Interventional Pain Medicine 2 (2023) 100172

Contents lists available at ScienceDirect

Interventional Pain Medicine

journal homepage: www.journals.elsevier.com/interventional-pain-medicine

The S1 dorsal foramen: Nuances of anatomy

Christin Tiegs-Heiden [a], Joel Talsma [b], Frank Willard [b], Timothy Maus [a], Christine El-Yahchouchi [c,d,*]

[a] Department of Radiology, Mayo Clinic, Rochester, MN, USA
[b] Department of Anatomy, University of New England College of Osteopathic Medicine, Biddeford, ME, USA
[c] Department of Anesthesiology and Pain Medicine, American University of Beirut, Beirut, Lebanon
[d] Sheikh Shakhbout Medical City, Abu Dhabi, United Arab Emirates

ARTICLE INFO

Keywords:
Transforaminal
Epidural steroid injection
Sacral anatomy

ABSTRACT

Background: Access to the dorsal S1 neural foramen is frequently performed, but can be challenging.
Purpose: To report previously undescribed nuances of dorsal S1 foraminal anatomy, including a bony flange that may obstruct access to the foramen.
Methods: Fluoroscopic – advanced imaging correlations of the S1 foraminal aperture were performed. The anatomy of the S1 foramen was examined in 27 cadaveric specimens (N = 49 S1 foramina) and the foraminal and flange dimensions quantified. The S1 foramen was examined in 50 CT datasets (N = 100 S1 foramina), and its dimensions quantified in PA and ipsilateral oblique orientations.
Results: The medial aspect of the S1 dorsal foramen is variably shielded by a bony flange, which extends from medial to lateral. The foraminal aperture is covered by a ligament extending from this flange to the lateral aspect of the foramen. On the cadaveric specimens, the mean vertical dimension of the foraminal aperture was 8.6 mm; the transverse dimension was 8.9 mm. The mean transverse dimension of the flange was 2.8 mm. The CT images demonstrated that the transverse dimension of the S1foraminal aperture increased from a mean of 6.23 mm in the PA orientation to 7.90 mm in the ipsilateral oblique.
Discussion: The bony flange at the S1 dorsal foramen shields its medial aspect; the flange on average covers one-third of the transverse dimension of the foramen, and in 14% covered one-half. The flange has little cortical bone at its margins and may be unseen at fluoroscopy. Ligamentous tissue extending laterally from the flange covers the remainder of the foramen. The transverse dimension of the foramen increased significantly from a posterior-anterior trajectory to an ipsilateral oblique trajectory, as the flange no longer obstructed access.
Conclusion: Access to the S1 dorsal foramen may be confounded by an unseen bony flange covering its medial aspect. An ipsilateral oblique trajectory targeting the lateral margin of the foramen will maximize successful access.

1. Introduction

Access to the S1 dorsal foramen for a transforaminal epidural steroid injection (TFESI) is a very common procedure in interventional pain practice. Most symptomatic lumbar disc herniations occur at the L4-5 or L5-S1 disc levels, resulting in L5 or S1 radiculopathy/radicular pain patterns, respectively [1]. A symptomatic S1 nerve can be accessed by an infraneural L5 approach, if the lateral recess is patient, or more reliably via the S1 dorsal foramen. The S1 dorsal foramen accounted for 30% of lumbar TFESI in a large clinical series [1].

Despite its commonality, access to the S1 dorsal foramen can be challenging due to the complex anatomy of the S1 sacral segment. The dorsal foramen can be difficult to visualize fluoroscopically. Interventional pain texts [2,3] emphasize ipsilateral oblique positioning to bring the fluoroscopic beam parallel to the S1 dorsal foraminal canal and thus maximally visualize the foramen, with the target point at the apex of the dorsal foramen. These authors advocate “walking” the needle into the foramen from its lateral aspect primarily as a means of establishing depth.

Herein we report previously undescribed nuances of anatomy of the

* Corresponding author. Department of Anesthesiology and Pain Medicine, American University of Beirut, Beirut, Lebanon.
E-mail addresses: TiegsHeiden.Christin@mayo.edu (C. Tiegs-Heiden), jtalsma@une.edu (J. Talsma), fwillard@une.edu (F. Willard), timpmaus@icloud.com (T. Maus), ce18@aub.edu.lb (C. El-Yahchouchi).

https://doi.org/10.1016/j.inpm.2022.100172
Received 22 October 2022; Received in revised form 4 December 2022; Accepted 5 December 2022
2772-5944/© 2022 The Authors. Published by Elsevier Inc. on behalf of Spine Intervention Society. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

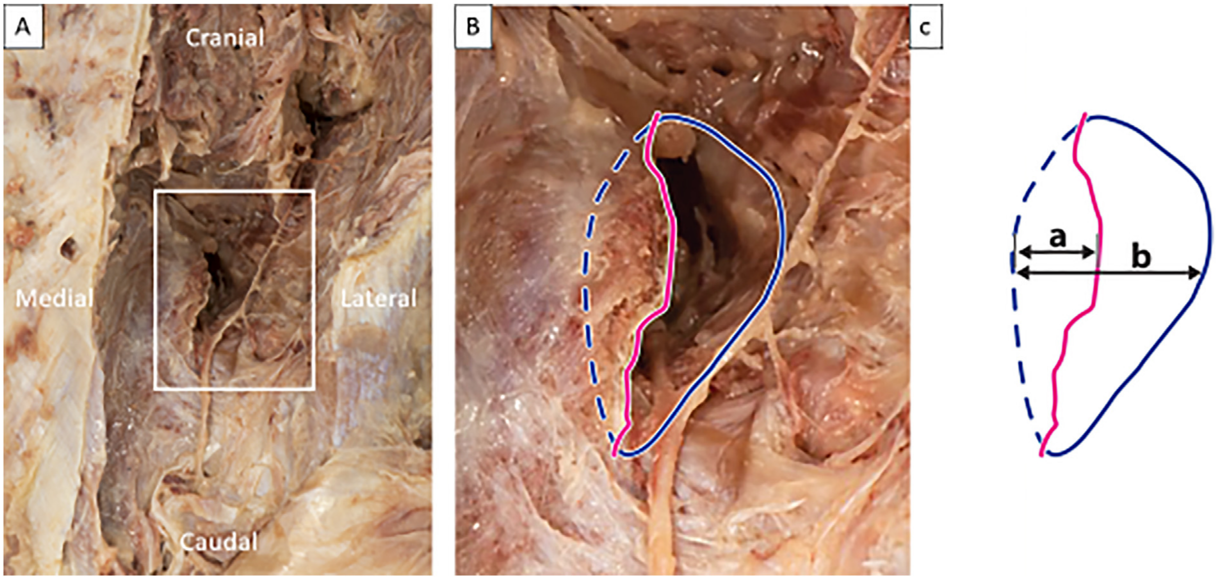


Fig. 1. (A) is a posterior view of a dissection of the right S1 dorsal foramen. In (B) the area in the white box in (A) is enlarged, and the boundaries of the flange (pink) and foramen (blue) are appended; this is shown schematically in (C). The transverse measurement of the flange is indicated by (a); the transverse dimension of the foramen by (b). To make these measurements, a ruler was inserted underneath (ventral) to the flange to identify the position of the medial foraminal boundary.

S1 sacral segment, specifically a dorsal bony flange which extends from medial to lateral and shields the medial aspect of the dorsal foramen. This flange offers little cortical bone parallel to an AP or oblique radiographic beam, and hence may be unseen at fluoroscopy. It is the need to avoid this flange that obligates an ipsilateral oblique trajectory to enter the foramen, and requires access from the lateral aspect of the foramen. A "down the beam" trajectory to the central or medial aspects of the S1 foramen may be frustrated by this unseen bony obstruction.

2. Methods

This report provides radiographic-fluoroscopic image correlations from an author (TPM) with over 20 years of experience performing S1 transforaminal injections, cadaveric anatomic observations (N = 49 foramina) to quantify the size of the bony flange, and a series of pelvic CT reconstructions (N = 100 foramina) to document the imaging appearance of the flange and quantify the size of the S1 dorsal foramen in AP and ipsilateral oblique projections.

2.1. Anatomic specimens

Twenty-seven adult human cadaveric specimens were studied (25 right, 24 left, N = 49 S1 foramina) at the University of New England College of Osteopathic Medicine. Each specimen was embalmed in the traditional formaldehyde and phenol-based method.

Each cadaveric specimen had some dissection completed by first year medical students but there was no disturbance of the S1 dorsal sacral foramina as a consequence of previous use.

For each specimen the posterior layer of thoracolumbar fascia was carefully reflected from its attachments on the sacrum to reveal the underlying multifidus lumborum muscle. Next, each multifidus was dissected away to expose the posterior sacroiliac and interosseous sacroiliac ligaments. These ligaments form a complex that overlies each of the dorsal sacral foramina with a very small opening for the sacral lateral branches to exit. After identification of the S1 dorsal foramina the ligamentous complex was dissected away to the bone to identify the entirety of the bony aperture of the foramen. Each foramen was then photographed and measured for data collection.

For each foramen, using a metric ruler, the maximum vertical (mm) and transverse (mm) axes were measured. Additionally, the transverse length of the bony flange was measured from the medial margin of the foramen to its free edge, as depicted in Fig. 1. The transverse measurements were obtained in the plane of the foraminal aperture, oriented in ipsilateral obliquity to the direct posterior-anterior plane. For the transverse measurements, the ruler was inserted ventral to the flange until it contacted the medial cortical margin of the foramen; this would correspond to the medial cortical margin of the foramen observed at fluoroscopy.

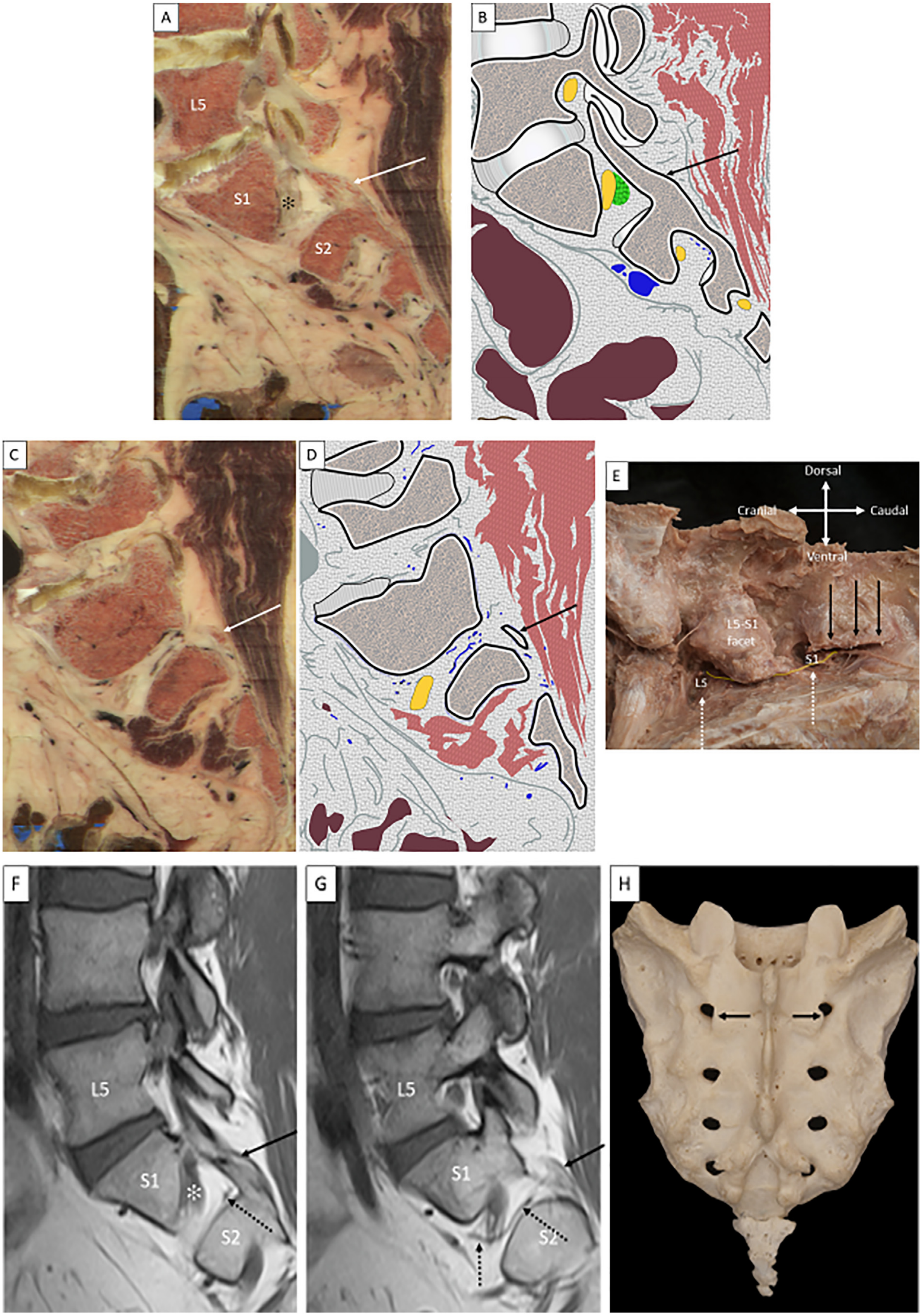
2.2. CT images

A Mayo Clinic institutional database of pre-existing Radiology examinations was searched to identify 50 CT scans of the pelvis which were performed with a uniform musculoskeletal protocol. The search was not limited by clinical indication for the scan. CT scans with or without IV contrast were included. There were no limitations based on prior lumbar, lumbosacral fusion, or sacroiliac joint fusion. Patients with poor scan quality due to excessive motion artifact or extremely low bone density were excluded, 5 patients.

Images were acquired between 2/9/2022 and 2/20/2022. There were 26 female and 24 male patients. Patient age ranged from 23 to 90 years (mean 59.3 years).

CT examinations were performed on one of several scanners at our institution (Siemens Healthcare, Forcheim, Germany). Scan parameters were as follows: 140 kV, 250 mAs, 1 s rotation time, and helical pitch of 1.0. Scan range was from the top of the iliac crests through the ischial tuberosities. Slice thickness was 2.0 mm with 1.0 mm increments.

CT images were retrospectively reviewed on a high-resolution picture archiving and communication system station (Visage Imaging, Richmond Australia) by a musculoskeletal Radiologist with dedicated spine intervention training and 6 years of experience. From the original axial images, a 3-dimensional (3D) volume rendered model of the osseous structures was created. This model could be manipulated in space by the reviewing Radiologist. This 3D model of the pelvis was first positioned in a straight posteroanterior (PA) projection, viewed from its dorsal aspect with the spinous processes positioned at midline. The model was angulated in the coronal plane until the dorsal S1 foramina were viewed en face, with the dorsal foramen positioned immediately cephalad to the ventral foramen. In this position, the aperture of the bilateral dorsal S1 foramina was measured in vertical (vert) and transverse (trans)



(caption on next page)

Fig. 2. Sagittal reconstruction of axial cadaveric images and illustrations through the midportion of the S1 foramen (A, B), and 9 mm lateral (C,D). The S1 DRG in (A) is identified by the star (✻) and is yellow in the illustrations. Note that the dorsal bony plate of the sacrum covers the midportion of the foramen (arrow in A); a lateral to medial vector is necessary to enter the foramen. In (C, D), 9 mm lateral to (A, B) the dorsal foramen is largely free of bone except for a small flange extending from medial to lateral (arrow in C,D).
In (E), a prosecuted specimen seen from a lateral perspective reveals the bony flange (black arrows) covering the medial aspect of the S1 foramen. The L5 and S1 foramina are indicated by dotted arrows.
Correlative T1 weighted MRI images in the midportion of the foramen (F) and the lateral aspect of the foramen (G) demonstrate the DRG in (F, white star), and the bony coverage of the dorsal foramen (arrows in F, G). Note also the prominent veins in the foramen (dotted arrows). In (H), a posterior view of the bony sacrum, the flange covering the medial aspect of the S1 foramen in identified by arrows.

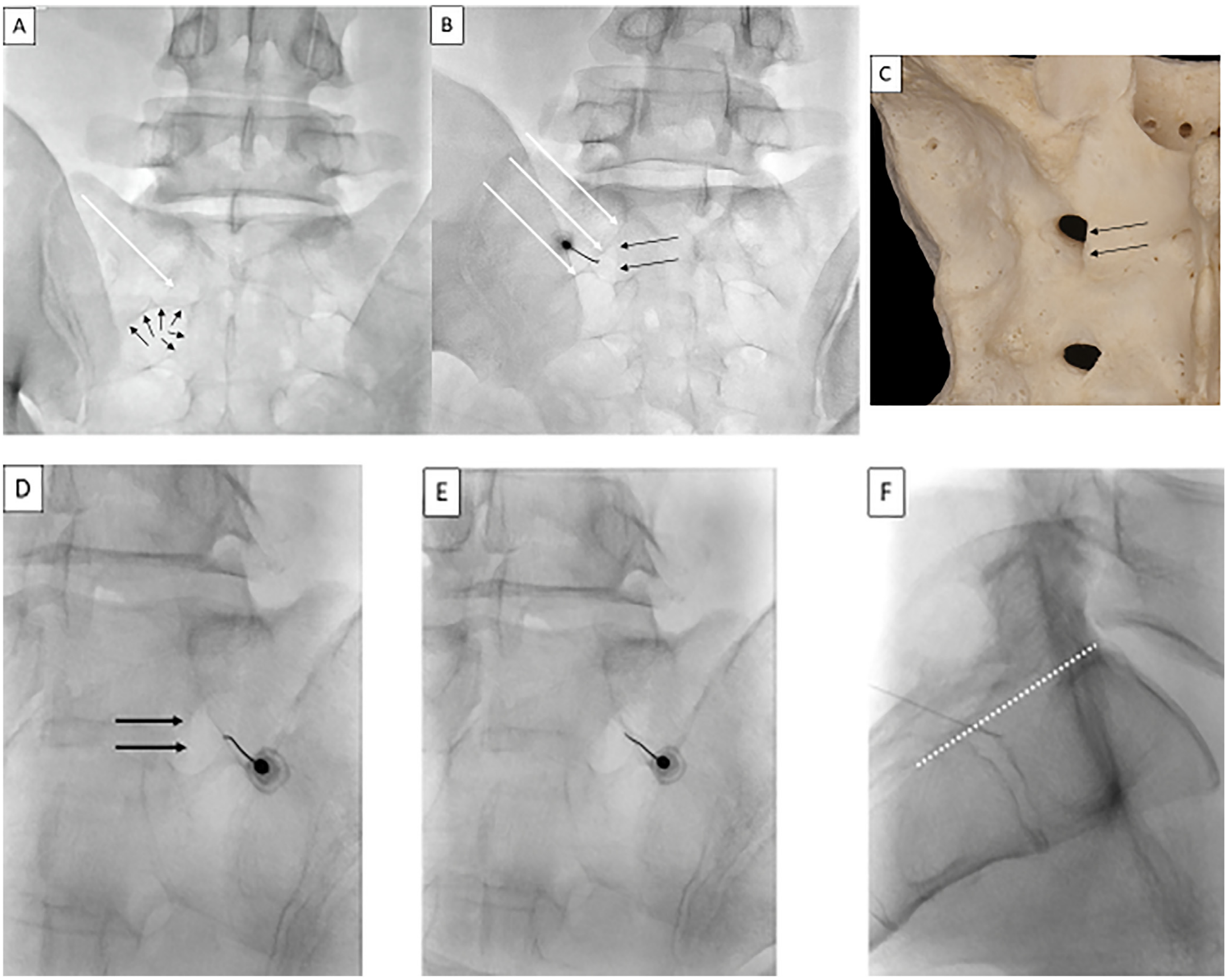


Fig. 3. Proper set up for a left S1 dorsal foramen access. On the AP view, (A), the S1 endplate is aligned with the beam. The left S1 dorsal foramen is faintly seen (white arrow); the arcuate line of Aprill (the medial margin of the S1 pedicle, in continuity with the lateral margin of the S1 canal) is not apparent. The S1 ventral foramen is an unclosed oval (black arrows). In (B), the C-arm has been rotated 10-15° ipsilateral oblique. Aprill's line is now apparent (white arrows in B). The dorsal foramen is positioned immediately cephalad to the ventral foramen using caudal to cranial angulation. A needle has been placed in the lateral aspect of the dorsal foramen. Note that the medial aspect of the dorsal foramen may be covered by the S1 bony flange (black arrows in B); its anatomic correlate is indicated by the black arrows in (C)· In another patient, the vertical cortical margin of the S1 bony flange is again seen in the ipsilateral oblique position (arrows, D). A 25-gauge needle contacts bone of the dorsal plate of the sacrum in (D), and is then manipulated into the lateral foramen in (E). In the lateral view(F) it is advanced deep to the dorsal margin of the body of the sacrum (dotted line) into proximity of the expected location of the S1 DRG.

diameters, in millimeters (mm). Subsequently, the 3D model was rotated into an oblique position to maximize the opening of the S1 dorsal foramen, as is done during standard fluoroscopically-guided dorsal S1 foraminal access. The ipsilateral dorsal S1 foramen was again measured in vertical and transverse dimension. The same procedure was repeated for the opposite side.

2.3. Statistical analysis

Descriptive statistics were performed for foraminal dimension measurements. The PA and oblique measurements were compared using a two-tailed *t*-test.

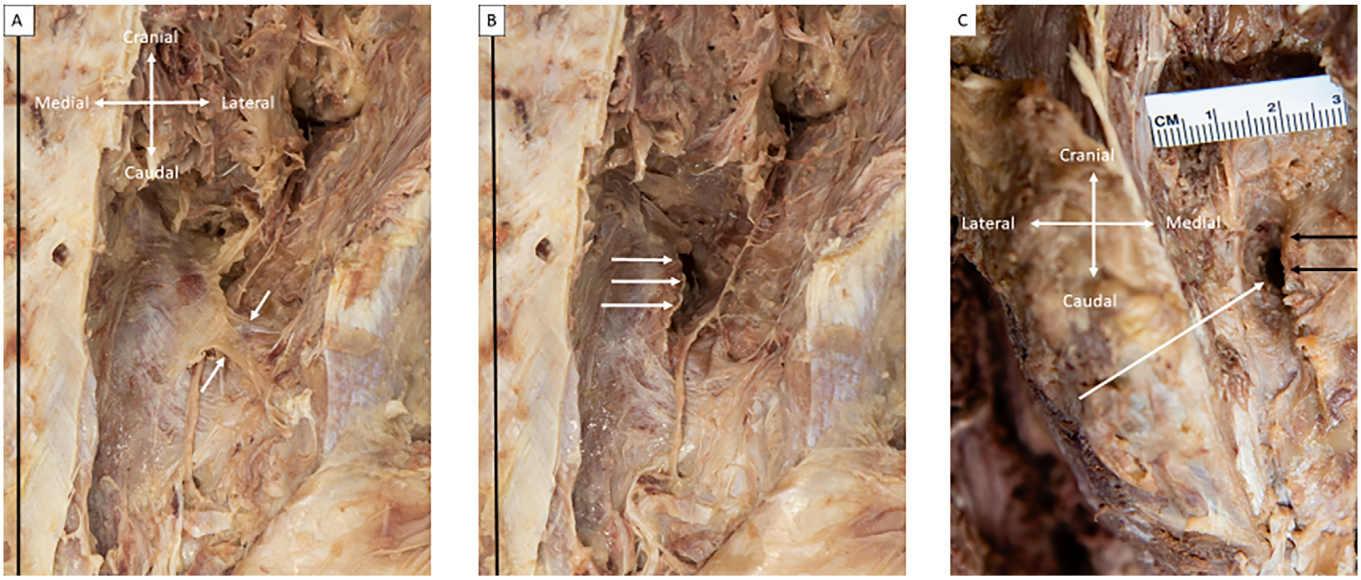


Fig. 4. Dissected, prone specimen demonstrating the right S1 dorsal foramen; the black line indicates the midline. In (A), the right S1 dorsal foramen is concealed by a typical ligamentous covering (arrows). In (B), the ligament has been removed, revealing the bony flange (arrows) that covers, and prevents access to, the medial aspect of the S1 dorsal foramen. Lateral sacral branches are visualized exiting the foramen.
In (C) a PA view of another prone specimen, the access to the left S1 dorsal foramen (white arrow) requires ipsilateral obliquity to pass under the bony flange (black arrows). The ligamentous covering over the dorsal foramen has been resected.

Table 1
S1 foraminal dimensions, cadaveric measurement (N = 49).

N = 24L N = 25R	Vertical Axis (mm)	Transverse Axis (mm)	Foramen area (mm^2)	Flange Length (mm)
Left	8.3	9.2	239	2.8
Right	8.8	8.6	241	2.8

3. Results

3.1. Correlative imaging

The authors have characterized the S1 bony flange using correlative anatomic, cross-sectional and fluoroscopic images. Fig. 2 illustrates that the sacral dorsal plate and flange may preclude direct PA access to the S1 foramen. The conventional set-up for a dorsal S1 access is shown in Fig. 3. Note that the lateral cortical margin of the flange is faintly visualized on high quality digital radiographs, and can be observed to prevent access to the medial foramen.

3.2. Anatomic dissections

Dissections of the 27 sacral specimens (24 left, 25 right, N = 49 S1 foramina) revealed that the dorsal foramen was consistently covered by a ligament extending from the medially situated bony flange to the dorsal plate at the lateral aspect of the foramen (Fig. 4). Only when this ligament was removed would the bony margins of the flange and its relationship to the foraminal aperture of the foramen by revealed. The

Table 2
Frequency distribution of S1 flange length (mm), cadaveric measurement (N = 49).

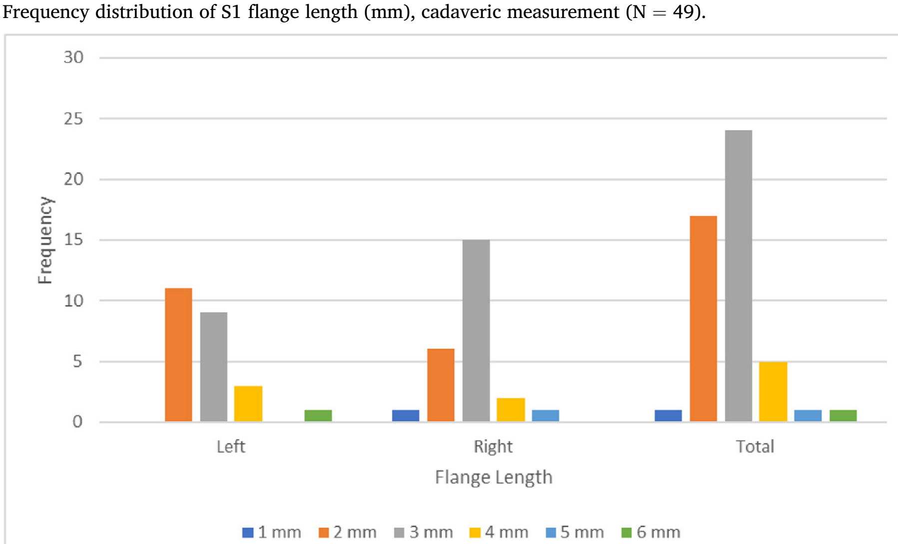


Table 3
Dimensions of S1 foraminal aperture in PA and Oblique projections, CT measurement (N = 100).

N = 100	Vertical Axis PA (mm)	Vertical Axis Oblique (mm)	Transverse Axis PA (mm)	Transverse Axis Oblique (mm)
Mean	9.96 ± 1.85	10.50 ± 1.97	6.23 ± 1.79	7.90 ± 1.70

dimensions of the dorsal S1 foraminal aperture are provided in Table 1. There was no laterality difference in foraminal dimensions or flange length. The frequency distribution of the horizontal length of the bony flange from its base to its free edge is seen in Table 2. The mean flange length was approximately one-third of the mean horizontal dimension of the foramen. In 7/49 foramina (14%) the flange covered nearly half of the horizontal width of the foramen.

3.3. *CT images*

In the straight PA position, the vertical dimension of the S1 foramina ranged from 6 to 16 mm (mean 9.96 ± 1.85). Transverse dimension ranged from 3 to 10 mm (mean 6.23 ± 1.79). In the ipsilateral oblique position, the vertical dimension of the foramina ranged from 6 to 18 mm (mean 10.50 ± 1.97). The transverse dimension ranged from 4 to 12 mm (mean 7.90 ± 1.70) Table 3. Frequency distribution of the horizontal axis (transverse) dimension foraminal measurements for the PA and oblique positions is shown in Table 4.

The vertical dimension was unchanged between the PA and oblique positions in 54/100 foramina, larger in the oblique position in 44/100, and larger in the PA position in 2/100 foramina. The 2 foramina which had a larger vertical dimension from the PA position occurred in the same patient. Dimension difference between the PA and oblique positions ranged from 0 to 3 mm (0.54 ± 0.77). There were 37 foramina with a 1 mm difference, 6 foramina with a 2 mm difference, and 3 foramina with a 3 mm difference. Two tailed *t*-test showed a significant difference in foraminal size between the PA and oblique positions ($t = -2.00$, $p = 0.047$).

The measurement of transverse foraminal dimension was larger in the oblique position in 85/100 foramina, unchanged between the PA and oblique position in 15/100 foramina, and was not larger in the PA position in any foramina (Fig. 5). Difference in transverse dimension between the PA and oblique positions ranged from 0 to 5 mm (1.50 ± 1.21). There were 35 foramina with a 1 mm difference, 31 foramina with a 2 mm difference, 8 foramina with a 3 mm difference, 9 foramina with a 5 mm difference, and 2 foramina with a 5 mm difference. There was a significant difference in foraminal size between the PA and oblique positions ($t = -6.77$, $p<0.001$). The frequency distribution of the transverse foraminal dimension in PA and oblique positions is shown in Table 4.

The frequency distribution of the change in transverse dimension of the S1 dorsal foramina in PA versus ipsilateral oblique positions (where the bony flange no longer blocks access to the foramen) is shown in Table 5.

4. Discussion

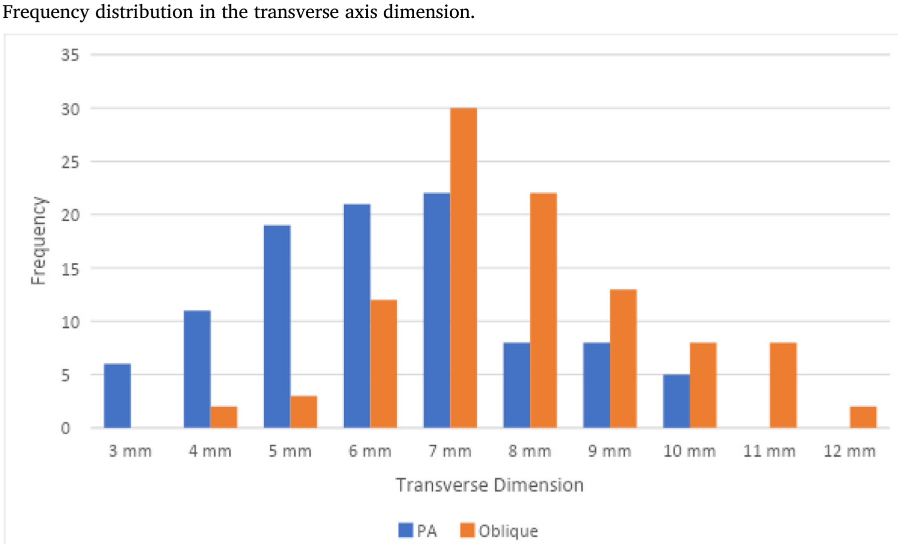
The complex anatomy of the S1 segment contributes to the challenges of S1 dorsal foraminal access. The S1 dorsal foraminal aperture is shielded in its medial aspect by the herein described bony flange, which may cover nearly one half of the horizontal width of the foramen in approximately 14% of patients. This bony flange has limited cortical bone at its margins and may be unseen at fluoroscopy. The dorsal foraminal aperture is also uniformly covered by a ligament extending from the bony flange to the dorsal plate of the sacrum lateral to the foramen.

These newly described anatomic nuances have practical implications for S1 foraminal access. A trajectory prescribed in ipsilateral obliquity will not merely sharpen the cortical margination of the dorsal foramen allowing it to be better seen, but more importantly allow safe needle passage without obstruction from the potentially unseen bony flange. The horizontal dimension of the bony aperture of the foramen was greater in 85% of cases in an oblique versus PA view. In approximately 20% (19/100) the horizontal dimension of the foraminal aperture changed by 3 mm or greater in the oblique position, nearly doubling the transverse dimension observed in the PA position (Table 5).

A trajectory which initially contacts bone at the lateral margin of the perceived dorsal foramen, and then is manipulated into the foramen from a lateral to medial vector does not just allow judgement of depth, it also provided the best opportunity to avoid encountering the bony flange. Trajectories targeting the mid or medial foramen may be doomed to fail, encountering the unseen bony flange. Operators should be aware that there will be a tactile sense of ligamentous penetration at the posterior margin of the foramen.

The existing primary texts describing S1 access [2,3] prescribe craniocaudal fluoroscopic angulation by aligning the beam to the S1

Table 4
Frequency distribution in the transverse axis dimension.



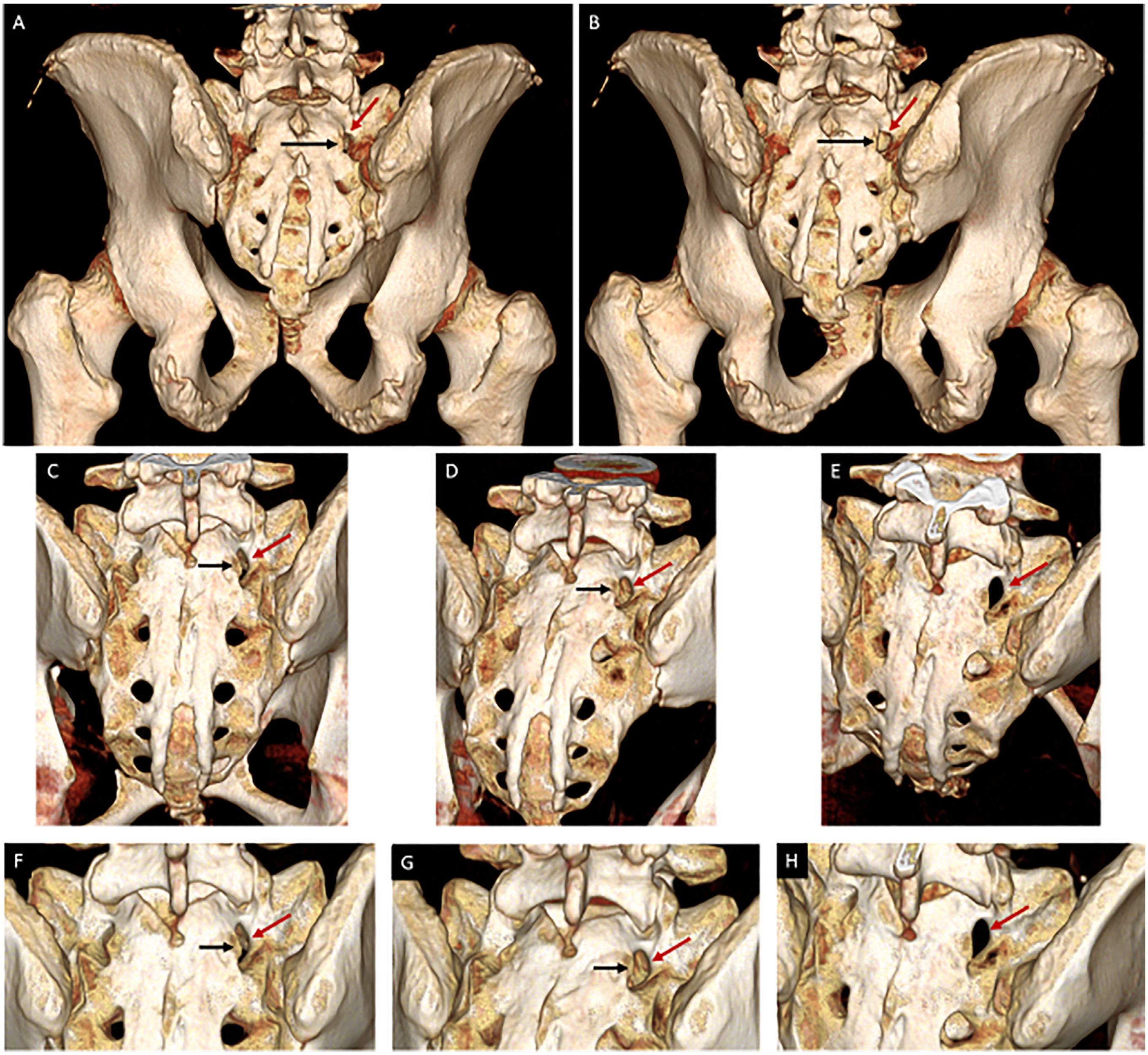


Fig. 5. 3D volume rendered images of the pelvis. In the PA projection (A), the dorsal right S1 neural foraminal opening (red arrow) measured 11 mm CC x 4 mm transverse, partially covered by the flange (black arrow). In the ipsilateral oblique position (B), the opening now measured 12 mm CC x 8 mm transverse; this trajectory prevents the flange from blocking access to the foramen.
In another patient, in the PA projection (C, F) the flange (black arrow) largely covers the S1 foraminal aperture (red arrow). In the ipsilateral oblique position with the dorsal foramen positioned tangentially cephalad to the ventral foramen (relative caudal to cranial trajectory, D,G), the foraminal aperture is now accessible; note there is bone deep to the dorsal foramen. In (E,H) the dorsal and ventral foramina are superimposed (more cranial to caudal angulation) and there is no bony impediment to the needle passing into the pelvis.

Table 5
Frequency distribution of the change in transverse axis dimension of the S1 foramina, PA to Oblique positioning.

Change in Transverse axis (mm)	0	1	2	3	4	5
Frequency N = 100	15	35	31	8	9	2

endplate, with additional manipulation as needed. The dorsal and ventral foramina are described as potentially overlapping, and are so illustrated in figures. In our CT measurements, the dorsal foramen was placed tangentially superior to the ventral foramen. As illustrated in Fig. 6, this creates a trajectory which is directed more cephalad, minimizing the risk of pelvic penetration and maximizing the likelihood of cephalad flow in the authors' clinical experience.

5. Conclusion

Access to the S1 dorsal foramen can be confounded by a dorsal bony flange which extends from medial to lateral across the transverse dimension of the foraminal aperture. The aperture is also protected by a ligament arising from this flange. As the flange may be poorly seen at fluoroscopy, the operator should utilize an ipsilateral oblique trajectory, from lateral to medial, to reliably access the foramen.

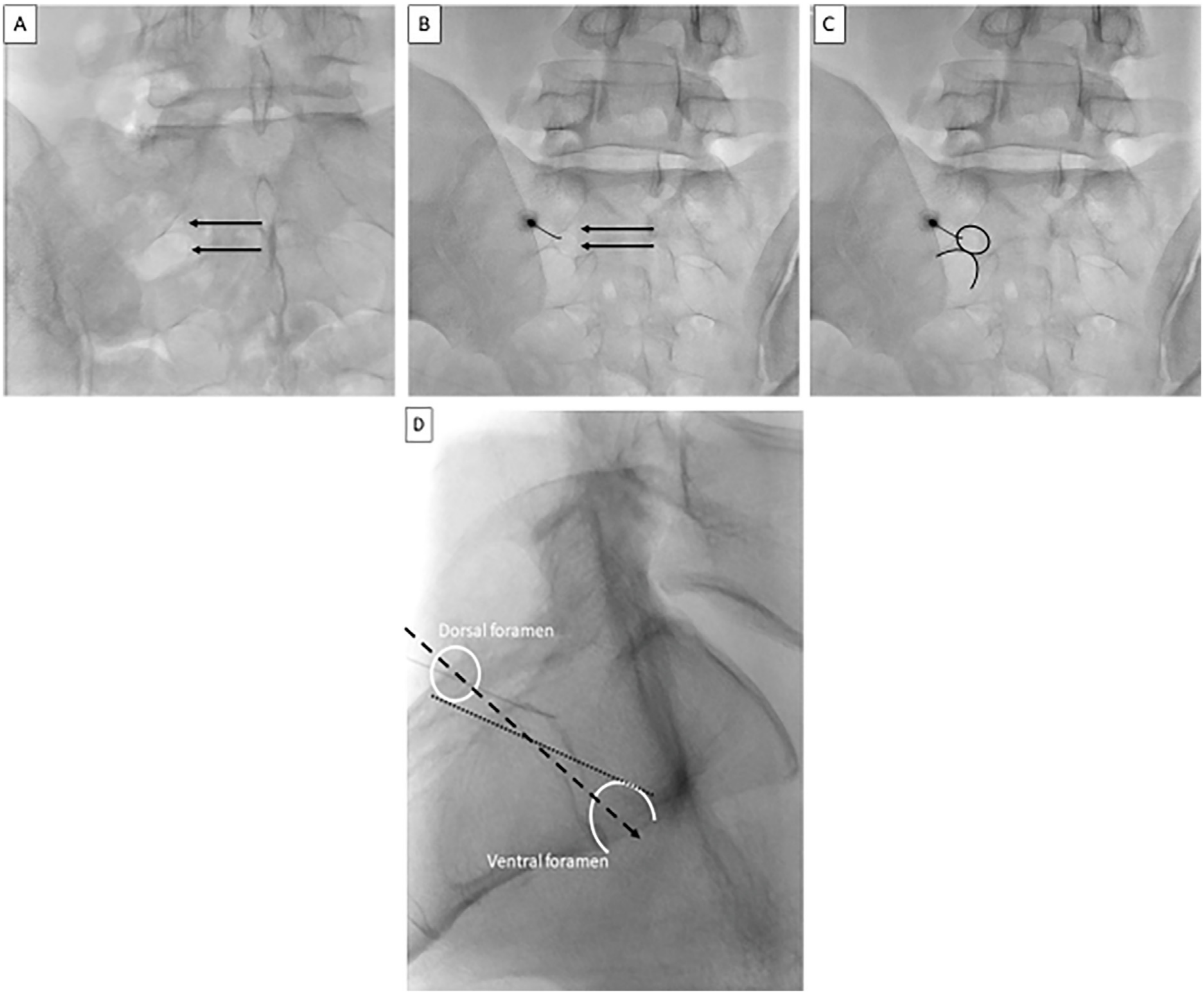


Fig. 6. In the unadjusted AP view (A), the left dorsal and ventral foramina are partially superimposed. A trajectory with superimposed foramina is depicted by the dashed line in D; this potentially runs the risk of entry into the pelvis, and also places the needle tip too caudal to provide a cephalad directed flow pattern. Placing the dorsal foramen tangent to the ventral foramen, to make the listing snowman (B,C, dotted black line in D) provides a trajectory like the placed needle and will result in a more cephalad needle tip position, and likely a more desirable flow pattern.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr Timothy Maus co-author serves on the editorial board of the journal.

Acknowledgements

Our thanks to Oran Suta, Medical Illustrator, UNE, for assistance with figures.

Thanks to Soha Bayginejad, UNE COM OMS-II, BA, BS and Vrushabh Daga, UNE COM OMS-II, BS for assistance with the dissections.

References

[1] Kaufmann TJ, Geske JR, Murthy NS, Thielen KR, Morris JM, Wald JT, Diehn FE, Amrami KK, Carter RE, Shelerud RA, Gay RE, Maus TP. Clinical effectiveness of single lumbar transforaminal epidural steroid injections. Pain Med 2013;14(8): 1126–33.

[2] Bogduk N, editor. Practice guidelines for spinal diagnostic and treatment procedures. second ed. San Francisco, USA: International Spine Intervention Society; 2013.

[3] Furman MB, editor. Atlas of image-guided spinal procedures. second ed. Philadelphia: Elsevier; 2018.