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ORIGINAL RESEARCH

Anatomical Location of the Segmental Spinal Arteries in the Cervical Intervertebral Foramina: 3D-Micro CT Findings Relevant to Transforaminal Epidural Injection

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Purpose: Cervical transforaminal epidural steroid injection (TFESI) is a common treatment for cervical radiculopathy but carries potential risks because of the presence of crucial arteries in the intervertebral foramina (IVF). This study analyzed the precise anatomical location of the segmental spinal artery (SSA) within the cervical IVF using 3D micro-CT imaging to provide guidance for safer TFESI procedures.

Participants and Methods: Fourteen embalmed cadavers were used in this study: three for serial sectional dissection, two for histological examination, and nine for micro-CT analysis. Each IVF was divided into quadrants (ASQ, antero-superior quadrant; PSQ, postero-superior quadrant; AIQ, antero-inferior quadrant; PIQ, postero-inferior quadrant) for detailed measurements of SSA locations, comparing dimensions and spatial relationships among C4–5, C5–6, and C6–7 levels.

Results: Forty-four IVFs were analyzed by micro-CT, and the results revealed that SSAs were predominantly located in the ASQ (36 of 44 cases, 82%) and PSQ (8 of 44 cases, 18%) of the IVF. No SSAs were observed in the AIQ and PIQ. Significant dimensions and shapes were consistent across individuals, with cervical IVF increasing in size from C4–5 to C6–7.

Conclusion: Together, these findings demonstrated the predominance of SSAs in the ASQ, emphasizing the need for precise anatomical guidance during TFESI to avoid vascular injury. In addition, the cervical spine exhibits anatomical variability, indicating that greater caution is required when treating the cervical spine compared with the lumbar spine and highlighting the importance of targeting the PIQ to avoid the SSA and other vascular structures.

Keywords: cervical transforaminal epidural steroid injection, micro-computed tomography, segmental spinal artery

Introduction

Cervical radiculopathy often causes symptoms like numbness, tingling, or weakness in the hands and arms, impacting a person's daily activities and quality of life.[1] These symptoms occur because the nerves in the cervical spine are being compressed. This compression is usually caused by degenerative changes, such as osteoarthritis, which wear down the spinal discs and joints and can lead to the narrowing of the spaces through which the nerves travel.[2] A herniated disc, in which the inner gel of the disc bulges out and presses on the nerves, can also cause this condition.

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For the treatment of cervical radiculopathy, steroids and local anesthetics are often injected into the epidural space to reduce inflammation and pain.[3] Cervical transforaminal epidural steroid injection (TFESI) is a method of injecting medication into the epidural space around the cervical nerve roots where they exit the spine through the intervertebral foramen (IVF).[3,4] For treatment at the cervical spine, fluoroscopically-guided TFESI typically involves an oblique angled approach from the front toward the back to reach the target area.[5,6] These injections need to be performed very carefully because there are important arteries in the IVF, such as the segmental spinal artery (SSA, described as the radicular artery in some clinical reports) and the segmental medullary artery.[7–9] Damage to these arteries can cause serious complications including spinal cord injury or cerebellar stroke.[7,10–12]

Traditional research methods for cervical spine anatomy have mainly relied on manual dissection; however, the cervical foramen is very small, and the surrounding structures move easily. This complicates spinal surgery as it involves manipulation of vessels and structures around the foramen. Additionally, visualizing nerve roots and vessels inside the foramen is challenging, especially determining their location in the oblique view of the needle approach during fluoroscopically-guided TFESI. For detailed and accurate analysis of the arteries within the IVF, we used three-dimensional micro-computed tomography (3D micro-CT) imaging. Unlike manual dissection, 3D micro-CT offers high resolution and the ability to visualize small, delicate structures without causing damage. Previous studies have used conventional manual dissection to observe the SSA but lacked intuitive visual guidance to the cervical IVF.[7,13–15] The present anatomical study analyzed the location of the SSA in the IVF using 3D micro-CT images. The study findings suggest the most frequent regions of SSA for safe TFESI in the cervical IVF.

Methods

Study Design and Ethical Compliance

This study included 14 embalmed cadavers (8 males and 6 females, mean age at death: 86 years) for serial sectional dissection, histologic examination, and micro-CT analysis. All experimental procedures were performed ethically in accordance with the World Medical Association's Declaration of Helsinki and were approved by the institutional review board of Yonsei University College of Medicine (approval no. 4–2024-0666). All cadavers were legally donated to the Surgical Anatomy Education Center of Yonsei University College of Medicine (approval number: YSAEC 24–007), and appropriate consent was obtained for their use. The participants provided written informed consent to donate their bodies for research purposes after death. The study adhered to the CACTUS guidelines by providing detailed descriptions of cadaver preparation, procedural techniques, and ethical compliance, with procedures performed by anatomists with over 10 years of experience, ensuring transparent and internationally compliant reporting of cadaver-based research. Every effort was made to follow all local and international ethical guidelines and law that pertain to the use of human cadavers donated for anatomical research.[16] No cadavers had operative procedure, trauma, or deformity in the cervical spine region.

Manual Dissection and Serial Sectional Dissection

We dissected the cervical spine region and examined the arteries traveling into the IVF. Three cervical vertebral tissue blocks from the C5 to C7 level were harvested from three cadavers. All specimens were serially cut in the oblique plane at 2–3 cm intervals. The sectioned specimens were examined.

Modified Masson's Trichrome Staining

Two specimens were obtained from each embalmed cadaver and incubated in a decalcification solution overnight. The specimens were neutralized in a 3% lithium carbonate solution for 1 h. The decalcified specimens were embedded in paraffin and cut into 4-μm-thick sections. The sections were then deparaffinized, rehydrated, and soaked in Bouin fluid (60°C) for 30 min. Weiger's iron hematoxylin was then applied. The sections were incubated in a Biebrich scarlet/acid fuchsin solution and preserved in a phosphomolybdic acid / phosphotungstic acid solution. Next, an aniline blue solution and a 2% acetic acid solution were applied to all sections. The sections were then dehydrated using 70%, 85%, and 90% ethanol and xylene and examined using an optical microscope (BX51, Olympus Inc., Tokyo, Japan).

Contrast-Enhanced Staining and 3D Reconstruction

Nine specimens (C4–C6 or C5–C7 levels) were harvested from nine cadavers. The specimens were dehydrated by consecutive immersion in 30%, 50%, and 70% ethanol solutions overnight. Afterward, all specimens were soaked in a 3% phosphotungstic acid solution with 70% ethanol for two months. Finally, the specimens were preserved in 70% ethanol before micro-CT scanning. Scanning was conducted using a Skyscan1173 (Bruker, Kontich, Belgium) with the following parameters: source current at 80 µA, source voltage 110 kV, image pixel size 40 µm, and image pixel grid of 2240×2240. All scanned images were reconstructed using NRecon software (version 1.7.0.4, Bruker, Kontich, Belgium). The CTvox software (version 2.7, Bruker, Kontich, Belgium) and Mimics (version 19, Materialse NV, Leuven, Belgium) were used for a more detailed examination of the three-dimensional rendered volume.

Analysis of 3D Micro-CT Images

The height, width, and diameter of the IVF were measured in an oblique view of 3D micro-CT images. The following references were established to facilitate a precise analysis of the location of the SSA (Figure 1).

1. The longest vertical line of the IVF: A line connecting the highest superior and lowest inferior osseous borders of the IVF.
2. The mid-horizontal line: The midpoint of the longest vertical line of the IVF.
3. The superior portion of the IVF: Above the mid-horizontal line, consisting of the antero-superior quadrant (ASQ) and the postero-superior quadrant (PSQ).
4. The inferior portion of the IVF: Below the mid-horizontal line, consisting of the antero-inferior quadrant (AIQ) and the postero-inferior quadrant (PIQ).

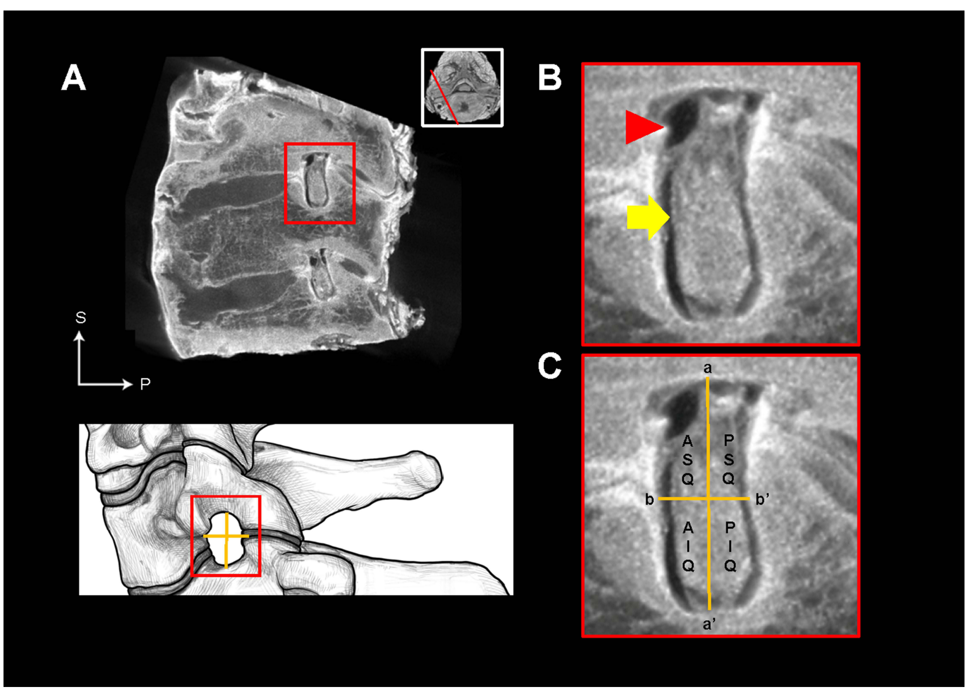

Figure 1 An oblique view of 3D micro-CT of the cervical vertebra (C4–6 level, superior) and illustration of the cervical vertebra (inferior) (**A**). Red boxes indicate the intervertebral foramen (IVF). The magnified image of the IVF shows the segmental spinal artery (SSA) marked with a red arrowhead and the spinal nerve root marked with a yellow arrow (**B**). The height of the IVF is defined as the longest vertical line connecting the highest superior and lowest inferior osseous borders (a to a'). The width of the IVF is defined by the mid-horizontal line of the longest vertical line (b to b') (**C**). The IVF was divided into quadrants by the longest vertical and mid-horizontal lines. The location of the SSA was determined relative to the IVF reference lines that divide the space into quadrants.

Abbreviations: ASQ, antero-superior quadrant; AIQ, antero-inferior quadrant; PSQ, postero-superior quadrant; PIQ, postero-inferior quadrant.

The IVF was divided into quadrants by the longest vertical and mid-horizontal lines. The location of the SSA was examined by measuring the distance from the center of the artery to the reference lines of the IVF to the quadrant divisions. All data were used to generate a scatter plot. IVF height measurement was applied to normalize the measurement data, providing a comparable reference SSA for IVF of varying sizes. All morphometric data are described as mean ± standard deviation. A parametric *t*-test was used because of the normal data distribution. All statistical analysis were performed using the Statistical Package of the Social Sciences (version 25.0, IBM Corporation, NY, USA). A p-value < 0.05 was considered significant.

Results

In this study, 44 intact IVFs were investigated in nine cervical vertebrae blocks (12 foramina in C4–5, 18 foramina in C5–6, and 14 foramina in C6–7 levels). Their shapes and dimensions were observed using micro-CT, cadaver sections, and histological observations. The arteries along the spinal nerve, the SSAs, were evident in all foramina. For morphological description and specification of arterial location, the IVF was defined as the lateral section perpendicular to the external entrance of the foramina, following the study by Gregg et al.[17] The IVF is formed by adjacent vertebral notches, with boundaries defined by pedicles, vertebral bodies, and zygapophyseal (facet) joints. The IVF faces the posterior surface of the disc or vertebral body as a wedge-shaped space filled with loose connective tissue.

Detailed dimensions of the IVF are shown in Table 1. There were no significant differences in shape and dimensions of the IVF based on sex (Supplementary Table 1). The standard deviation of the height and width of the IVF was approximately 1 mm, indicating a typical morphology across individuals. As the vertebrae descend, they increase in both height and width, and the IVF of C6–7 is approximately 50% larger in area than the IVF of C4–5. Generally, the cervical IVF is vertically elongated and oval in shape. As the IVF descends, it becomes more rounded (less elongated), with a decreasing ratio of width to height (2.3 at C4–5, 2.2 at C5–6, and 2.0 at C6–7).

In all foramina, the spinal nerve was significantly larger than the artery within the IVF (Figure 2A). This finding corresponds with the oblique section of the cadaver and the histological findings (Figure 2B–D). Additionally, loose connective tissue was found to demarcate both the vascular and nerve spaces. The SSA was observed as a single artery in the upper half of the IVF. During dissection, the vertebral artery was found to ascend through the transverse foramina, as previously reported. The ascending path of the vertebral artery was located in the most anterior area of the IVF in the anteroposterior direction. From the vertebral artery, the SSA branched off before the vertebral artery entered the transverse foramen and mostly proceeded laterally via the ASQ of the IVF (Figure 3 and Table 2).

Table 1 Measurements of the Height, Width, and Diameter of the Cervical Intervertebral Foramina on the Oblique View of 3D Micro-CT

Cervical levels	n	Measurements	Mean	Range	SD
C4–5 level	12	IVF height, mm	8.45	7.3–9.92	0.68
		IVF width, mm	3.67	2.78–4.6	0.50
		IVF diameter, mm	29.25	22.358–36.445	4.77
C5–6 level	18	IVF height, mm	9.31	7.44–10.92	0.98
		IVF width, mm	4.25	2.97–5.69	0.81
		IVF diameter, mm	38.04	22.865–58.242	9.34
C6–7 level	14	IVF height, mm	9.69	8.07–11.83	1.11
		IVF width, mm	4.84	3.66–6.12	0.77
		IVF diameter, mm	44.63	33.011–60.109	9.34
All levels	44	IVF height, mm	9.15	7.3–11.83	0.92
		IVF width, mm	4.25	2.78–6.12	0.69
		IVF diameter, mm	37.31	22.358–60.109	7.82

Abbreviations: SD, standard deviation; IVF, intervertebral foramina.

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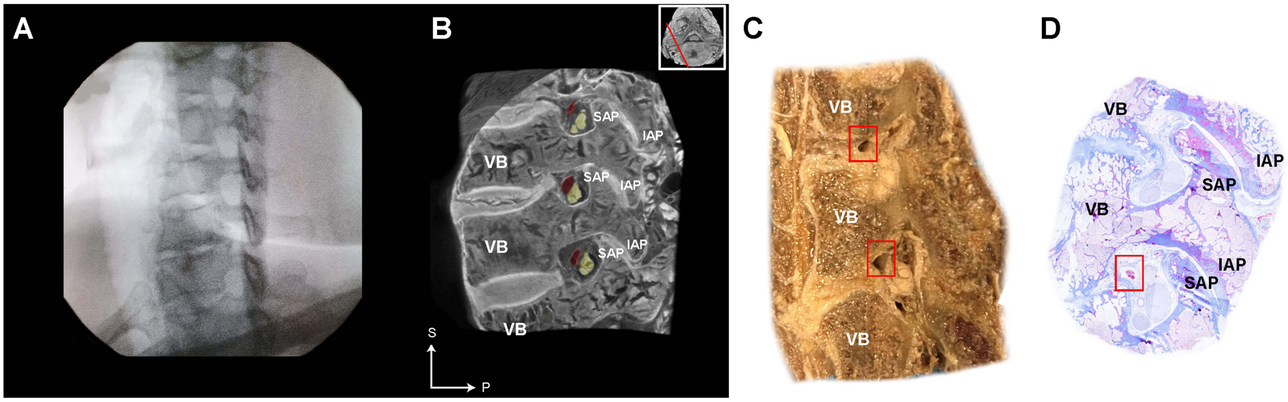

Figure 2 A fluoroscopic oblique view for transforaminal epidural approach in the cervical region (**A**). A micro-CT image showing the segmental spinal arteries (SSAs) in the antero-superior quadrant of the intervertebral foramen and the spinal nerve in the postero-inferior quadrant (**B**). In all foramina, this finding corresponds with the oblique section of the cervical spine (**C**) and its histological findings (**D**). Red boxes indicate the SSA.
Abbreviations: VB, vertebral body; SAP, superior articular process; IAP, inferior articular process.

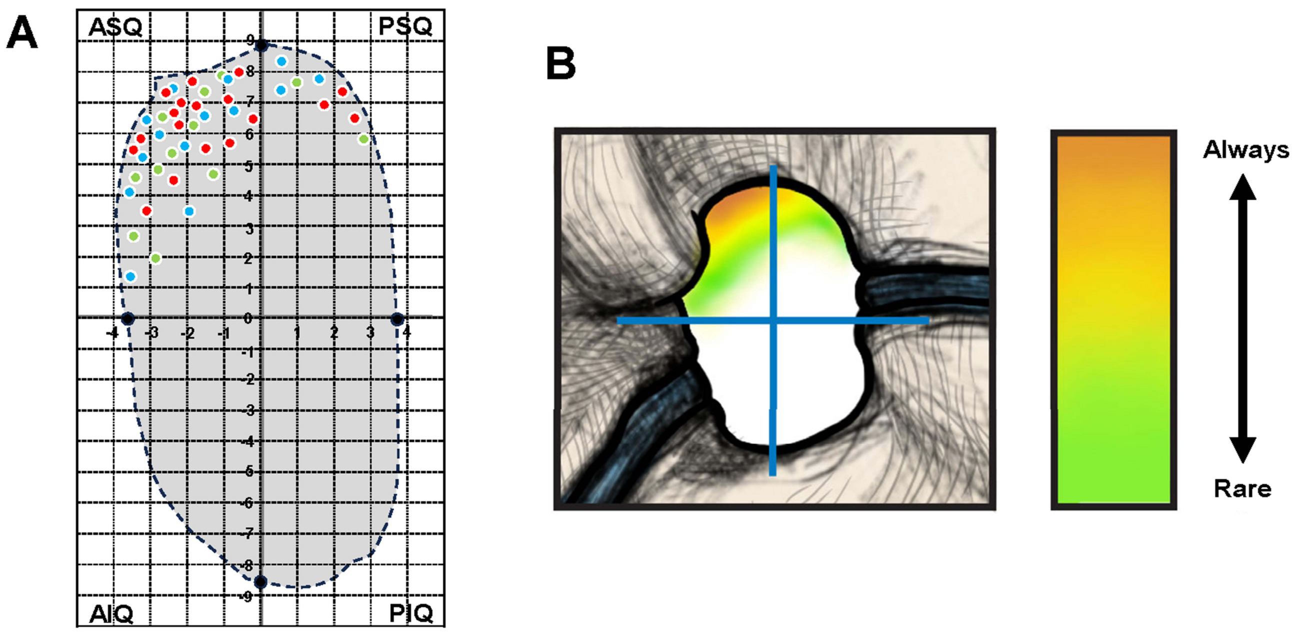

Figure 3 A scatter plot visualizing the locations of the segmental spinal arteries (SSAs) within the intervertebral foramina (IVF) (**A**). The green, red, and blue dots indicate SSA locations in the IVF at C4–5, C5–6, and C6–7 levels, respectively. A density plot based on the frequency of SSA locations within the IVF (**B**).
Abbreviations: ASQ, antero-superior quadrant; PSQ, postero-superior quadrant; AIQ, antero-inferior quadrant; PIQ, postero-inferior quadrant.

The locations of the SSA within the IVF are detailed in Table 2, and their relative positions are shown in Figure 3 through topographic calibration for accurate superimposition. Approximately 80% (range 79–83%) of the SSAs were located in the ASQ and approximately 20% (range 17–21%) were located in the PSQ of the IVF at C4–5, C5–6, and C6–7 levels. No SSAs

Table 2 Locations of Segmental Spinal Arteries in the Cervical Intervertebral Foramina

Cervical levels	n	ASQ	PSQ	AIQ	PIA
C4–5 level	12	10 (83%)	2 (17%)	0 (0%)	0 (0%)
C5–6 level	18	15 (83%)	3 (17%)	0 (0%)	0 (0%)
C6–7 level	14	11 (79%)	3 (21%)	0 (0%)	0 (0%)
All levels	44	36 (82%)	8 (18%)	0 (0%)	0 (0%)

Abbreviations: ASQ, antero-superior quadrant; PSQ, postero-superior quadrant; AIQ, antero-inferior quadrant; PIA, postero-inferior quadrant.

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were observed in the AIQ or PIQ of any IVF. Notably, the SSAs were located at the edges of the IVF, with no artery found in the central area. All SSAs in the PSQ were extremely close to the edge, as the larger spinal nerve pushes the SSA to the edge of the foramen.

Discussion

Our results indicate that the SSAs are predominantly located in the ASQ of the IVF. This confirms previous studies in the lumbar region and emphasizes the importance of directing the needle toward the PIQ during TFESI to avoid these arteries.[17] Such needle direction can prevent not only SSA puncture, but also accidental deep needle penetration damage of the vertebral artery just anterior to the IVF.[6] Given the severe complications that can arise from arterial puncture, including spinal cord infarction and cerebellar stroke, this study reinforces the need for precise anatomical guidance around the IVF during cervical spine injections.[7,10–12] Additionally, our study focused on the lower cervical region, which is most frequently involved in TFESI, emphasizing the clinical relevance of our findings.

The arteries supplying the spinal cord are oriented either longitudinally in a craniocaudal direction (with one anterior and two posterior spinal arteries) or segmentally (the SSAs at each level) in a mediolateral direction. Of these, the segmental arteries are particularly vulnerable to injury from spinal nerve injections via the IVF approach. The cervical SSA originates from the vertebral artery, whereas the trunk SSA originates from the lumbar arteries or the intercostal arteries of the aorta. In our study, the vertebral artery was positioned in the anterior half of the IVF, anteroposteriorly. Thus, the AIQ of the IVF also is vulnerable to deep needle penetration that could reach the vertebral artery and the spinal canal, even though no SSA was found there.

After branching, the SSA continues horizontally through the IVF and then bifurcates into the anterior and posterior radicular arteries along the anterior and posterior rami of the spinal nerve. Within the vertebral canal, the radicular arteries divide into several smaller arteries along the roots emerging from the spinal cord. Most of the segmental arteries anastomose with the longitudinal arteries supplying the spinal cord, implying a complementary blood supply that can compensate for regional vessel rupture. The term "radiculomedullary (feeder) artery" refers to a distinct single or partially double radicular artery that reaches the anterior median fissure of the spinal cord. Thus, it seems more reasonable to refer to the artery we observed within the IVF as the SSA rather than the radicular artery, as described in some studies.[8,18]

The TFESI procedure involves guiding the needle tip just outside the IVF, emphasizing the need for precise terminology, as the artery leading to the radicular artery can be punctured at this site. Huntoon et al[13] noted in 2008 that "the naming of arteries that contribute to spinal cord blood flow has created significant confusion among clinicians" as "the artery joining the anterior spinal artery is commonly called a 'radicular artery'".[19] However, many clinical studies still refer to the SSA as the radicular artery.[9–11] Some studies acknowledge this controversy, referring to the puncture site as a branch of the vertebral artery, an artery around the foramen, or indirectly mentioning that the radicular artery can be damaged due to arterial puncture.[7,12] Given the clinical importance of the SSA in the TFESI procedure, standardizing terminology related to vascular anatomy is needed for clarity and safety in clinical practice.

In the present study, 18% of the arteries were in the PSQ of the cervical IVF, which is a notable departure from observations in the lumbar region.[17] The smaller size of the cervical IVF compared with the lumbar IVF may explain why some cervical arteries were found in the PSQ of the IVF, unlike the lumbar segmental arteries, of which 96% were found in the ASQ.[17] This anatomical insight, along with the need to avoid the AIQ to prevent damage to the vertebral artery, suggests that targeting the PIQ of the cervical IVF may be necessary to avoid vascular structures, requiring greater caution compared with the lumbar spine. The cervical spine has a higher diversity of vascular structures and greater severity of potential complications compared with the lumbar spine, necessitating greater caution during needle placement.[20] This anatomical variability may also influence surgical approaches, emphasizing the need for customized methods to prevent vascular injury during cervical spine surgeries.

Additionally, Gregg et al reported that the lumbar SSA was found in only 83% of living subjects, whereas we found the SSA in all foramina of cadaveric samples. Although we cannot exclude the possibility of a true topographic difference, this discrepancy could be due to the high resolution of micro-CT and the verification by histological observation in our study. The high-resolution micro-CT imaging used in this study provided detailed insights into the spatial relationships between the SSAs, spinal nerves, and surrounding tissues. Previous study on lumbar SSA used flat-panel catheter angiotomography

(FPCA) to observe the lumbar IVF in living patients.[17] FPCA allows real-time imaging and the ability to study living subjects. In contrast, micro-CT offers superior resolution and clarity. In addition, use of cadaver specimens allowed us to eliminate movement effects and to use pretreatments like phosphotungstic acid to differentiate tissue densities. Importantly, our results enabled the visualization of nerve roots and the SSA inside the IVF on the oblique view of 3D micro-CT, which is similar to the oblique view seen during an actual fluoroscopically-guided TFESI procedure. Combining micro-CT imaging with histological verification allowed us to achieve a comprehensive understanding of the vascular anatomy of the cervical foramen, which is crucial for guiding clinical and surgical procedures.

One of the limitations of this study is the relatively small sample size, which constrained the ability to perform robust subgroup analyses based on sex. Although results were grouped by sex for observational purposes, no statistically significant differences were identified. This limitation underscores the difficulty in drawing definitive conclusions about potential demographic variations due to insufficient statistical power. Even though similarities were observed, they should be interpreted with caution given the limited scope of the analysis.

Conclusion

In conclusion, this study demonstrated that SSAs are predominantly located in the ASQ of the IVF in the lower cervical region. From these results, understanding of the vascular anatomy of the cervical IVF could assist clinicians in further investigating and refining TFESI performance, with the ultimate goal of optimizing analgesic efficacy and improving patient safety.

Abbreviations

TFESI, transforaminal epidural steroid injection; IVF, intervertebral foramen; SSA, segmental spinal artery; 3D micro-CT, three-dimensional micro-computed tomography; ASQ, antero-superior quadrant; AIQ, antero-inferior quadrant; PSQ, postero-superior quadrant; PIQ, postero-inferior quadrant; FPCA, flat-panel catheter angiotomography.

Data Sharing Statement

Dataset used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

All experimental procedures were performed ethically in accordance with the World Medical Association's Declaration of Helsinki and were approved by the institutional review board of Yonsei University College of Medicine (approval no. 4-2024-0666). All studies were conducted with approval of the Yonsei University Medical College Surgical and Anatomy Education Center (approval number: YSAEC 24-007).

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Author Contributions

All authors made a significant contribution to this work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Consent for Publication

Participants provided written consent for publication.

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Disclosure

All authors declare no conflicts of interest for this work.

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