J Anaesth Analg
ISSN 2220-1181 EISSN 2220-1173

ORIGINAL RESEARCH

Comparing paediatric caudal injection simulation on a 3D-printed, gelatine-cast part-task trainer and the Life/form® Pediatric Caudal Injection Simulator, to real anatomy, by specialist opinion

H Janse van Rensburg, DJ van der Merwe

Department of Anaesthesiology, Kalafong Provincial Tertiary Hospital, University of Pretoria, South Africa
Corresponding author, email: *u27000975@tuks.co.za*

Background: Paediatric caudal anaesthesia is an established technique. Commercially, only one paediatric caudal part-task trainer (PTT) exists. In the South African context, access to caudal block simulation training is lacking. A reusable paediatric caudal anaesthesia trainer was produced through three-dimensional (3D) printing, silicone moulding and gelatine casting. This study compared the local and commercial trainers to patient-based anatomy, by specialist opinion. This was done to validate the locally manufactured PTT for potential anaesthesia training.

Methods: Specialist anaesthesiologists (n = 30) randomly performed a caudal block on each trainer. Visual analogue scales were completed for each PTT, comparing four variables to real patient anatomy (i.e. palpation of bony landmarks and sacral hiatus; simulation of soft tissue; loss of resistance to needle insertion into the epidural space; overall similarity of the experience to caudal injection on a real patient). As a secondary outcome, correct needle placement was confirmed using ultrasound on the 3D-printed trainer.

Results: Bony landmark and sacral hiatus palpation rated a median of 36.50% for the 3D-printed trainer and a mean of 36.58% for the Life/form® trainer (p = 0.28). Soft tissue simulation rated a median of 56.75% for the 3D-printed trainer and a mean of 43.23% for the Life/form® trainer (p = 0.11). Loss of resistance rated a median of 56% and 48.50% for the 3D-printed and Life/form® trainers, respectively (p = 0.44). Overall similarity of the experience to real anatomy rated a median of 52% for the 3D-printed trainer and a mean of 41.97% for the Life/form® trainer (p = 0.23). Simultaneous comparison of all four variables between the two trainers showed no statistically significant difference (p = 0.64). Ultrasound confirmed correct needle placement for 86.67% of participants on the 3D-printed trainer.

Conclusion: The two caudal anaesthesia PTTs demonstrated no significant difference in performance, as judged by specialist opinion. Both models need improvement in terms of fidelity, compared to real anatomy. Using 3D printing to produce PTTs may improve local availability.

Keywords: paediatric caudal anaesthesia, part-task trainer, 3D printing

Introduction

Many medical and surgical specialities have employed three-dimensional (3D) printing technology in training, research, development, preoperative planning and implant construction.[1-3] Although this technology is commonly used in other specialities, there is a significant paucity in literature on 3D printing application in anaesthesiology.[4] In line with this, West et al.[5] rendered a 3D model of an adult lumbar spine using a real patient CT scan and commercial software. The 3D-printed model was used to develop an ultrasound part-task trainer (PTT) for spinal injection training. The conclusion was that 3D printing is a promising method for producing affordable PTTs with designs that can easily be shared between institutions. However, most of the available literature seems to be centred on models that simulate adult anatomy.

There is a developing trend towards the implementation of simulation-based training in paediatric anaesthesiology.[6] Literature shines a light on various modalities available to anaesthesiology trainees. This includes PTTs, computer-based simulations, and low- and high-fidelity manikins.[7-9] Although many commercial paediatric lumbar injection PTTs are available, only the Life/form® Pediatric Caudal Injection Simulator supports caudal injection simulation training.[8,10] Caudal anaesthesia is a widely used and accepted form of regional anaesthesia in the paediatric population. Its administration is indicated for anaesthesia and analgesia in surgical and non-surgical sub-umbilical interventions.[11]

Anaesthesiologists have been pioneering simulation-based education as critical skills need to be taught and mastered in a manner that prioritises patient safety.[7] The clinical skills centres of all the South African universities that offer medical training confirmed that they do not own a paediatric caudal injection PTT. The anaesthesiology departments of three academic institutions in Gauteng also confirmed that they do not own such a PTT and that patient-physician contact is used to teach paediatric caudal injection. Multiple authors have commented on the value of simulation-based task training before patient-physician contact.[12,13] It has the potential to refine trainees' skills prior to patient contact, and to improve the safety and efficacy of paediatric regional anaesthesia.

A paediatric caudal anaesthesia PTT was produced locally using 3D printing technology, silicone moulding and gelatine casting. This study compared the locally manufactured PTT and commercially available model to patient-based anatomy, by specialist opinion. This was to validate the 3D-printed, gelatine-cast PTT for potential use in anaesthesia training.

Methods

Approval to conduct this cross-sectional comparative study was obtained from the relevant authorities, including the Ethics Committee and the MMed Protocol Committee of the University of Pretoria. All participants were given an information sheet and verbally consented to participate. All data were collected by completion of anonymous questionnaires.

In consultation with a biostatistician from the South African Medical Research Council, a minimum sample size of 26 participants was identified. All participants were specialist anaesthesiologists who have performed at least ten paediatric caudal blocks during their professional careers.

The Life/form® simulator and consumables were acquired through Live Wire Learning, a company that imports training models to South Africa.

An anonymised CT scan dataset from a paediatric patient was obtained from the Department of Radiology at Kalafong Provincial Tertiary Hospital with the necessary ethical clearance. Open-source software 3D Slicer (http://slicer.org) was used to render a digital 3D model of the bony sacrum. Meshmixer software was used to correct anatomical variation in the digital model. Less than 10% of the original anatomy was modified.

The bony elements were 3D printed through a process called laser sintering with a nylon-type material. A ligamentum flavum was modelled from a negative cast of the 3D-printed sacrum and made from silicone paste. A dural sac was mimicked by filling a finger of a rubber glove with blue food colourant and psyllium husk, to act as a tracer on ultrasound (Figure 1). The final model was scaled to match the commercial caudal PTT in size and then mounted on a computer-aided design and 3D-printed three-way adjustable axial system to orientate its position within the final gelatine mould.

Liquid rubber and gauze mesh was used to create a mould from an artistically created terracotta sculpture of a toddler's back and buttock. A mixture consisting of 300 g food grade gelatine, 300 ml glycerine, 1 600 ml water, 12.5 ml honey and 12.5 ml food colourant was used to cast the bony element within the rubber mould (Figure 2).

A total of 30 participants were recruited from the Department of Anaesthesiology, University of Pretoria. Each participant was asked two questions: (i) How many paediatric caudal blocks do they estimate to have done during their career (10–50; > 50); and (ii) Do they think training on a caudal block PTT would be beneficial before physician-patient interaction (yes; no; undecided). Participants had one attempt to perform a caudal block on each PTT with a 22 G caudal needle. Participants were randomised to start on either of the PTTs using http://www.randomizer.org. Once the participant was satisfied with needle tip placement in the epidural space, the needle was left in situ. The participant then anonymously completed a questionnaire. Each PTT was compared to real paediatric patient anatomy by rating four variables on a visual analogue scale (VAS): (i) palpation of bony landmarks and sacral hiatus; (ii) the simulation of soft tissue; (iii) loss of resistance to needle insertion into the epidural space; and (iv) overall similarity of the experience to caudal injection on a real patient. Each variable was scored between 0% (no similarity) and 100% (exact similarity).

Subsequently, the position of the needle tip was assessed by a single observer. Fluid backflow through the needle on the 3D-printed PTT signified dural sac puncture and incorrect needle tip placement. As a secondary outcome, correct needle tip placement in the epidural space was confirmed on ultrasound. Figure 3 shows the transverse and longitudinal ultrasound views of the 3D-printed PTT before and after caudal needle insertion. Reciprocally, fluid backflow through the needle on the Life/form® PTT signified correct needle tip placement. The model was set up as a water-based system. It uses continuous, water-filled latex tubing that runs from the lumbar spine down to the sacral hiatus. Needle puncture of this tube in the lumbar section mimics cerebrospinal fluid backflow. Puncture with backflow in the sacral section represents needle tip placement in the caudal epidural space. According to the instruction manual,[14] this latex tubing can also be set up as a water-free system, where puncture

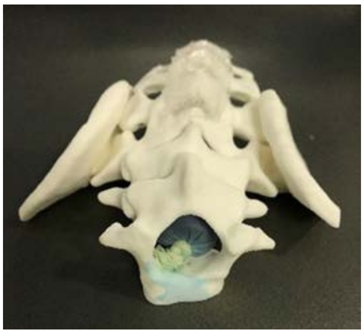

Figure 1: 3D-printed sacrum with ligamentum flavum and dural sac

Figure 2: Final gelatine-cast task trainer

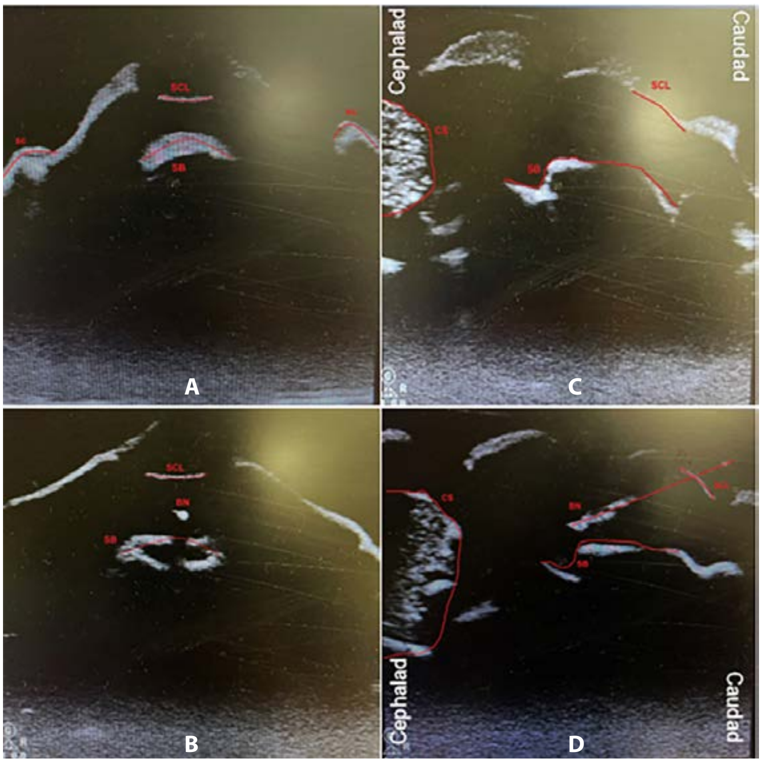

Figure 3: Transverse ultrasound view of 3D-printed PTT before (A) and after (B) needle insertion; longitudinal ultrasound view of 3D-printed PTT before (C) and after (D) needle insertion

SC – sacral cornua, SB – sacral base, SCL – sacrococcygeal ligament, CS – caudal sac, BN – block needle

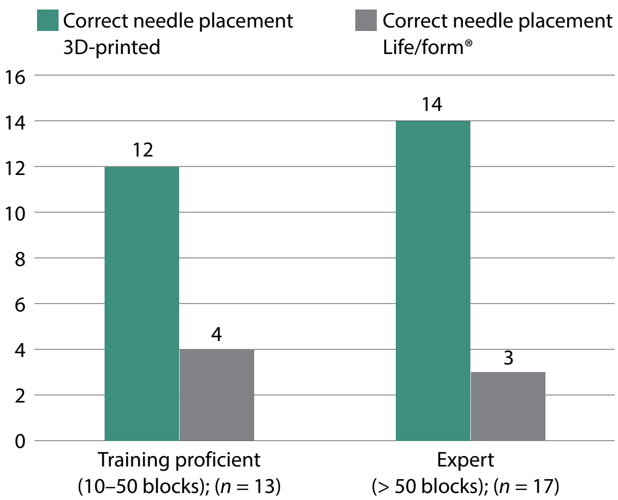

Figure 4: Number of correct needle tip placements on 3D-printed and Life/form® PTTs, grouped according to estimated number of caudal blocks performed

of the tubing and fluid injection mimics caudal injection. The Life/form® PTT was not amenable to ultrasound.

The 3D-printed PTT was recast after each use. This was done to prevent introducing bias by possible residual needle tracks visible in the gelatine after puncture. The gelatine also showed variable degrees of breakdown after palpation. The back pad on the Life/form® PTT was replaced after every ten needle insertions even though it did not show any residual puncture marks during the first ten punctures. However, to prevent introducing bias by possible residual puncture marks visible from overuse, the back pads were consistently replaced.

Data were captured into a Microsoft® Excel spreadsheet (Microsoft, USA). STATA 16 (StataCorp LCC, USA) was used to perform a statistical analysis of the data. Frequencies and proportions were calculated for categorical data. Normally distributed data were reported as means and standard deviations (SD). Non-normally distributed data were reported as medians, ranges and interquartile ranges (IQR). Hotelling's T-squared multivariate test was used to compare differences between the 3D-printed and Life/form® PTTs, to test whether all four variables for each PTT were simultaneously different from zero. Paired t-tests were used to compare the 3D-printed PTT with the Life/form® PTT on each of the four variables individually. A *p*-value of < 0.05 was statistically significant. Pearson correlation was used to test for associations between the VAS scores for both PTTs.

Results

This study recruited 30 specialist anaesthesiologists, which were grouped according to the estimated number of paediatric caudal blocks performed during their careers. There were 13 participants (43.33%) who performed 10–50 blocks, and this group was classified as training proficient. The group of anaesthetists who had performed > 50 blocks was classified as expert and had 17 participants (56.66%). When asked whether they think training on a caudal block PTT would be beneficial before physician-patient interaction, 96.67% ($n = 29$) of the participants answered 'yes' and 3.33% ($n = 1$) answered 'undecided'.

Most participants failed to site the needle tip into the latex tubing that mimics the epidural space on the Life/form® PTT. Figure 4 shows that the number of correct needle tip placements on the 3D-printed PTT was consistently higher than on the Life/form® PTT in both participant groups.

Compared to normal anatomy, bony landmark and sacral hiatus palpation was rated a median of 36.50% (27.00–61.69%) for the 3D-printed PTT and a mean of 36.58% (± 23.23%) for the Life/form® PTT ($p = 0.28$). Soft tissue simulation was rated a median of 56.75% (31.53–69.00%) for the 3D-printed PTT and a mean of 43.23% (± 22.46%) for the Life/form® PTT ($p = 0.11$). Loss of resistance was rated a median of 56% (36.75–71.81%) and 48.50% (28.13–59.25%) for the 3D-printed and Life/form® PTTs, respectively ($p = 0.44$). Overall similarity of the experience to real anatomy was rated a median of 52% (33.75–66.63%) for the 3D-printed PTT and a mean of 41.97% (± 25.41%) for the Life/form® PTT ($p = 0.23$). Comparison between the two PTTs for each variable was not statistically significant. Figure 5 shows the box and whisker plots for each rated variable.

When all four variables were simultaneously compared between the two PTTs (Figure 6) there was no statistically significant

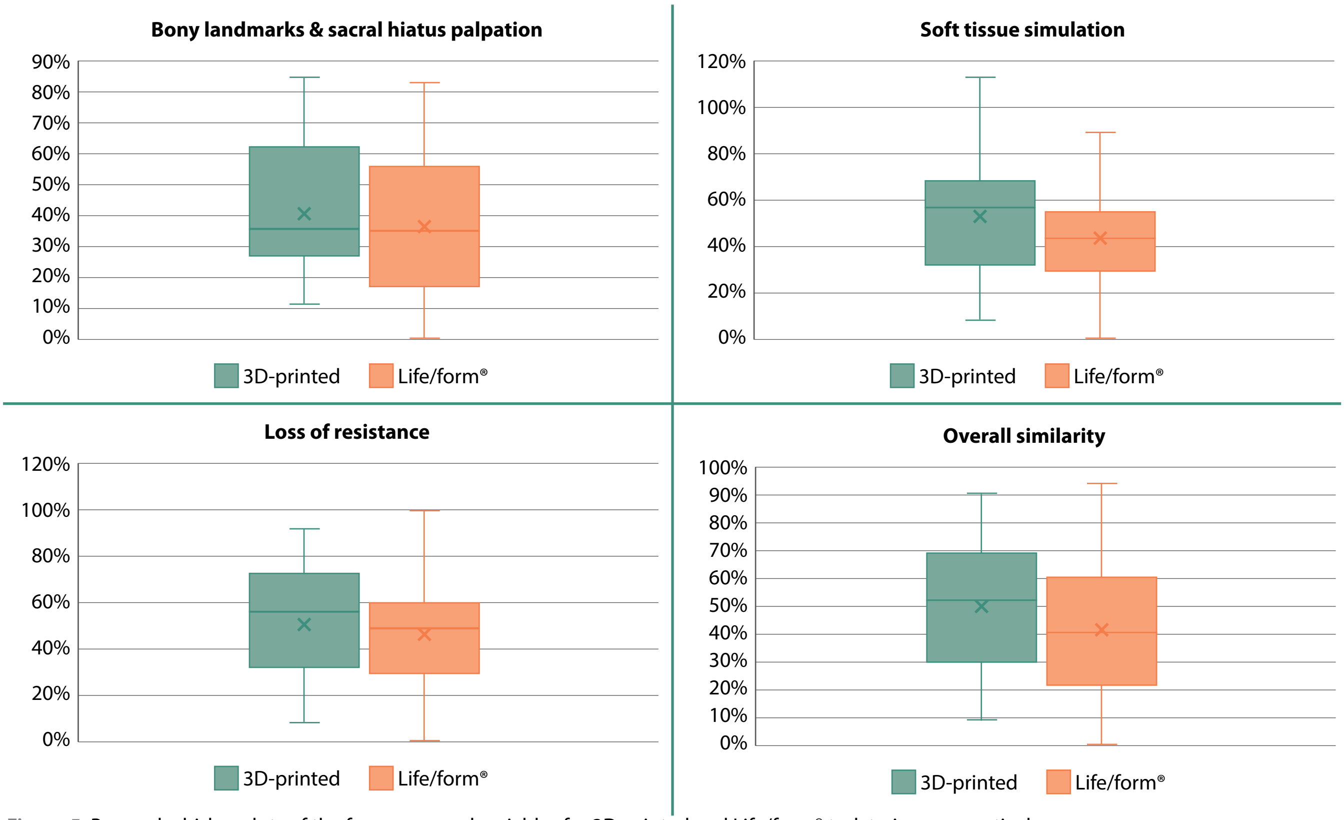

Figure 5: Box and whisker plots of the four measured variables for 3D-printed and Life/form® task trainer, respectively

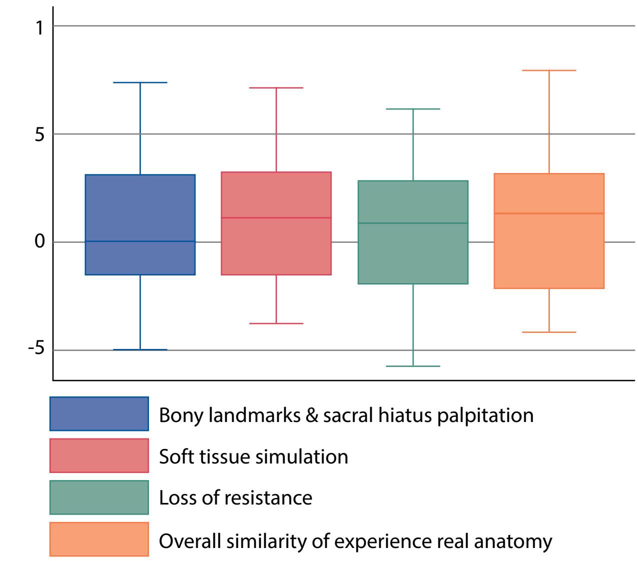

Figure 6: Box and whisker plots for simultaneous comparison of task trainer variables

difference between the 3D-printed and Life/form® PTTs (p = 0.64). There was a low linear correlation between the data for the two PTTs which resulted in low power.

Discussion

Paediatric caudal injection is a commonly used technique to achieve anaesthesia and analgesia. Nearly 25% of anaesthetic procedures performed on paediatric patients today involve regional anaesthesia. Caudal anaesthesia accounts for 34–40% of these procedures.[11] Although ultrasound-guided caudal injection has been described for quite some time, the majority of anaesthesiologists still perform the procedure blindly by relying on palpation and tactile feedback to confirm correct local anaesthetic administration.[15] In the South African academic milieu, caudal anaesthesia training relies on theoretical knowledge of the procedure and supervised patient-physician interaction. Caudal anaesthesia PTTs are not readily available and certainly not ultrasound compatible. This study indicated that 97.67% of participants, who represented anaesthesia providers with a wide range of experience levels in paediatric caudal anaesthesia administration, thought training on a PTT before patient-physician contact would be beneficial.

Comparing the main tactile aspects of caudal injection between the two PTTs showed that there is no significant difference between the two. In all four of the rated variables, the 3D-printed PTT scored a higher median or mean, and maximum percentage than the Life/form® PTT. This translates to the 3D-printed PTT being on par with the only commercially available paediatric caudal injection simulator, by specialist opinion. The 3D-printed PTT was locally produced, making it less expensive and easier to acquire for South African academic anaesthesiology departments. The current cost of the Life/form® PTT is R20 692. Taking current product and service costs into consideration, the 3D-printed PTT would cost approximately R3 000 to construct.

The 3D-printed PTT also held the added benefit of being ultrasound compatible. In all 30 attempts on the 3D-printed PTT, the needle tip was clearly visualised in both the long and the short axis ultra-sonographic views. Correct needle tip placement was thus easily confirmed. Ultrasound compatibility avails the 3D-printed PTT to the possibility of ultrasound-guided caudal block training. Having a caudal anaesthesia PTT that is ultrasound compatible and locally producible could aid in cultivating safer paediatric caudal injection practises. 3D printing technology makes this a possibility.

Study limitations

The gelatine mixture used to simulate soft tissue variably showed breakdown during palpation of the 3D-printed PTT. The severity and rate of gelatine breakdown were as follows: none – 20% (*n* = 6); mild – 63.33% (*n* = 19); moderate – 6.67% (*n* = 2); and gross 10% (*n* = 3). The gelatine-based PTT needed to be refrigerated overnight, which hampered operational use and scaling in a training environment. Furthermore, casting and setting the PTT was laborious, and occasionally the bony axial system dislodged from its orientation during refrigeration, requiring recasting.

Future improvement could include a more durable silicone-based cast of the PTT which would likely also improve trainer fidelity. Various silicone rubbers have been used to construct ultrasound compatible PTTs.[16,17] Silicone casting would increase production expenses but will allow for the reuse of the PTT. Silicone is considered inert and therefore less toxic to the environment, but silicone recycling is energy intensive and more research is needed to improve these processes.[18]

Conclusion

The two paediatric caudal anaesthesia PTTs demonstrated no significant difference in performance, as judged by specialist opinion. Both models have room for improvement in terms of fidelity compared to real anatomy. This study has shown that there is value in constructing a 3D-printed, gelatine-cast paediatric caudal anaesthesia PTT. It could facilitate training in ultrasound-guided caudal injection and familiarise anaesthesiology trainees with the tactile aspects of caudal blocks before patient-physician interaction. Using 3D printing for local production of simulators may improve the availability of PTTs in South African academic institutions.

Conflict of interest

This project was done in partial fulfilment of the requirements for the degree MMed in Anaesthesiology for Dr H Janse van Rensburg. The concept was presented by Dr DJ van der Merwe at the Innovation in Anaesthesia symposium hosted by the University of the Free State in February 2022. The results of this project was presented, as a condition of funding from the Scholarship of Teaching and Learning, at the Flexible Futures congress hosted by the University of Pretoria in August 2022.

Funding source

Funding was sourced from The Scholarship of Teaching and Learning at the University of Pretoria for the procurement of a departmental 3D printer. Funding from this platform in no way influenced the research design and was sourced after ethics clearance was granted.

Ethical approval

This study was approved by the University of Pretoria Faculty of Health Sciences Research Ethics Committee (Reference number: 590/2020) and the South African National Health Research Database (Reference number: GP_202101_003).

ORCID

H Janse van Rensburg https://orcid.org/0000-0002-1497-4901
DJ van der Merwe https://orcid.org/0000-0001-9126-8800

References

1. Mitsouras D, Liacouras P, Imanzadeh A, et al. Medical 3D printing for the radiologist. Radiographics. 2015;35(7):1965-88. https://doi.org/10.1148/rg.2015140320.
2. Michalski MH, Ross JS. The shape of things to come: 3D printing in medicine. JAMA. 2014;312(21):2213-4. https://doi.org/10.1001/jama.2014.9542.
3. Ventola CL. Medical applications for 3D printing: current and projected uses. P T. 2014;39(10):704-11.
4. Chao I, Young J, Coles-Black J, et al. The application of three-dimensional printing technology in anaesthesia: a systematic review. Anaesthesia. 2017;72(5):641-50. https://doi.org/10.1111/anae.13812.
5. West SJ, Mari J-M, Khan A, et al. Development of an ultrasound phantom for spinal injections with 3-dimensional printing. Reg Anesth Pain Med. 2014;39(5):429-33. https://doi.org/10.1097/AAP.0000000000000136.
6. Kovatch KJ, Powell AR, Green K, et al. Development and multidisciplinary preliminary validation of a 3-dimensional-printed pediatric airway model for emergency airway front-of-neck access procedures. Anesth Analg. 2020;130(2):445-51. https://doi.org/10.1213/ANE.0000000000003774.
7. Fehr JJ, Honkanen A, Murray DJ. Simulation in pediatric anesthesiology. Pediatr Anesth. 2012;22:988-94. https://doi.org/10.1111/pan.12001.
8. White ML, Ades A, Shefrin AE, Kost S. Task and procedural skills training. In: Grant VJ, Cheng A, editors. Comprehensive healthcare simulation: pediatrics. Cham: Springer International Publishing; 2016. p. 139-52. https://doi.org/10.1007/978-3-319-24187-6_11.
9. Vaughan N, Dubey VN, Wee MYK, Isaacs R. A review of epidural simulators: where are we today? Med Eng Phys. 2013;35(9):1235-50. https://doi.org/10.1016/j.medengphy.2013.03.003.
10. Nasco. Life/form® Pediatric Caudal Injection Simulator [Internet]; 2021. Available from: https://www.enasco.com/p/%3Cstrong%3ELife-form%C2%AE%3C-strong%3E-Pediatric-Caudal-Injection-Simulator%2BLF01006.
11. Wiegele M, Marhofer P, Lönnqvist P-A. Caudal epidural blocks in paediatric patients: a review and practical considerations. Br J Anaesth. 2019;122(4):507-17. https://doi.org/10.1016/j.bja.2018.11.030.
12. Green M, Tariq R, Green P. Improving patient safety through simulation training in anesthesiology: where are we? Anesthesiol Res Pract. 2016;2016:4237523. https://doi.org/10.1155/2016/4237523.
13. Udani AD, Kim TE, Howard SK, Mariano ER. Simulation in teaching regional anesthesia: current perspectives. Local Reg Anesthes. 2015;8:33-43. https://doi.org/10.2147/LRA.S68223.
14. Nasco. Life/form® Pediatric caudal injection simulator LF01006U instruction manual. Fort Atkinson, Wisconsin: Nasco; 2014.
15. Adler AC, Belon CA, Guffey DM, et al. Real-time ultrasound improves accuracy of caudal block in children. Anesth Analg. 2020;130(4):1002-7. https://doi.org/10.1213/ANE.0000000000004067.
16. Maggi L, Von Kruger MA, Pereira WCA, Monteiro E. Development of silicon-based materials for ultrasound biological phantoms. 2009 IEEE International Ultrasonics Symposium, Rome. 2009;1962-5. https://doi.org/10.1109/ULTSYM.2009.5441472.
17. Li P, Yang Z, Jiang S. Tissue mimicking materials in image-guided needle-based interventions: a review. Mater Sci Eng C Mater Biol Appl. 2018;93:1116-31. https://doi.org/10.1016/j.msec.2018.09.028.
18. Rupasinghe B, Furgal JC. Degradation of silicone-based materials as a driving force for recyclability. Polymer Int. 2022;71(5):521-31. https://doi.org/10.1002/pi.6340.