Interventional pain training using phantom model during COVID-19 pandemic

Victor Silva MD, FIPP, CIPS ⬤ | **Luis Martínez MD** ⬤ | **Margarita Santiago MD** ⬤ |
Anna López MD ⬤ | **Juan Sánchez MD** | **Eduardo Vázquez-Garza MD, PhD** |
Fernando Cantú MD | **Baltazar García MD** | **Daniel Chora MD** | **Miguel Guerra MD** |
María Franco-Cabrera BSc, MScPhys

Pain Management Department, Hospital Zambrano Hellion, Tecnologico de Monterrey, Escuela de Medicina y Ciencias de la Salud, San Pedro Garza García, México

Correspondence
Victor Silva, Pain Management Department, Hospital Zambrano Hellion, Batallón de San Patricio 112, Real San Agustín, 66278 San Pedro Garza García, México.
Email: drvictorsilva@gmail.com

Funding information
The authors have no sources of funding to declare for this article.

Abstract

Background: Fluoroscopic-guided lumbar procedures have increased in daily pain practice because the lumbar spine is one of the most common sources of pain. Interventional pain fellows must develop a minimum number of skills during their training in order to achieve the competences without neglecting radiological safety. However, medical training in fluoroscopic-guided interventions is being affected by the current coronavirus disease 2019 (COVID-19) situation.

Methods: The objective of this study was to evaluate the use of a phantom model for lumbar injection as a training strategy during the COVID-19 pandemic in fellows of interventional pain. The study was divided into theoretical and practical modules. The hands-on practice was performed in a lumbar model phantom where fellows were evaluated in four fluoroscopically guided approaches: intra-articular facet block (IAFB), medial branch block (MBB), transforaminal block (TFB), and interlaminar block (ILB) divided in 5 sessions. The aim was to make as many punctures as possible in every session. We measured total procedural performance (TPP), total needle hand time (TNH), and total radiation dose generated by the fluoroscopic machine (TRD) during each procedure. Additionally, a survey was applied to evaluate confidence and satisfaction before and after training.

Results: A total of 320 lumbar punctures were completed. The results were statistically significant in all approaches attempted ($p < 0.01$). The fellow's survey for satisfaction and confidence demonstrated a significant difference between pre and post-test ($p < 0.01$).

Conclusions: The results of this study highlight the importance of adaptations and adoption of new educational models. The use of the phantom model for simulation could be a strategy for other emerging situations, like the COVID-19 pandemic. Including this practice in the interventional pain programs could lead to better results for the patient and operator radiology safety.

KEYWORDS
Coronavirus disease 2019 (COVID-19), interventional pain program, interventional pain training, pain fellows, pain program, phantom model, radiation safety, simulation

INTRODUCTION

Interventional pain medicine is evolving as a distinct discipline that requires detailed knowledge and expertise. Familiarity with radiographic anatomy and practice on image-guided injections is needed to perform the variety of techniques the practitioners must master. As new interventional techniques are introduced in pain practices, it is important that pain physicians are properly trained to perform the multiple pain-relieving techniques in a way that conducts to a successful treatment, but also ensuring safety, both for the operator and the patient.[1] Fluoroscopic-guided procedures have increased in daily practice, not only in pain medicine, but in a variety of specialties, gaining relevance as a diagnostic and therapeutic tool. Fluoroscopic imaging guidance is frequently used when performing a variety of pain interventions and has been associated with an increased success rate with minimum complications, less procedural time performance by the target specificity, and reductions in traumatic punctures when compared to landmarked procedures.[2–4]

There are multiple procedure approaches within the skills and competences that encompass the specialty of interventional pain management, depending of the targeted anatomic area. Lumbar procedures are the most frequently performed approaches in interventional pain practice, because the lumbar spine is one of the most common sources of pain in the burden health worldwide,[5] and their optimal execution is imperative. For this, the interventional pain fellows must develop a minimum of skills during their training in order to achieve the competences without neglecting radiological safety both for the patients and themselves.

However, some emerging situations could threaten their practice, like the unprecedented crisis that we are currently experiencing with the coronavirus disease 2019 (COVID-19) pandemic, which has devastated the world with 65.8 million reported cases and 1.5 million deaths globally until early December 2020.[6] This has not only impacted the healthcare system around the world, but has had a negative impact at medical programs not related to COVID-19 infection and/or its complications.[7] Interventional pain fellows around the world, who had traditionally learned through direct observation and immediate practice in a clinical setting with real patients, could benefit from training their skills in other methods, like phantoms and cadaveric trainings, before conducting a procedure in a real patient for the first time, so the COVID-19 pandemic is only an additional situation. Historically, one of the learning alternatives has been the cadaver practice, but due to the high costs, maintenance, and availability of this method, this practice is complicated to achieve.

We suggest that the use of phantom models made by synthetic materials could be a reasonable alternative as this practice improves fellow's learning and confidence,

---

Highlights

- Use of phantom models improves interventional pain fellow learning and confidence.
- Simulated training increases fellow confidence and satisfaction.
- New educational models should be adopted in COVID-19 pandemic.
- Phantom model training decreases procedure time.
- Total radiation exposure decreases on simulation practice.
- Interventional pain fellows benefit from phantom model learning.

---

while avoiding the risk of erroneous punctures into real patients, which can lead to serious complications. The use of these simulated scenarios has already been described in other specialties, such as surgery.[8]

When it comes to radiation exposure, Cohen et al. recently reported a retrospective analysis of 6234 spinal injections in experienced practitioners in which they proposed reference levels of cumulative radiation doses and exposure, they did not include training fellows, who are also exposed to radiation and should also be monitored.[9] Repetitive practice in a controlled, simulated environment has proven to lead to a better procedural performance in the clinical setting, including effective education, less radiation exposure, avoidance of possible complications, and better outcomes when starting their practice.[10]

The objective of this study was to evaluate the use of a lumbar phantom model as a training strategy in combination with a short theoretical practice during COVID-19 pandemic in interventional pain fellows. The importance of this work is that, although there are many studies describing the use of phantom model training, they have mostly been carried out in the interventional radiology field. To this date, we have not found previous studies about the phantom model practice by interventional pain fellows.

We hypothesize that with the use of the lumbar phantom model the interventional pain fellows could improve their skills during the COVID-19 pandemic.

METHODS

This article adheres to the applicable Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Previous informed consent from the participants was obtained. Four interventional pain fellows (2 in the first year and 2 in the second year), coursing a pain management program in Mexico, with previous formal training

in anesthesiology, were included. The study was not conducted in humans.

A radiopaque anatomic lumbar model phantom manufactured by Sawbones was used (model #1352-44) Image 1. Overview of the model: lumbar, L1 to the sacrum, articulated with a 19 mm anterior latex ligament and flexible discs with radiopaque properties. The manufacturer does not specify how many punctures can be handled by the phantom model nor the time suggested for its replacement. There is a replaceable cover that can be used when broken due to multiple punctures and the cost is US $53.00. However, as part of our learning program and to ensure a constant quality control, we renewed the cover every 6–8 months.[11] All procedures in the study were performed with a BV Endura C-arm (Phillips) with a 12-inch image intensifier. This X-ray unit provides direct readings of fluoroscopy time, and air kinetic energy released per unit mass (kerma) accumulated at a reference point located 30 cm from the entrance of the image intensifier in the direction of the focal spot.[12] During the study, all participants wore personal radiological protection (lead apron, thyroid collar, and lead glasses) and followed as low as reasonably achievable (ALARA's) recommendations.[13]

The study was divided into theoretical and practical modules; the theoretical module consisted in 1-hour lecture of lumbar anatomy, interventional techniques, and complications. This module was performed 1 hour previous to each of the practical sessions. Completing a total of 5 theoretical sessions, or 5 total hours of theoretical learning, being as this was the number of total practical sessions. In order to assess the acquired knowledge, a 0–100 score test was applied to the participants at the end of the complete training (both theoretical and practical). The test consisted of 20 multiple-answer questions involving lumbar spine anatomy and procedure technique. Each question had a value of 5 points, being able to obtain a score from 0 to 100. Additionally, we also evaluated confidence (from 0 to 5 where 0 means no confidence and 5 means complete confidence) and satisfaction (from 1 to 10 where 1 meant no satisfaction and 10 meant complete satisfaction) with Likert-scales, before and after completing the training. Before hands-on practice was performed, the professor in charge of the practice module, who is an anesthesiologist and experienced interventional pain physician, gave a demonstration of each approach. Only one professor participated during the whole training. Four fluoroscopically guided approaches were included: intra-articular facet block (IAFB), medial branch block (MBB), transforaminal block (TFB), and interlaminar block (ILB), divided in 5 sessions. All procedures were performed on lumbar vertebral levels L1, L2, L3, L4, L5, and S1, either on the model's right or left side, randomly. The total number of punctures practiced during the training by the 4 pain fellows were 320; each fellow performed 80 punctures divided as follows: 4 punctures for each different procedure during each session, with a total of 5 sessions. The time we dedicated to each session was determined by the performance of the trainees, with the sessions being over when every procedure was completed by each of the students, without a time limit. The final needle position was checked by the professor to verify accuracy. All the procedures were performed from June 2020 to August 2020.

It was considered a successful attempt when the final position of the needle was on the following anatomic references and fluoroscopic projections: ILB: the needle tip was confirmed in contralateral oblique view slightly anterior to the ventral interlaminar line.[14] TFB: the needle tip resided within the "safe triangle" as described by Bogduk,[15] with the needle tip between the middle and posterior third of the superior aspect of the foramen in lateral view and at 6 o'clock of the pedicle in anteroposterior (AP) view.[16] IAFB: the needle tip was in the middle to the upper half of the joint and toward the medial border of the joint space silhouette, a lateral view was obtained to estimate the needle depth and position.[16] MBB: the needle tip was in the junction between the superior articular process and the transverse process, a lateral C-arm image was checked to verify the final position and confirmed with an AP view at the lateral margin of the superior articular process.[17]

The performance of the participants was characterized by 3 quantitative variables: (1) total procedural time performance (TPP), defined as the total time, measured from the first X-ray emitted by the C-arm to the instant when the needle reaches its final position. (2) Total needle hand time (TNH), defined as the time in seconds measured from the introduction of the needle by the participant until its arrival to the final position. (3) Total radiation dose used (TRD), given by the air kerma in mGy, accumulated at the C-arm's reference point during the TPP. All these variables were recorded during each approach attempted.

Statistical analysis

Variables were analyzed for normality using the D'Agostino-Pearson test. Survey analysis was performed using the Wilcoxon Signed Rank test. Statistical data are presented as the mean and SEM. Comparisons of the mean values between the medical residents' attempts of each procedure were made by analysis of variance (ANOVA). Differences were considered significant when $p < 0.05(*)$, $p < 0.01(**)$, and $p < 0.001(***)$.

Data processing, graphs, and statistical analysis were performed with GraphPad Prism (version 5.01).

RESULTS

A correlation between each session and the TPP was found, because all the approaches showed significant lower times at TPP over each time session (Table 1; $p < 0.01$).

Our results demonstrated that most of the approaches had the highest reduction at session number 2, specifically the TFB, which showed an important reduction over the time, compared to the ILB, which since the first session showed improvements (Figure 1; $p < 0.01$). In addition, significant results were found when analyzing TNH (see Table 1; $p < 0.01$).

We observed that the TRD (mGy) decreased over time in all of the approaches. The highest reduction over time was observed for the TFB (Figure 2; $p < 0.01$), however, ILB and MBB showed the lowest radiation dose generated at the end of the sessions (see Figure 2; $p < 0.01$; Table 2).

The fellows' survey for satisfaction and confidence demonstrated a significant difference between pre and post-test, according to the Wilcoxon Signed Rank test (Figure 3; $p < 0.01$). After applying the questionnaires, we observed an important improvement in confidence with an increase from 2.8 to 4 in the Likert scale (see Figure 3). In terms of fellow's satisfaction, the mean for the pre-test was 4.25, whereas the mean for the post-test was 9.75. Evaluation of knowledge was also included with a score of 58 of 100 before training and 88 of 100 in the final evaluation.

DISCUSSION

Spinal injections are the most common procedures performed by interventional pain physicians as low back pain prevalence and its health burden worldwide.[5] This has led to the adoption of interventional practice during training in several pain programs in Mexico. The COVID-19 pandemic has provoked significant alterations in all medical training programs around the world by dedicating all efforts to fight this virus. Pain medicine fellows in our country have not been the exception and some modifications training, such as the use of phantom models, should be encouraged.

The results of this study highlight the importance of adopting new educational models. Unfortunately, in the interventional pain field this has not been studied as in other disciplines, such as surgical specialties.[8] We consider that there are parameters that should be measured in interventional pain training as time and radiation in order to ensure security during the procedures.

Our results showed reduction in time performance in all the procedures after completing the fifth session. The IAFB approach had a total mean time of 132.56 s; previously, Rocha et al. had reported 240.48 s in interventional radiology fellows.[17] Even though time performance is an important measure, a shorter time does not correlate with procedure quality, but it suggests the acquisition of confidence and familiarity with the fluoroscopic images. This improvement has also been seen in other simulated learning models and shows reduction and prevention of errors. We consider that these simulated practices are important before the contact with real patients and should be included during the first months of training.[8]

We can infer that the TFB requires higher skills in comparison with other techniques like the MBB. Even the TFB showed a significant reduction in TPP and TNH despite having the highest scores at the beginning of the practice. This correlates with the results of Joswig et al.,[18] who observed a reduction from 7.8 to 3.8 min immediately after the first puncture whilst our results showed a reduction from 3.78 to 1.41 min. TFB had higher TRD emitted at the second session reaching values closer to 0.6 mGy, whereas the others did not. This correlation between TPP and TNH suggests that this approach is the most difficult to learn by inexperienced fellows or in training despite, to our knowledge, there is no previous literature that report difficulty levels in any of the approaches included in this study.

The ILB and MBB also showed significant reductions in TPP and TRD after the second session. This matches with the Wang et al.[19] study; they affirm that the MBB is one of the simplest techniques to perform and they suggest initiating training with this technique.

In our results, some TPP remains distant from the reported for an experimented radiologist, because they reported IAFB in 39 s and our results showed 52 s.[18]

A reduction in TPP could result in lower radiation doses generated by the C-arm, which is related to other factors, such as a greater attention from the fellow to
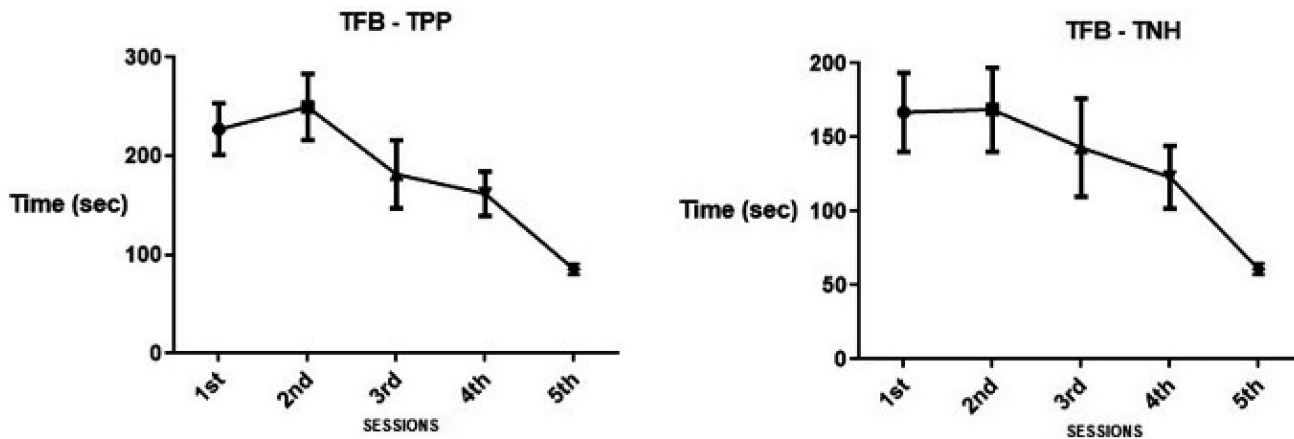
TABLE 1 Resume of the results showing significant reduction over the time in all of the 4 approaches performed in TPP, TNH, and TRD ($p < 0.01$)

	Mean (SEM)	Median (IQR, PCT25/PCT75)	p value
TPP (s)			
IAFB	132.56 (17.77)	112.1 (90.51/151.11)	<0.01
MBB	122.55 (10.4)	121.3 (89.36/151.41)	<0.01
TFB	181.2 (24.34)	146.5 (123.51/219.51)	<0.01
ILB	113.35 (11.79)	100.4 (81.15/135.75)	<0.01
TNH (s)			
IAFB	83.36 (12.08)	69 (50.2/107.41)	<0.01
MBB	18.24 (9.18)	68.2 (53.65/105.01)	<0.01
TFB	132.64 (22.63)	107.5 (77.76/157.84)	0.01
ILB	93.30 (8.24)	86.2 (67.1/117.88)	<0.01
TRD (mGy)			
IAFB	0.2294 (0.0244)	0.208 (0.1655/0.273)	<0.01
MBB	0.2198 (0.0163)	0.207 (0.168/0.2725)	<0.01
TFB	0.3036 (0.0381)	0.268 (0.214/0.352)	<0.01
ILB	0.2041 (0.0148)	0.191 (0.166/0.241)	<0.01

Abbreviations: IAFB, intra-articular facet block; ILB, interlaminar block; IQR, interquartile range; MBB, medical branch block; TFB, transforaminal block; TNH, total needle hand time; TPP, total performance procedure; TRD, total radiation dose generated by the fluoroscopic machine.

FIGURE 1 TFB approach had significant reduction over the time at TPP (left) and TNH (right) ($p < 0.01$). TFB, transforaminal block; TNH, total needle hand time; TPP, total performance procedure
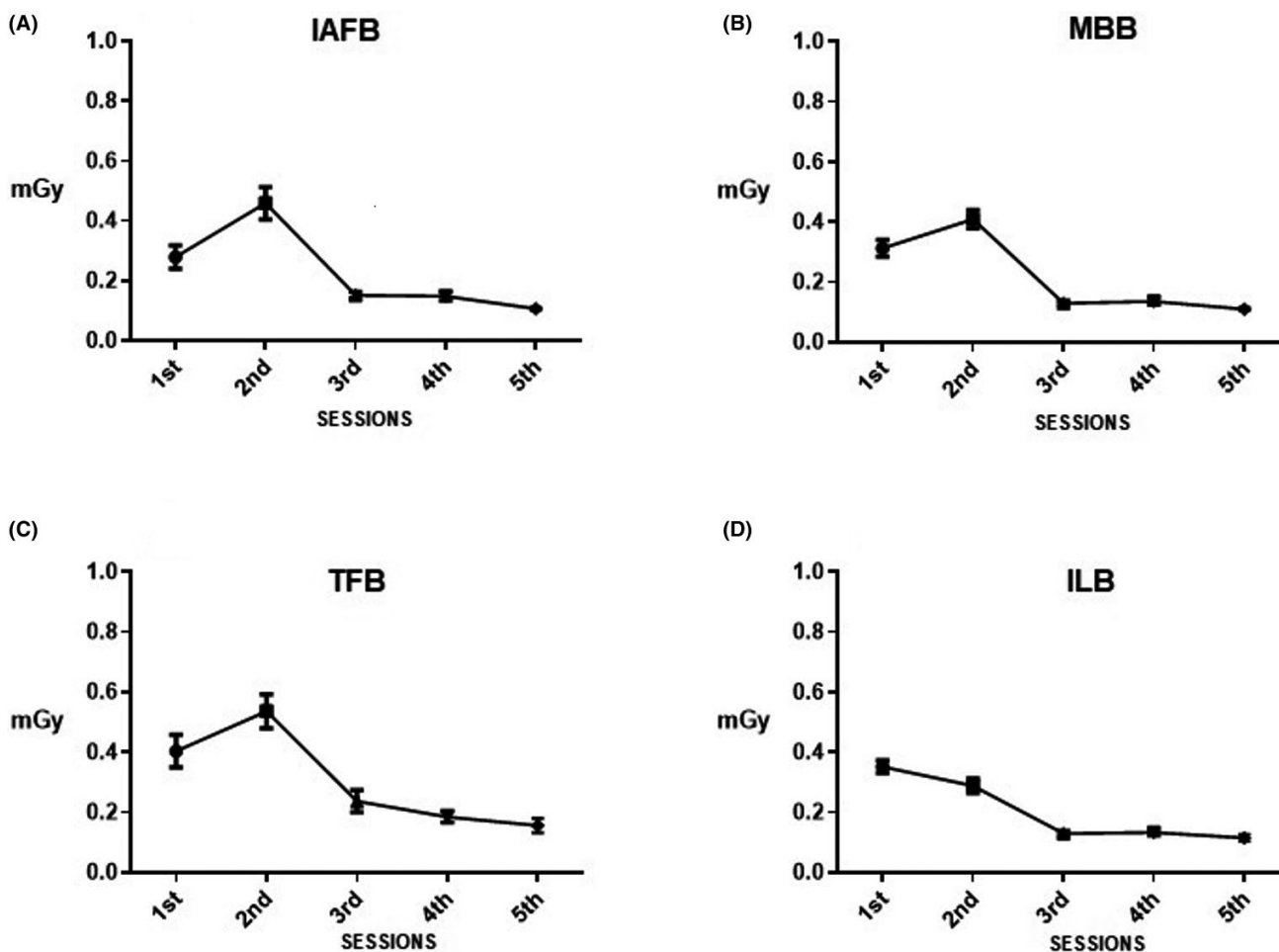

FIGURE 2 All the approaches showed a significant reduction over the time in TRD. We can observe that ILB (D) did not show an increment at the second session as the IAFB (A), MBB (B), and TFB (C). IAFB, intra-articular facet block; ILB, interlaminar block; MBB, medial branch block; TFB, transforaminal block; TRD, total radiation dose generated by fluoroscopy machine

avoid the unnecessary use of fluoroscopy.[20] We think this is the most remarkable finding in the study. We observed significant reductions in TRD over the time in all approaches attempted by the fellows. TFB had the lowest dose emitted at the last session with total standard error of the mean (SEM) 0.15 ± 0.02 mGy.

TABLE 2 Resume of the results in all of the four approaches performed in TPP, TNH, and TRD

	1st Mean (SEM), Median	2nd Mean (SEM), Median	3rd Mean (SEM), Median	4th Mean (SEM), Median	5th Mean (SEM), Median
Intra-articular facet block (IAFB)					
TPP	138.50 ± 35.23	220.90 ± 25.42	110.40 ± 11.40	97.69 ± 8.32	95.31 ± 8.48
TNH	82.88 ± 18.30	129.80 ± 20.46	81.94 ± 8.89	59.94 ± 6.35	63.25 ± 6.46
TRD	0.27 ± 0.03	0.45 ± 0.05	0.15 ± 0.01	0.14 ± 0.01	0.10 ± 0.00[**]
Medial branch block (MBB)					
TPP	160.30 ± 13.42	183.50 ± 12.87	85.19 ± 8.48	109.70 ± 9.93	74.06 ± 7.30[***]
TNH	101.40 ± 13.39	104.20 ± 10.44	54.75 ± 6.17	80.50 ± 8.26	50.38 ± 7.64[*]
TRD	0.31 ± 0.02	0.40 ± 0.03	0.13 ± 0.00	0.13 ± 0.10	0.11 ± 0.00[***]
Transforaminal block (TFB)					
TPP	227.40 ± 26.09	249.80 ± 33.33	181.70 ± 34.46	161.80 ± 22.50	85.38 ± 5.35[***]
TNH	167.00 ± 26.50	168.80 ± 28.34	143.10 ± 33.17	123.20 ± 21.28	61.13 ± 3.86[*]
TRD	0.40 ± 0.05	0.53 ± 0.05	0.23 ± 0.03	0.18 ± 0.01	0.15 ± 0.02[**]
Interlaminar block (ILB)					
TPP	181.10 ± 13.91	129.10 ± 21.93	92.44 ± 9.70	102.50 ± 9.67	61.63 ± 3.77[***]
TNH	145.70 ± 12.52	94.56 ± 7.41	79.69 ± 5.74	90.50 ± 8.65	56.06 ± 6.92[***]
TRD	0.35 ± 0.02	0.28 ± 0.02	0.13 ± 0.00	0.13 ± 0.00	0.11 ± 0.01[***]

Abbreviations: IAFB, intra-articular facet block; ILB, interlaminar block; MBB, medical branch block; TFB, transforaminal block; TNH, total needle hand time; TPP, total performance procedure; TRD, total radiation dose generated by the fluoroscopic machine.

$*p < 0.05.; **p < 0.01.; ***p < 0.001.$

As Figure 3 shows, TRD at 3 of the 4 blocks attempted in the practice (TFB, MBB, and IAFB) increased at the second session, this could be explained by an increase in the technique corrections made by the professor in charge. On the other hand, ILB did not show this increment during the practice, this could be because there was less necessity of corrections. Despite that the initial dose emitted in the first session was the lowest when compared to the others, this reduction continued through the sessions and was statistically significant (<0.01). This calls into question if MBB is the easier approach to learn as reported by Wang.[21] We

consider that TPP is not the only parameter that must be measured before making conclusions, because radiation dose is an essential radiation safety parameter in our daily practice.[13]

The fellows' survey demonstrated improvement in satisfaction, confidence, and knowledge. Additionally, this finding reinforces the importance of training based on repetition and not only on observation, which ensures radiological safety for both the patient and the team.[22] It is necessary to obtain more evidence about the use of simulation in the training of interventional pain management.

There are limitations to this study. A primary limitation is that there is no control group, and the number of participants included is small. However, given the substantial improvement after the training was completed, we believe this can serve as a preliminary reference for fellows in training who are dealing with limitations in procedures availability due to the massive reduction of elective procedures in the COVID-19 pandemic.

The use of the phantom model for simulation could be a strategy for other emerging situations where fellow training could be at risk. Including this practice to the pain programs could lead to better results for the patient and radiation safety for the operator. This type of training has not been widely used in specialties like pain management, despite showing effectiveness in other specialties. Due to the impact of the COVID-19 pandemic in training, it is of vital importance to look for alternatives to reach the institutional goals within each pain program. In addition, despite
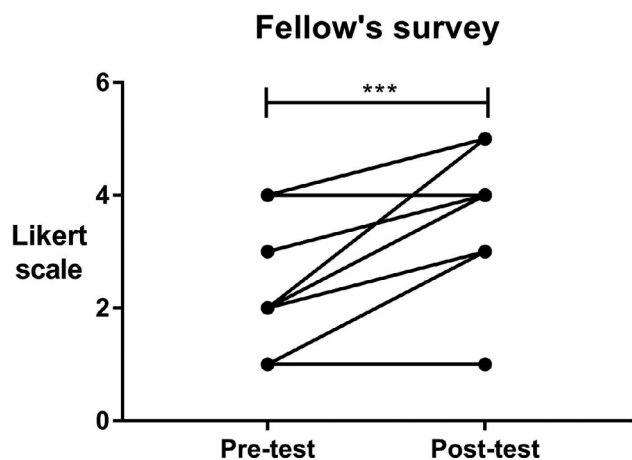
Fellow's survey

FIGURE 3 Fellow's survey for satisfaction and confidence demonstrated a significant difference between pre and post-test according to Wilcoxon Signed Rank test, ***p < 0.001

the actual pandemic, it is important to emphasize that the phantom is an important tool for interventional pain management training.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

V.M.S.-O., M.S., A.L., L.A.M., J.C.S.C., F.C., B.G., D.C., and M.G. helped complete the article. E.V.G. helped with statistical analysis. M.F.-C. provided the technical information and advice on the fluoroscopy unit and its dose indicators.

ORCID

Victor Silva https://orcid.org/0000-0003-3275-5881
Luis Martínez https://orcid.org/0000-0002-4050-8605
Margarita Santiago https://orcid.org/0000-0002-5576-5516
Anna López https://orcid.org/0000-0001-7865-6980

REFERENCES

1. Rathmell JP, Brown D L. Education, training, and certification in pain medicine. Chapter 7. In: Practical management of pain, 5th edn. Philadelphia: Elsevier, 2014.78–83.
2. Faulkner AR, Bourgeois AC, Bradley YC, Hudson KB, Heidel RE, Pasciak AS. Simulation-based educational curriculum for fluoroscopically guided lumbar puncture improves operator confidence and reduces patient dose. Acad Radiol. 2015;22:668–73.
3. Faulkner AR, Bourgeois AC, Bradley YC, Pasciak AS. A robust and inexpensive phantom for fluoroscopically guided lumbar puncture training. Simul Healthc. 2015;10:54–8.
4. Rias TR, Junior JD, Abdala N. Learning curve of radiology residents during training in fluoroscopy-guided facet joint injections. Radiol Bras. 2017;50:162–9.
5. GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. Lancet. 2020;396(10258):1204–22. https://doi.org/10.1016/S0140-6736(20)30925-9. Erratum in: Lancet. 2020 Nov 14;396(10262):1562.
6. World Health Organization. World Health Organization coronavirus disease 2019 (COVID-19) situation report. Accessed 12 December 2020.
7. DeFilippis EM, Stefanescu Schmidt AC, Reza N. Adapting the educational environment for cardiovascular fellows-in-training during the COVID-19 pandemic. J Am Coll Cardiol. 2020;75:2630–4.
8. Grantcharov T, Kristiansen V, Bendix J, Bardram L, Rosenberg J, Funch-Jensen P. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. Br J Surg. 2004;91:146–50.
9. Cohen S, Schneider R, Carrino J, Zeldin R, Pavlov H. Radiation dose practice audit of 6,234 fluoroscopically-guided spinal injections. Pain Physician. 2019;22:E119–25.
10. Udani AD, Kim TE, Howard SK, Mariano ER. Simulation in teaching regional anesthesia: current perspectives. Local Reg Anesth. 2015;8:33–43.
11. Sawbones. Orthopaedic models website. 2018. https://www.sawbones.com/spine-l1-sac-foam-cortical-shell-w-cancellous-l1-sac-radiopaque-cortex-open-cell-cancellous-same-as-1352-39-1352-44.html. Accessed 4 Apr 2021.
12. BV Endura V.2.3 Koninklijke Philips Electronics N.V.; 2012.
13. Kaplan D, Patel J, Liporace F, Yoon R. Intraoperative radiation safety in orthopaedics: a review of the ALARA (As low as reasonably achievable) principle. Patient Saf Surg. 2016;10:27.
14. Gill JS, Nagda JV, Aner MM, Keel JC, Simopoulos TT. Contralateral oblique view is superior to the lateral view for lumbar epidural access. Pain Med. 2016;17:839–50.
15. Manchikanti L, Kaye AD, Falco FJ, Hirsch JA. Essentials of interventional techniques in managing chronic pain. New York: Springer International Publishing; 2018.
16. Furman MB, Berkwits L, Cohen I, Goodman B, Kirschner J, Lee TS, et al. Atlas image-guided spinal procedures, 2nd edn. Philadelphia: Elsevier; 2017.
17. Kim DH. Minimally invasive percutaneous spinal techniques. Philadelphia: Saunders Elsevier; 2011.
18. Rocha T, da Costa JD, Abdala N. Learning curve of radiology residents during training in fluoroscopy-guided facet joint injections. Radiol Bras. 2017;50:162–9.
19. Wang L, McKenzie A, Hord A. Lumbar spinal injection. Handbook of C-arm fluoroscopy-guided spinal injections, 1st edn. Oxfordshire, New England: Taylor & Francis Group; 2006. p. 72–149.
20. Miller DL, Kwon D, Bonavia GH. Reference levels for patient radiation doses in interventional radiology: proposed initial values for U.S. practice. Radiology. 2009;253:753–64.
21. Joswig H, Haile S, Hildebrandt G, Stienen M. Residents' learning curve of lumbar transforaminal epidural steroid injections. J Neurol Surg A. 2017;78:460–6.
22. Manchikanti L, Cash K, Moss T, Rivera J, Pampati V. Risk of whole body radiation exposure and protective measures in fluoroscopically guided interventional techniques: a prospective evaluation. BMC Anesthesiol. 2003;3:1–7.