Experimental Model for Interlaminar Endoscopic Spine Procedures

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BACKGROUND: **Endoscopic spinal surgery is becoming quite popular, and the pursuit of a training model to improve surgeons' skills is imperative to overcome the limited availability of human cadavers. Our goal was to determine whether the porcine spine could be a representative model for learning and practicing interlaminar percutaneous endoscopic lumbar procedures (IL-PELPs).**

METHODS: **Lumbar and cervical segments of the porcine cadaver spine were used for the IL-PELP. We have described the technical notes on the difficulties of the procedure and the relevant anatomical features. To endorse the porcine cadaver for this procedure, 5 neurosurgeons underwent 1 day of training and completed a survey.**

RESULTS: **The porcine lumbar spine has small interlaminar windows, and laminectomy is necessary, mimicking the translaminar approaches for higher human lumbar spine levels. The porcine cervical spine has wide and high interlaminar windows and mimics the human L5-S1 interlaminar approach. Entering the spinal canal with the working sheath and endoscope and training the rotation maneuver to access the disc space is only possible in the lumbar segment. It was possible to perform flavectomy and to identify and dissect the dural sac and nerve root in both the lumbar and cervical spine. The neurosurgeons considered the porcine model of good operability and, although different, possible to apply in humans.**

CONCLUSIONS: **The porcine spine is an effective and representative model for learning and practicing IL-PELPs. Although the described anatomical differences should be known, they did not interfere in performing the main surgical steps and maneuvers for IL-PELPs in the porcine model.**

INTRODUCTION

Endoscopic spine surgery for lumbar disc herniation and stenosis has become quite popular owing to the several potential advantages compared with conventional techniques, such as reduced tissue trauma, reduced postoperative pain, a lower risk of surgical site infection, the rapid recovery, improved patient mobility, and lower overall complication rate.[1-7]

Minimally invasive techniques such as tubular retraction and endoscopic-assisted microdiscectomy and simple indirect endoscopic decompressions using the inside-out technique do not represent the actual state of the art of spinal endoscopy. Thus, it is relevant to affirm that the technique considered in the present study uses direct decompression under full continuous irrigation, with the working channel within the optic. It has also been termed "full endoscopy," "underwater," or "truly endoscopic."[6,8]

Although the use of cadaver spines has been considered the reference standard for spine surgery education, the availability of human cadaver material has been very limited in many regions.[9-11] Porcine spines have been frequently used as an alternative model to human specimens for in vivo and in vitro experiments involving spinal fusion and instrumentation techniques.[11-15] However, none have considered its use for interlaminar percutaneous endoscopic lumbar procedures (IL-PELPs). Owing to the mobility of the porcine cervical spine, the cervical interlaminar window will be wider and higher than that in the porcine lumbar spine; thus, the porcine cervical spine can mimic

Key words
- Disc herniation
- Endoscopic discectomy
- Interlaminar
- learning curve
- Lumbar spine
- Porcine model

Abbreviations and Acronyms
AP: Anteroposterior
IL-PELP: Interlaminar percutaneous endoscopic lumbar procedure

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the human lumbar spine.[16-18] Therefore, it has been hypothesized that the full-endoscopic interlaminar approach for L5-S1 used in humans could be practiced using the porcine cervical spine.

The goal of the present study was to determine whether the lumbar or cervical porcine spine could be a representative model for learning and practicing IL-PELPs and to describe the technical notes pertaining to the procedure with this animal model.

METHODS

The 2 fresh porcine cadavers used in the present study were obtained according to the ethics guidelines for experimental animal research. The animal used for the lumbar procedures was a 6-month-old feral pig (*Sus scrofa feral*) weighing 50 kg. All thoracic and abdominal viscera were removed, leaving the complete neurological axis. The other animal was an 8-month-old pig (*Sus scrofa domesticus*) weighing 45 kg and was used for the cervical interlaminar procedure. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted.

Our procedure entails the use of a thin tubular device that contains the optical system and working channel, which was introduced through a stab incision guided by anteroposterior (AP) and lateral fluoroscopic images. The dilator was inserted and directed toward the interlaminar window. The working sheath was passed over the dilator, which was removed to insert the endoscope. The use of a monoportal technique was standard, and surgery was performed under constant saline irrigation.[6,19-21] After instrument insertion under fluoroscopic guidance and endoscopic visualization, the anatomical structures were identified, and the specific maneuvers were attempted.

Five experienced neurosurgeons volunteered to complete a survey to determine whether they believed the model would be useful for practicing endoscopic spine surgery and whether the training had provided any benefit. The inclusion criteria for the participants was previous participation in other surgical cadaver training courses with either with human or animal cadavers, with little or no previous experience with spinal endoscopy. The surgeons participated in a full-day hands-on course using a porcine cadaver. Afterward, they completed a questionnaire with 5 questions (Table 1) using a 5-point Likert scale (1, no confidence or worst and 5, high confidence or best). Question 4 had the following options: 1) very different, impossible to apply in humans; 2) different, possible to apply in humans, but would prefer training with a human cadaver before applying the technique for a human patient; 3) different but possible to apply in humans if guided by an experienced endoscopic surgeon; 4) different but possible to apply in humans, with training using the porcine model enough; and 5) slightly different and easily applicable in humans.

RESULTS

Porcine Lumbar Spine

IL-PELP was performed at 3 lumbar spine levels, consisting of 2 parts: insertion of the instruments with fluoroscopic guidance, followed by endoscopic visualization for identification of the anatomical structures and training in the specific maneuvers. Relevant considerations and comparisons with actual interlaminar endoscopic procedures have been described. The next steps required real-time AP and/or lateral views using the C-arm.

Positioning, Marking, and Instrument Insertion. In the AP view, a guide wire was positioned over the inferior margin of the superior laminae of the desired disc level (Figure 1A). After selection of the entry point for the IL-PELP and skin and fascia incision, the dilator was inserted without a needle, and the desired position was checked in the AP view (Figure 1B). Next, a bevel-ended working sheath was introduced along the obturator. After removal of the obturator (Figure 1C) and insertion of the endoscope, the first step of the procedure was complete.

Endoscopic View and Anatomic Identification. For the second step, fluoroscopy was only used to check the position of the instruments and verify the anatomic parameters (Figure 1D). After insertion of the endoscope and cleaning of the operative field with radiofrequency ablation, it was possible to identify the same structures as those in human procedures: inferior laminae, superior laminae, and interlaminar window (Figure 2A). However, the interlaminar windows in the porcine model, even

Table 1. Current Porcine Model Fluoroscopic Measurement of Important Parameters for Interlaminar Percutaneous Endoscopic Lumbar Procedures

Surgeon No.	Experience in Spine Surgery (years)	Confidence in Performing Interlaminar Endoscopy before Training (Score Range, 1—5)	Operability of Porcine Model (Score Range, 1—5)	Applicability of Experience with Porcine Model on Humans (Score Range, 1—5)	Confidence in Performing Interlaminar Endoscopy After Training (Score Range, 1—5)
1	20	1	4	2	3
2	35	1	4	2	1
3	7	1	4	3	1
4	5	1	5	3	3
5	4	1	4	3	3
Average	14.2	1	4.2	2.6	2.2

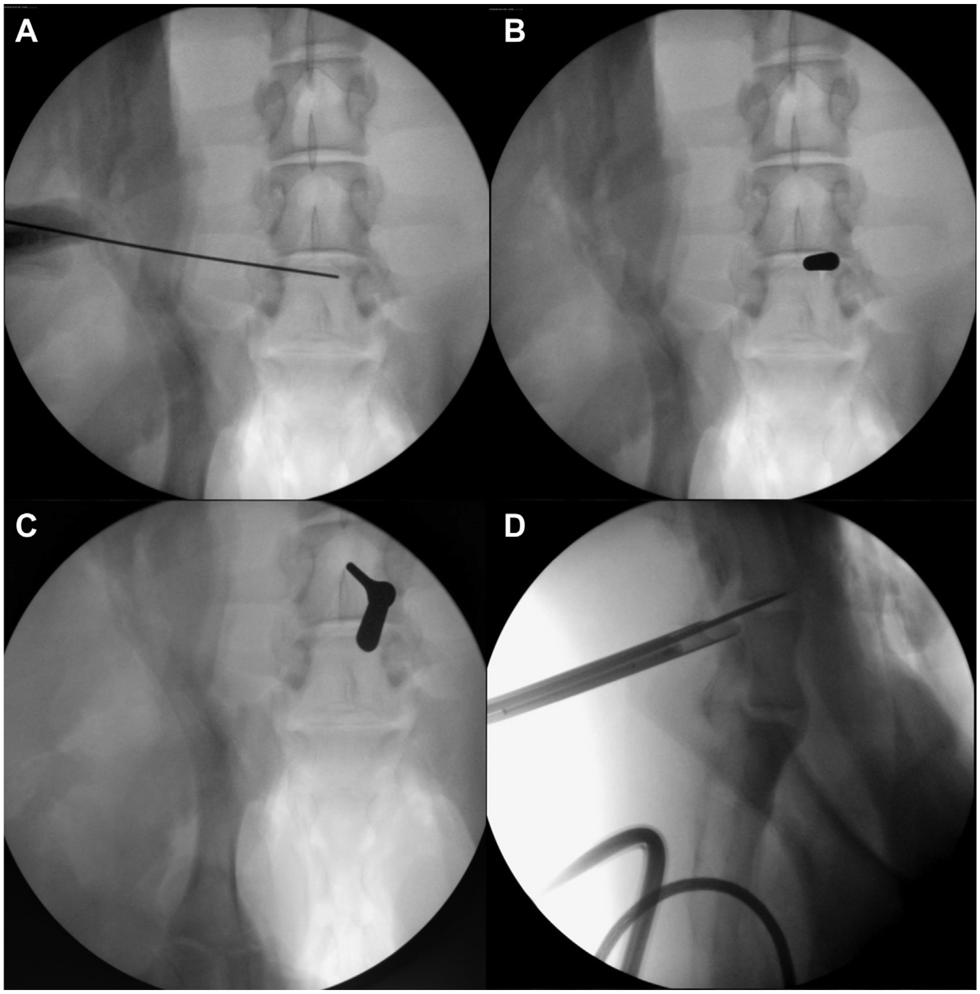

Figure 1. Fluoroscopic views of the procedure on the lumbar spine. (**A**) Marking the entry point, (**B**) insertion of the obturator, (**C**) insertion of the working cannula, and (**D**) documentation of instruments inside the disc at the end of the procedure on lateral view and the working cannula inside the canal.

in the lower lumbar levels, are very narrow compared with those in the human spine.

Laminectomy and Flavectomy. Using an oval cutting burr and a Kerrison punch, it was possible to perform resection of the inferior margin of the superior laminae and the superior margin of the inferior laminae. The ligamentum flavum is thin; a part of it was resected during the laminectomy, and the rest was resected using punches until good visualization of the dural sac, nerve root, and epidural space had been achieved (**Figure 2B—D**).

Working Sheath Rotation Maneuver and Discectomy. After good exposure of the epidural space, it was possible to insert the working sheath inside the canal lateral to the dural sac. The rotation of the working sheath will allow for protection of the nerve tissue and safe access to the disc. Although the disc spaces were narrow, their identification was very clear, and it was possible to introduce a chisel inside (**Figure 1D**).

Porcine Cervical Spine

The IL-PELP was performed at 3 cervical spine levels, with the steps similar to those used for the porcine lumbar spine.

Positioning, Marking, and Instrument Insertion. In the AP view, a pointed instrument was positioned to mark the entry point, in the middle point between the inferior margin of the superior laminae and the superior margin of the inferior laminae and middle point between the medial sagittal line and the lateral end of the interlaminar window (**Figure 3A**). After selection of the entry point for the IL-PELP and skin and fascia incision, the obturator was inserted without a needle, and its desired position was checked using the AP (**Figure 3B**) and lateral (**Figure 3C**) views. Next, a bevel-ended working sheath was introduced along the obturator. With removal of the obturator and insertion of the endoscope, the first step of the procedure was complete.

Endoscopic View and Anatomic Identification. In the second step, fluoroscopy was only used to check the position of the

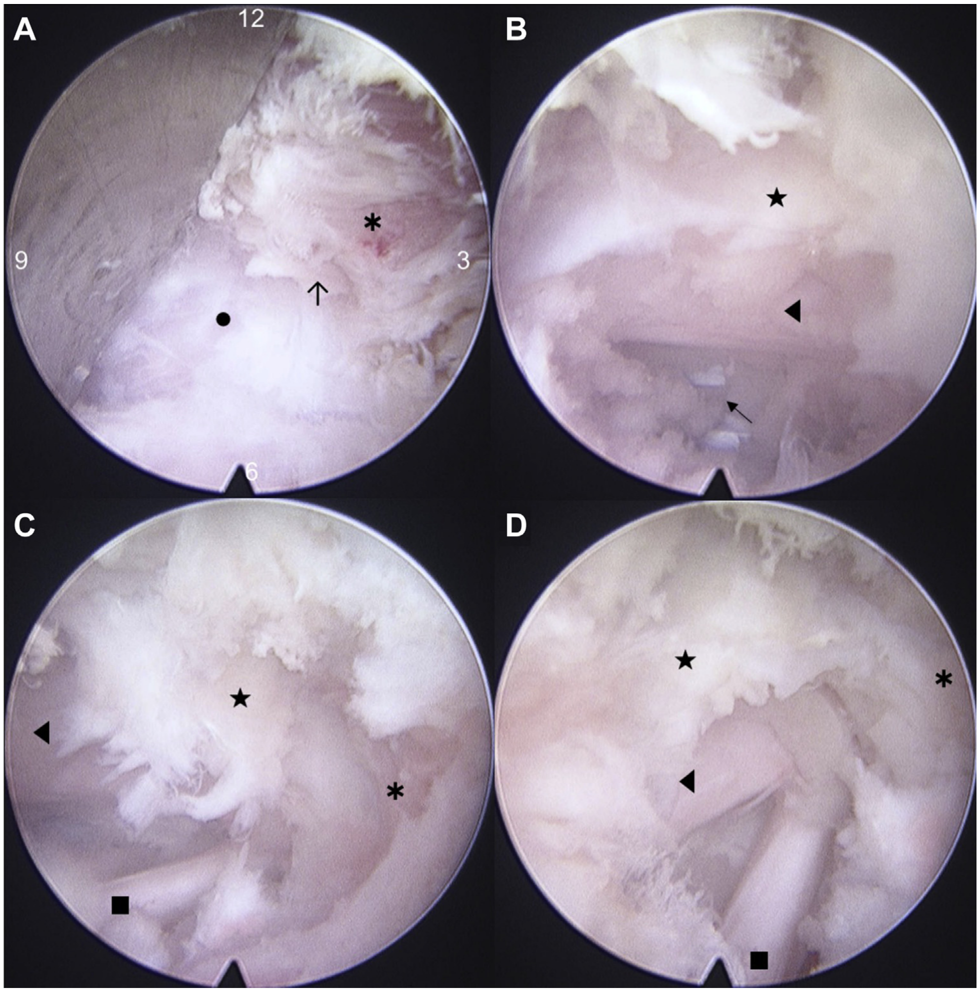

Figure 2. Endoscopic views of the procedure: the 12-o'clock position is the midline; 3-o'clock, cranial; 6-o'clock, lateral; and 9-o'clock, caudal. (**A**) *Asterisk* indicates inferior laminae; *black circle,* superior laminae; and *arrow,* interlaminar window; (**B**) *north east arrow* indicates the epidural space (axilla of the nerve root); *arrowhead,* dural sac; and *star,* yellow ligament; (**C**) *arrowhead* indicates dural sac; *star,* yellow ligament; *black square,* nerve root; and *asterisk,* inferior laminae; and (**D**) *arrowhead* indicates dural sac; *star,* yellow ligament; *black square,* nerve root; and *asterisk,* inferior laminae.

instruments and verify the anatomic parameters. After insertion of the endoscope and cleaning of the operative field with radiofrequency ablation, it was possible to identify the wide interlaminar window with its flavum ligament (**Figure 4A**).

Flavectomy. Using a cutting instrument called a punch, it was possible to perform resection of the ligamentum flavum (**Figure 4B–D**) until good visualization of the dural sac, nerve root, and epidural space had been achieved (**Figure 4D–F**). Owing to the characteristics of the cervical nerve structures and the perpendicular exit of the nerve root, it was not possible to insert the working sheath as freely as in the lumbar spine. However, it was possible to dissect the axilla and the shoulder of the nerve root (**Figure 4F,G**) and explore the space to find the intervertebral disc space.

Survey

The surgeons' answers to the survey are presented in **Table 1**. The 5 neurosurgeons, with an average experience of 14.2 years, considered endoscopy training on the porcine spine to be of good to excellent operability. Three considered it different but possible to apply in humans if guided by an experienced endoscopic surgeon. However, 2 surgeons indicated they would prefer to train using a human cadaver before applying the technique in real human surgery.

DISCUSSION

The increasing interest in spine endoscopy has followed the technical advances in the field of cameras, coaxial working sleeves, optics, video processing equipment, radiofrequency devices, as well as development of new surgical approaches.[6] The full-endoscopic interlaminar approach is a technically demanding procedure for surgeons, similar to thoracoscopic, laparoscopic, and transforaminal endoscopic techniques in spine surgery.[22,23] This surgical procedure can be more complex and significantly different from traditional open surgical approaches.

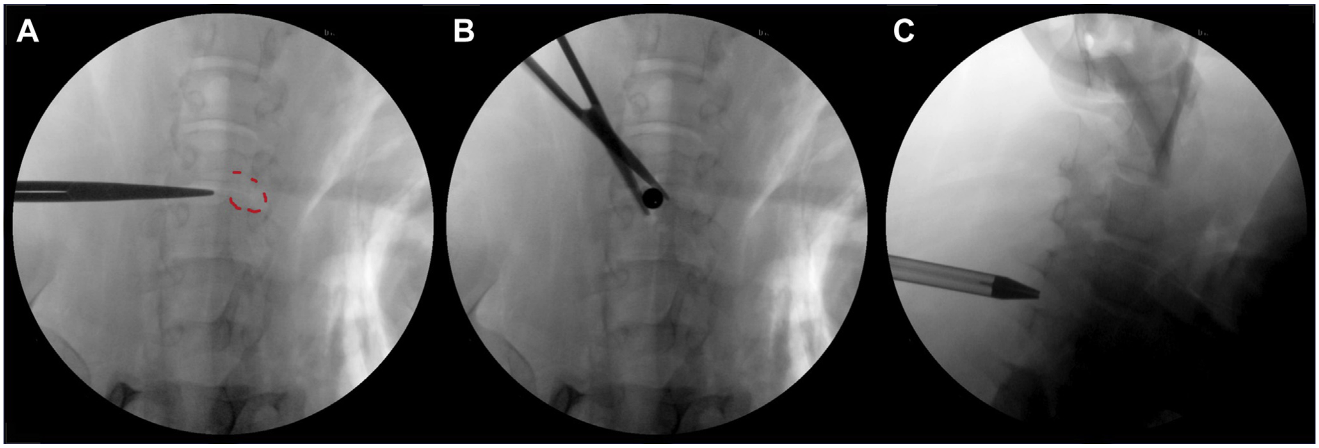

Figure 3. Fluoroscopic views of the procedure on the cervical spine. (**A**) Marking the entry point, and insertion of the obturator on the (**B**) anteroposterior view and (**C**) lateral view. The *red dotted line* shows the interlaminar window on the contralateral side.

The loss of visualization in 3 dimensions, loss of touch, and large dependence on surgical instruments, among other factors, could be unfamiliar to surgeons in the initial stages of adopting the endoscopic technique. In addition, hand—eye cooperation with the use of the endoscopic instruments and the identification of anatomic structures using the endoscope can also appear daunting. Thus, a steep learning curve can be expected,[22-24] with the lack of proper training often leading to poor clinical results, inevitably discouraging the use of this undoubtedly effective technique. Owing to the limited availability of human cadaver spines, especially in Brazil, surgeons have been forced to travel abroad to participate in the available cadaver hand-on courses to learn or improve such techniques or might even have eliminated this important step of the learning curve.[9]

Amato et al.[9] have already shown that the porcine spine is a representative model for learning and practicing transforaminal percutaneous lumbar procedures. However, the IL-PELP is a

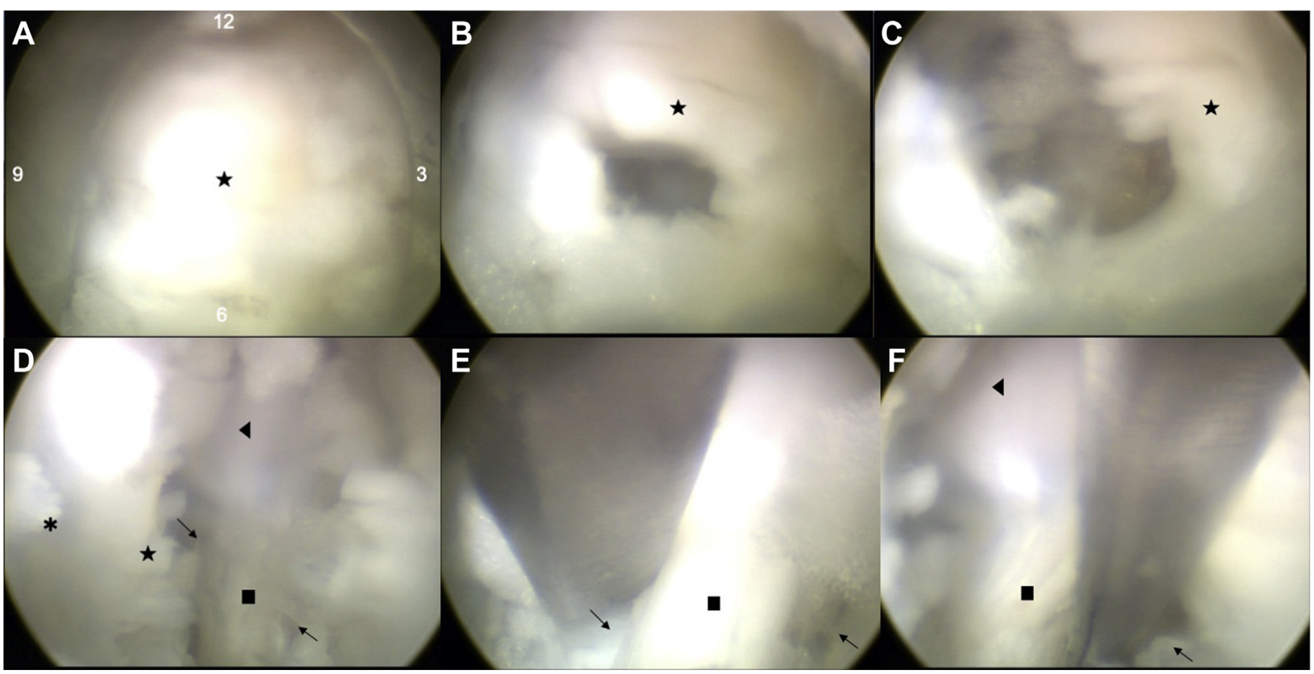

Figure 4. Endoscopic views of the procedure: the 12-o'clock position is the midline; 3-o'clock, cranial; 6-o'clock, lateral; and 9-o'clock, caudal. (**A**) The *star* indicates the yellow ligament; (**B,C**) view showing an opening on the yellow ligament, through which the epidural space and fat can be seen; (**D**—**F**) views showing the yellow ligament wide open. The *black square* indicates the nerve root; *asterisk,* the inferior laminae; *north west arrow*, the epidural space (shoulder of the nerve root); *arrowhead,* dural sac; *south east arrow,* epidural space (axilla of the nerve root).

posterior approach that encounters different surgical anatomy, and whether the porcine spine is a representative model for these approaches has yet not been determined.

Just as with several other anatomical studies of the porcine spine, the present study has shown that this representative animal model reflects some anatomical characteristics of the human spine,[11] at least enough to train in and practice endoscopic procedures. Busscher et al.[11] used 4-month-old domestic Landrace pigs with an average weight of 40 kg in a fine anatomical study using computed tomography scans. Dath et al.[15] used 18–24-month-old hybrid pigs weighing 60–80 kg. They macroscopically dissected the vertebrae to perform anatomical measurements. The pigs used in the current model were larger than those used by Busscher et al.[11] and smaller than those used by Dath et al.[15] However, the main characteristics and proportions were maintained as previously reported[9]; an important factor in the evaluation of whether our study could be replicated. Although the intervertebral disc height was slightly greater compared with the samples used by Busscher et al.,[11] it was still much smaller than that in humans. The human spine requires relatively larger caudal vertebral bodies to balance the greater longitudinal loads, in contrast to the quadruped spine. Also, the greater range of motion of the lumbar human spine requires adaptable joints. These are probably some of the explanations for the smaller intervertebral discs heights observed in the pig, which can be $\leq$4 times smaller than the human disc heights in the lumbar region, as described by Busscher et al.[11] Also, the lack of motion in the porcine lumbar spine should also justify the smaller lumbar interlaminar window noted in the current models.[9,11,15]

In both the cervical and lumbar porcine spine, the insertion of endoscopic instruments could be strictly reproduced, and the fluoroscopic images could be clearly used for anatomic orientation. Two main types of errors can occur with imprecise anatomic orientation: lateral or medial placement of the working sheath. After insertion of the endoscope, the presence of facet cysts, muscle, and ligaments can limit identification of the ligamentum flavum; thus, the use of the interlaminar window.[23] The large interlaminar windows in the porcine cervical spine mimicked the human L5-S1 and the small interlaminar windows in the porcine lumbar spine mimicked the human upper lumbar levels where resection of at least the superior laminae will be required to access the spinal canal. Despite these differences, standard dissection and the use of fluoroscopic guidance permitted anatomy identification and orientation outside the spinal canal of the porcine model.

Training to perform the incision of the ligamentum flavum in the porcine cervical spine is similar to that in the human lumbar spine, probably owing to its increased mobility. The ligamentum flavum of the porcine lumbar spine is otherwise very thin, and most of the ligamentum flavum will usually be resected during laminectomy.

Another potentially difficult step in interlaminar endoscopic approaches is the management of instruments inside the spinal canal. Careless manipulation of neural elements is a potential pitfall.[23] In the porcine lumbar spine, after good exposure of the epidural space, it was possible to insert the endoscope inside the canal and practice the working sheath rotation maneuver to provide safe access to the disc. In the porcine cervical spine, owing to cervical nerve structure characteristics and the perpendicular exit of the nerve root, it was not possible to insert the working sheath as freely as in the lumbar spine. However, it was possible to practice the manipulation of nerve structures such as dissection of the axilla and the shoulder of the nerve root to find the intervertebral disc space.

The porcine model has been used for the development of several novel laparoscopic and endoscopic techniques used in different medical specialties.[25] Mühlbauer et al.[26] reported experimental laparoscopic and thoracoscopic discectomy and spinal fusion instrumentation using a porcine model. Participants in a hands-on training course for laparoscopic spine surgery agreed that a large animal model should be used for training before performing complex laparoscopic procedures in humans.[10,25,26] In our survey, the 5 participating neurosurgeons, considered endoscopy training on the porcine spine to be of good to excellent operability. Three considered it different but possible to apply in humans if guided by an experienced endoscopic surgeon, and 2 had stated they would prefer to train using a human cadaver before applying the technique in humans (participants 1 and 2). Of the 5 surgeons, the first 2 were the surgeons with longer experience in neurosurgery, with the last 3 having $<$10 years of experience in neurosurgery. It is fair to assume that younger surgeons would be more familiar with the newest technologies and/or that the more experienced surgeons would be more skeptical of them. Although the number of participants was not enough to determine a significant common viewpoint, we believe that although some anatomical differences exist, the skills required to perform endoscopic spine surgery in the porcine model are the same as those necessary for performing the procedures in humans.

Mladina et al.[27] showed that novice surgeons could, in fact, improve their kills, measuring the time spent for certain exercises, by training in endoscopic sinus and skull base surgery techniques using a lamb head model. As previously reported, novice surgeons must spend energy and attention on gaining basic surgical skills, in particular, the skills of simultaneous bimanual manipulation of the endoscope and instruments and simultaneous watching of the procedure on the screen. Practicing the hand–eye coordination necessary and how to manage the long instruments inside a dark and small working channel simply does not permit enough attention to sufficiently explore the demanding endoscopic anatomy.[27] More advanced surgeons, or those who have previous experience with neuroendoscopy or arthroscopy, might note the anatomic details and differences from the human anatomy. However, this will not prevent them from practicing advanced surgical skills such as bone resection and nerve manipulation.

CONCLUSIONS

The porcine spine is an effective, easily reproducible, and representative model for learning and practicing interlaminar and translaminar percutaneous endoscopic lumbar procedures. Although the described anatomical differences should be known, they will not interfere in learning and practicing the main surgical steps and maneuvers required for IL-PELPs in the porcine model.

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REFERENCES

1. Markovic M, Zivkovic N, Spaic M, et al. Full-endoscopic interlaminar operations in lumbar compressive lesions surgery: prospective study of 350 patients. "Endos" study. *J Neurosurg Sci*. 2016.

2. Choi KC, Kim J-S, Park C-K. Percutaneous endoscopic lumbar discectomy as an alternative to open lumbar microdiscectomy for large lumbar disc herniation. *Pain Physician*. 2016;19:E291-E300.

3. Kong L, Shang XF, Zhang WZ, et al. Percutaneous endoscopic lumbar discectomy and microsurgical laminotomy: a prospective, randomized controlled trial of patients with lumbar disc herniation and lateral recess stenosis. *Orthopade*. 2019;48:157-164.

4. Garg B, Nagraja UB, Jayaswal A. Microendoscopic versus open discectomy for lumbar disc herniation: a prospective randomised study. *J Orthop Surg (Hong Kong)*. 2016;19:30-34.

5. Rasouli MR, Rahimi-Movaghar V, Shokraneh F, Moradi-Lakeh M, Chou R. Minimally invasive discectomy versus microdiscectomy/open discectomy for symptomatic lumbar disc herniation. *Cochrane Database Syst Rev*. 2014;9:CD010328.

6. Birkenmaier C, Komp M, Leu HF, Wegener B, Ruetten S. The current state of endoscopic disc surgery: review of controlled studies comparing full-endoscopic procedures for disc herniations to standard procedures. *Pain Physician*. 2013;16:335-344.

7. Soliman HM. Irrigation endoscopic discectomy: a novel percutaneous approach for lumbar disc prolapse. *Eur Spine J*. 2013;22:1037-1044.

8. Teli M, Lovi A, Brayda-Bruno M, et al. Higher risk of dural tears and recurrent herniation with lumbar micro-endoscopic discectomy. *Eur Spine J*. 2010;19:443-450.

9. Amato MCM, Aprile BC, de Oliveira CA, Carneiro VM, de Oliveira RS. Experimental model for transforaminal endoscopic spine. *Acta Cir Bras*. 2018;33:1078-1086.

10. Olinger A, Pistorius G, Lindemann W, Vollmar B, Hildebrandt U, Menger MD. Effectiveness of a hands-on training course for laparoscopic spine surgery in a porcine model. *Surg Endosc*. 1999;13:118-122.

11. Busscher I, Ploegmakers JJW, Verkerke GJ, Veldhuizen AG. Comparative anatomical dimensions of the complete human and porcine spine. *Eur Spine J*. 2010;19:1104-1114.

12. Bozkus H, Crawford NR, Chamberlain RH, et al. Comparative anatomy of the porcine and human thoracic spines with reference to thoracoscopic surgical techniques. *Surg Endosc*. 2005;19:1652-1665.

13. McLain RF, Yerby SA, Moseley TA. Comparative morphometry of L4 vertebrae: comparison of large animal models for the human lumbar spine. *Spine (Phila Pa 1976)*. 2002;27:E200-E206.

14. Goel VK, Panjabi MM, Patwardhan AG, Dooris AP, Serhan H. Test protocols for evaluation of spinal implants. *J Bone Joint Surg Am*. 2006;88(suppl 2):103-109.

15. Dath R, Ebinesan AD, Porter KM, Miles AW. Anatomical measurements of porcine lumbar vertebrae. *Clin Biomech*. 2007;22:607-613.

16. Sheng SR, Wang XY, Xu HZ, Zhu GQ, Zhou YF. Anatomy of large animal spines and its comparison to the human spine: a systematic review. *Eur Spine J*. 2010;19:46-56.

17. Sheng SR, Xu HZ, Wang YL, et al. Comparison of cervical spine anatomy in calves, pigs and humans. *PLoS One*. 2016;11:1-10.

18. Yingling VR, Callaghan JP, McGill SM. The porcine cervical spine as a model of the human lumbar spine: an anatomical, geometric, and functional comparison. *J Spinal Disord*. 1999;12:415-423.

19. Ahn Y, Kim CH, Lee JH, Lee SH, Kim JS. Radiation exposure to the surgeon during percutaneous endoscopic lumbar discectomy: a prospective study. *Spine (Phila Pa 1976)*. 2013;38:617-625.

20. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. *Spine (Phila Pa 1976)*. 2002;27:722-731.

21. Ahn Y, Lee S-H, Park W-M, Lee H-Y, Shin S-W, Kang H-Y. Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases. *Spine (Phila Pa 1976)*. 2004;29:E326-E332.

22. Lee DY, Lee S-H. Learning curve for percutaneous endoscopic lumbar discectomy. *Neurol Med Chir (Tokyo)*. 2008;48:383-389.

23. Wang B, Lü G, Patel AA, Ren P, Cheng I. An evaluation of the learning curve for a complex surgical technique: the full endoscopic interlaminar approach for lumbar disc herniations. *Spine J*. 2011;11:122-130.

24. Aguilera Bazán A, Gómez Rivas J, Linares-Espinós E, Alvarez-Maestro M, Martínez-Piñeiro L. [Training program in urological laparoscopic surgery: future perspective]. *Arch Esp Urol*. 2018;71:85-88.

25. Rubino F, Deutsch H, Pamoukian V, Zhu JF, King WA, Gagner M. Minimally invasive spine surgery: an animal model for endoscopic approach to the anterior cervical and upper thoracic spine. *J Laparoendosc Adv Surg Tech*. 2009;10:309-313.

26. Mühlbauer M, Ferguson J, Losert U, Koos WT. Experimental laparoscopic and thoracoscopic discectomy and instrumented spinal fusion: a feasibility study using a porcine model. *Minim Invasive Neurosurg*. 1998;41:1-4.

27. Mladina R, Skitarelić N, Cingi C, Chen L, Muluk NB. The validity of training endoscopic sinus and skull base surgery techniques on the experimental head model. *J Craniofac Surg*. 2018;29:498-501.

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