Check for updates

Clinical Anatomy

WILEY

CLINICAL ANATOMY

REVIEW

Understanding Vascular Risks in Lumbar Transforaminal Epidural Injections: Insights From Anatomy and Clinical Evidence

Martin Avellanal[1] | Irene Riquelme[1] | Antonio Ferreiro[2] | Francisco Reina[3] | Anna Carrera[3] | R. Shane Tubbs[4,5,6,7,8] | André P. Boezaart[9,10] | Miguel A. Reina[9,11]

[1]Pain Clinic, Hospital Universitario La Moraleja, Madrid, Spain | [2]CUHMED, School of Medicine, Madrid, and Department of Radiology, Madrid University Hospital, Madrid, Spain | [3]Grupo de Investigación en Anatomía Clínica, Embriología y Neurociencias (NEOMA), Human Anatomy Unit, Facultat of Medicine, Universidad de Girona, Girona, Spain | [4]Department of Neurosurgery, Tulane Center for Clinical Neurosciences, Tulane University School of Medicine, New Orleans, Louisiana, USA | [5]Department of Anatomical Sciences, St. George's University, St. George's, West Indies | [6]Department of Structural and Cellular Biology, Tulane University School of Medicine, New Orleans, Louisiana, USA | [7]Department of Neurosurgery and Ochsner Neuroscience Institute, Ochsner Health System, New Orleans, Louisiana, USA | [8]Department of Neurology, Tulane University School of Medicine, New Orleans, Louisiana, USA | [9]Department of Anesthesiology, University of Florida College of Medicine, Gainesville, Florida, USA | [10]Lumina Health, Surrey, UK | [11]CEU-San Pablo University, School of Medicine, Madrid, and Department of Anesthesiology, Madrid-Montepríncipe University Hospital, Madrid, Spain

Correspondence: Martin Avellanal (avellanalmartin@gmail.com)

Received: 9 November 2025 | **Revised:** 2 February 2026 | **Accepted:** 19 February 2026

Keywords: epidural | injections | intervertebral foramen | low back pain | pain management | spinal blood supply | spine

ABSTRACT

Transforaminal epidural steroid injections (TFESIs) are frequently used to treat lumbar and radicular pain. Although ischemic complications are extremely rare, their severity—often resulting in irreversible paraplegia—necessitates a thorough understanding of the anatomical and procedural risk factors. This review carefully examines the vascular anatomy of the lumbar intervertebral foramen, the distribution and risks associated with radiculomedullary arteries, and reported cases of severe complications related to lumbar TFESIs. Anatomical and radiological data indicate that radicular arteries are particularly rare below the L2–L3 level and are more common on the left side. The upper third of the intervertebral foramen, especially at T12–L3, is the most likely site of arterial involvement, raising concerns about the safety of traditional subpedicular approaches. Kambin's triangle appears to be a safer alternative, reducing arterial contact while still enabling effective drug delivery. The use of particulate corticosteroids, especially methylprednisolone and triamcinolone, is strongly associated with ischemic events owing to their larger particle sizes. Non-particulate options such as dexamethasone are preferred, particularly at higher spinal levels. Although rare, venous punctures and hematomas require vigilance and careful steroid selection. Test doses of local anesthetics remain controversial and do not provide clear protective benefits. Current evidence indicates that adjusting techniques—including needle placement, imaging guidance, and corticosteroid choice—can help reduce risks while maintaining the effectiveness of lumbar TFESIs.

1 | Introduction

Transforaminal epidural steroid injections (TFESIs) have been used since the 1960s to treat lumbar and radicular pain (Botwin et al. 2000). Their use became widespread during the 1990s, sparking ongoing debate about the safest and most effective anatomical approach (Murphy et al. 2010; Park et al. 2011; Kroszczynski et al. 2013; Khalaf et al. 2020), especially given reports of serious complications involving vascular injury during the procedure (Glaser and Shah 2010; Chang and Ng 2020;

© 2026 American Association of Clinical Anatomists and British Association of Clinical Anatomists.

Cohen and Rossc 2024). The introduction of dorsal root ganglion (DRG) pulsed radiofrequency therapy in the late 1990s further increased the use of TFESI procedures.

The close anatomical relationship between the intervertebral foramen (IVF) and critical neural and vascular structures—including the nerve root, the DRG, and radiculomedullary arteries—has raised concerns about potential complications including intravascular injection of particulate steroids or anesthetics, direct arterial injury causing vasospasm or endovascular edema, thrombosis leading to spinal cord infarction, or hematoma-induced vascular compression resulting in neurological injury (Cohen and Rossc 2024). The most likely cause of vasospasm is arterial impingement, not cannulation of its lumen. Another potential complication of impingement on the artery is loosening of an atheromatous plaque, with a ball valve effect (Slavin et al. 1975; Shav 2014). These risks have prompted numerous anatomical studies on the vascular structure of the IVF and its importance for spinal and radicular circulation (Gilchrist et al. 2002; Demondion et al. 2012; Yuan et al. 2015; Uchikado et al. 2020).

Several anatomical studies have suggested potential "safe zones" for transforaminal needle placement; however, the results are often inconsistent. The proposed safe zones include: (1) the subpedicular or "safety" triangle (Bogduk 2004), (2) Kambin's triangle or suprapedicular zone (Park et al. 2011), and (3) the posterior middle third of the IVF (Khalaf et al. 2020).

While the value of anatomical studies is acknowledged, their sample sizes are seldom large and rarely include cases with foraminal pathology. Although radiological studies could be more clinically representative, they frequently fail to distinguish between arterial and venous structures and tend to focus on the more cranial lumbar (L1–L2) or caudal thoracic IVF regions, while most TFESIs are performed between the third lumbar (L3) and first sacral (S1) vertebra.

The aim of this article is to review the literature on the vascular anatomy of the lumbar IVF and the complications associated with TFESI critically, and to develop and propose evidence-based recommendations for safer clinical practice.

2 | Vascular Anatomy of the Lumbar Intervertebral Foramen (IVF)

2.1 | Arterial Supply

The blood supply to the spinal cord is extensive, anatomically complex, and highly variable, with many anastomoses. This vascular abundance helps explain why ischemic events are less common in the spinal cord than the brain (Pavel et al. 2023). Segmental medullary arteries originating from the thoracic and lumbar aorta supply the spinal cord, vertebral bodies, paraspinal muscles, dura mater, DRG, and spinal nerve roots. At lower lumbar and sacral levels, these arteries can also receive contributions from the internal iliac artery via the iliolumbar and lateral sacral arteries (Pavel et al. 2023). The radiculomedullary artery at these levels is known as the artery of Desproges-Gotteron (Masson and Bardin 2009).

Distal radicular arteries originate from the lumbar arteries at the level of the IVF (Figure 1). These segmental arteries often run alongside the lumbar IVF, supplying blood to the posterior paraspinal muscles. Their diameter ranges from 0.2 to 2 mm (Demondion et al. 2012). Generally, radicular arteries run anterior to their associated nerve roots (Figure 2) (Demondion et al. 2012; Iwanaga et al. 2025; Tabira et al. 2026).

Only a small number of radicular arteries contribute to spinal cord perfusion by anastomosing with the anterior spinal artery (ASA); these are known as radiculomedullary arteries and include both anterior and posterior variants (Figure 1). Among them, the artery of Adamkiewicz (AKA)—also known as the arteria radicularis magna—is the largest and most important. It supplies the ASA in the region responsible for lower limb innervation, making it critical for the perfusion of the spinal cord's anterior two-thirds, while the two posterolateral spinal arteries supply the posterior third.

The AKA is the most dominant radiculomedullary artery supplying the spinal cord between T8 and the conus medullaris. Its origin varies widely; it can arise from the T3–T12 intercostal arteries or the L1–L4 lumbar arteries, but most often from the left side between T8 and L1 (Taterra et al. 2019). Cadaver studies reveal that in 75% of cases the AKA originates between T9 and T12; in 87.4% of these it is a single vessel, and in 76.6% it originates from the left (Taterra et al. 2019; Pavel et al. 2023). Variants include right-sided origin, multiple AKAs, or origins

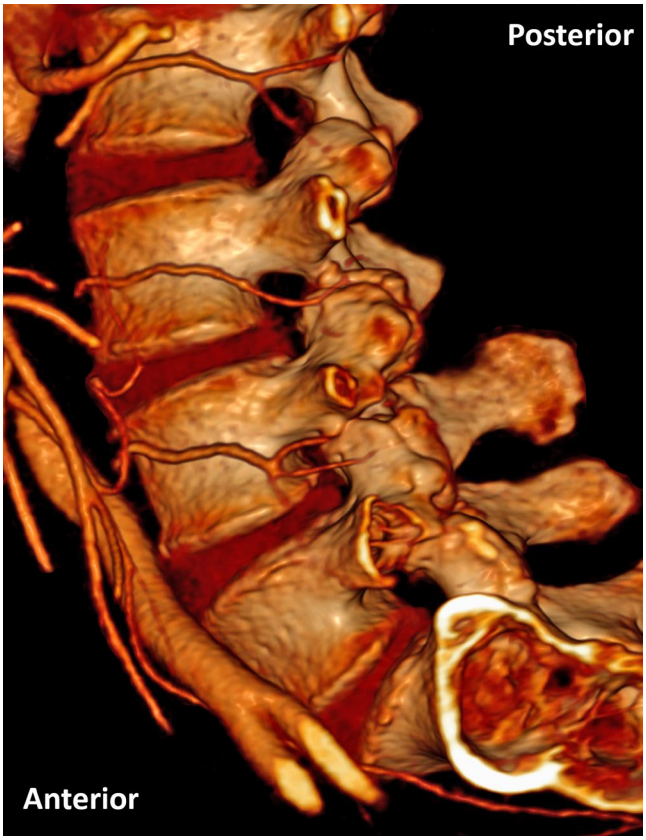

FIGURE 1 | A 3D reconstruction of a lumbar spine CT angiography shows the lumbar arteries crossing near the IVF. At the L2–L3 level, a radicular artery enters the upper third of the IVF. CT, computed tomography; IVF, intervertebral foramen.

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

outside the T8–L2 range. Only 1.6% of cases show origins below L1 (Taterra et al. 2019; Pavel et al. 2023).

Collateral circulation can develop in response to gradual occlusion, arising from muscular branches or other intercostal or lumbar arteries. This creates a small but significant risk that a lumbar or sacral foramen could harbor a radiculomedullary artery supplying the conus medullaris, potentially putting the cord at risk if such an artery is inadvertently punctured or catheterized (Laredo et al. 2023).

A thoracolumbar cadaver study ($n = 24$) by Kroszczynski et al. identified 39 anterior medullary arteries, including 23 AKAs. Only seven radiculomedullary arteries were found at the lumbar level—six at L1 and one at L2—all entering the IVF in the upper third, primarily in the anterosuperior quadrant (Kroszczynski et al. 2013).

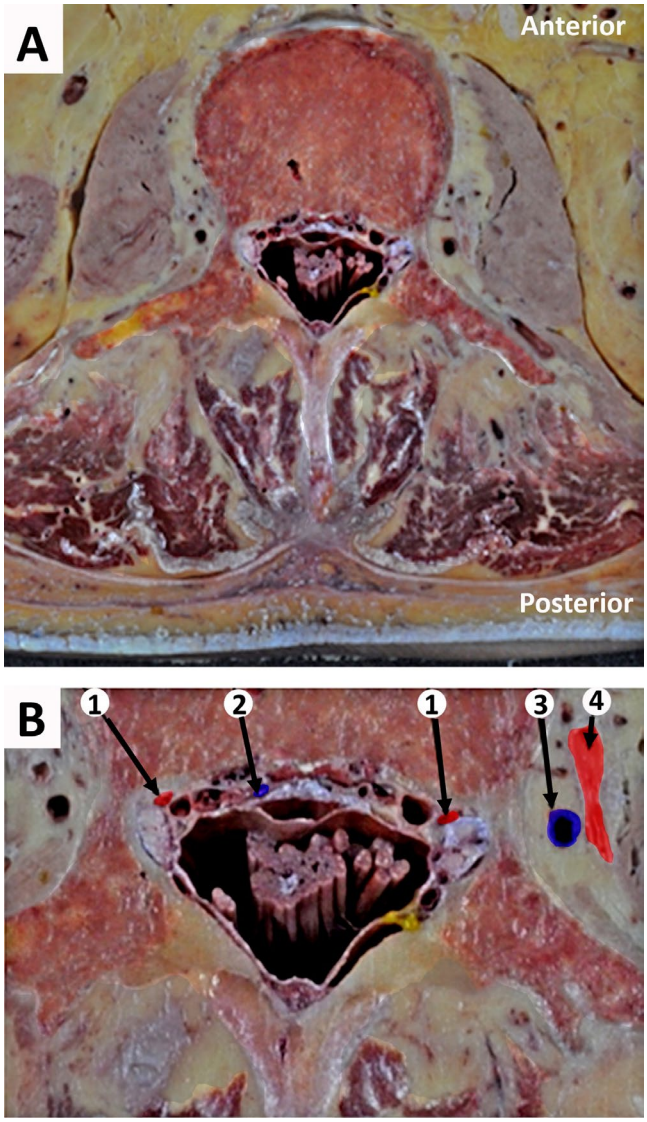

FIGURE 2 | Axial section of the lumbar spine at the L2 level in a cadaver. In this specimen, an anterior radicular artery is identified bilaterally, located anterior to the spinal root. (1) Radicular artery, (2) anterior epidural venous plexus, (3) lumbar ascending vein, (4) lumbar artery. (A) Entire cross-section, (B) detail of "A" at higher magnification.

In contrast, an anatomical study of 51 cadavers reported a high incidence of AKAs below T12 (70.5%) and between L1 and L3 in 64.7% of cases (Lo et al. 2002). In rare instances (three out of 4000), the AKA was observed at the L4–L5 level.

A selective angiographic study involving 75 patients found radicular arteries providing an anterior radiculomedullary artery in 24.4% of cases at L1, predominantly on the left side. Three were identified at L2, one at L3, and none at lower levels. In 96% of cases, the artery was located in the anterosuperior quadrant of the IVF (Gregg et al. 2017). Similar findings were reported in 248 thoracolumbar angiograms by Murphy et al. fewer than half had radiculomedullary arteries, nearly all located above L3 and predominantly on the left. In 88% of cases, the artery entered the IVF through the upper third (Murphy et al. 2010).

2.2 | Venous Drainage

Venous drainage in the lumbar spine involves two main plexuses, the epidural (internal) and the paravertebral (external). The epidural venous plexus is most prominent in its two anterolateral and two posterolateral columns. These columns are interconnected by circumferential venous rings that encircle the thecal sac at the midbody level of each vertebra (Groen et al. 1997).

The internal and external plexuses communicate through foraminal veins that pass through the IVF, forming a perineural venous plexus around each nerve root (Borg et al. 2022; Pavel et al. 2023). This mostly valveless venous system is highly variable, densely distributed, and ultimately drains into the inferior vena cava at the lumbar level.

Foraminal veins are usually located in the upper part of each IVF, both in front of and behind the nerve root or DRG, and they can also be found in the lower IVF (Demondion et al. 2012). It is estimated that more than 95% of the blood vessels in the IVF are venous (Pavel et al. 2023).

2.3 | Vascular Anatomy Summary

While some reports suggest that the AKA can originate from any thoracic or lumbar IVF (Glaser and Shah 2010), evidence from anatomical dissections and selective angiographic studies indicates that a radiculomedullary artery below the L1 level is extremely rare and exceptionally uncommon below L2. There is a strong predominance of left-sided origin. When present at the level of the IVF, these arteries are most often located in the upper third, particularly within the anterosuperior quadrant. Furthermore, magnetic resonance and computed tomography imaging studies reveal multiple vascular structures within the IVF, predominantly located in the upper third. However, nearly all of these vessels are venous.

3 | Complications of Lumbar Transforaminal Epidural Steroid Injections (TFESIs)

Although the incidence of ischemic complications following lumbar TFESIs is extremely low (Botwin et al. 2000; Chang and

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Ng 2020), their potential severity—most notably irreversible paraplegia—necessitates strict precautions in every case. Most of the serious TFESI-related complications reported in the literature have arisen during cervical procedures (Schultz 2004; Chang-Chien et al. 2012), where the risk of vascular injury and inadvertent intra-arterial injection is significantly higher because of the vascular supply to the cervical spinal cord. As a result, many institutions have stopped using the cervical transforaminal approach, particularly with a sharp needle, because there is no reliable way to ensure that the radiculomedullary artery is not entered.

Serious vascular complications following lumbar TFESIs are extremely rare, especially considering the high and increasing number of interventions performed at that level. These include diagnostic or therapeutic injections, DRG pulsed radiofrequency treatments, and transforaminal epiduroscopy (Avellanal et al. 2019; Chang and Ng 2020).

A review by Chang and Ng analyzed data from four studies involving over 7000 patients who had undergone lumbar TFESI (Manchikanti et al. 2012; Karaman et al. 2011; McGrath et al. 2011; Chang and Ng 2020). Minor complications occurred in fewer than 10% of cases and included vasovagal episodes, vascular punctures (primarily venous), exacerbation of back or leg pain, facial flushing, transient hypertension, and nerve root irritation. Importantly, these adverse effects resolved spontaneously without lasting sequelae, and no major complications were reported in these cohorts.

3.1 | Major Complications

To date, only 25 cases of major complications following lumbar TFESIs have been documented in the literature (Table 1) (Houten and Errico 2002; Huntoon and Martin 2004; Kabbara et al. 2004; Kennedy et al. 2009; Glaser and Falco 2005; Somayaji et al. 2005; Quintero et al. 2006; Lyders and Morris 2009; Glaser and Shah 2010; Wybier et al. 2010; Chang-Chien et al. 2012; Levi et al. 2023; Desai and Dua 2014; Gharibo et al. 2016; Gungor and Aiyer 2017; Kim et al. 2019). One additional case is cited, but it lacks published details as it is currently under legal review. Table 1.

Among these 25 cases, 20 involved severe ischemic events that led to paraplegia. Three cases were caused by spinal hematoma but resolved completely, and one involved an epidural abscess that responded well to antibiotics with no long-term effects. Another case involved bilateral L1–L2 injections of dexamethasone, which caused transient paraplegia lasting 30 min, probably attributable to the 1 mL of 1% lidocaine administered bilaterally as a test dose (Levi et al. 2023).

Among the 20 ischemic cases, 12 were male and eight were female, with an average patient age of 60.2 years (range: 40–83). Follow-up data are limited, but one case achieved full recovery (Houten and Errico 2002) and three had partial neurological recovery (Huntoon and Martin 2004; Glaser and Shah 2010; Wybier et al. 2010), transitioning from paraplegia to paraparesis or isolated lower-limb weakness over time.

Laterality analysis revealed that ischemic events occurred nearly twice as often on the left side (12 cases) than the right (seven cases). Interestingly, twice as many complications resulted from injections performed below L3 as those between T12 and L2.

The corticosteroids most frequently associated with complications were methylprednisolone (eight cases) and triamcinolone (five cases). Other agents implicated included betamethasone, hydrocortisone, and dexamethasone. There was also variability in the use and concentration of local anesthetics. Some corticosteroids were injected undiluted, while others were mixed with bupivacaine (the most common), lidocaine, or ropivacaine at various concentrations.

Finally, the most commonly used needle type was the Quincke spinal needle, with diameters ranging from 20G to 26G, 20G being the most common.

3.2 | Complications Summary

In summary, severe complications after lumbar TFESIs are extremely rare. Among the few cases reported in the literature, ischemic events are usually irreversible, while other vascular complications, such as spinal hematomas, generally have a favorable clinical outcome. These complications occur with similar frequency in both sexes, though they are more often associated with left-sided TFESIs. Notably, such events can arise at any spinal level and with any corticosteroid agent, although methylprednisolone is the most frequently implicated.

4 | Discussion

4.1 | Lumbar TFESI Usage and Risk Distribution

TFESIs are among the most commonly used interventions for treating low back and radicular pain. In clinical settings, most procedures are performed below the L3 level—areas traditionally viewed as the safest, as supported by anatomical evidence. However, TFESIs at higher levels are becoming increasingly common due to degenerative changes associated with aging and adjacent-segment pathology following lumbar arthrodesis (Lai et al. 2020).

4.2 | Pathophysiology of Severe Complications

Severe complications from TFESI can result from intra-arterial injection and embolization of corticosteroid particles through radicular arteries, especially the AKA. Additional proposed mechanisms include direct mechanical trauma to arteries, leading to thrombosis, vasospasm, ball-valve plaque, vascular or neural compression, and neurotoxicity (Cohen and Rossc 2024).

4.3 | Anatomical and Radiological Evidence

Anatomical and radiological evidence consistently demonstrate that radicular arteries rarely access the spinal canal below L2-L3 (Murphy et al. 2010; Kroszczynski et al. 2013; Gregg et al. 2017), with a strong left-sided predominance (Gregg et al. 2017). Although ischemic complications also tend to favor the left side,

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 | Detailed list of published cases of major complications resulting from lumbar transforaminal injections.

Authors	Article	Patients	Male/Female	Age	Lumbar pathology	TFESI side/level	Needle	Dosis test	Steroid	Dilution	Complication
Chang-Chien et al. (2012)	Case report	1	M	80	Low back pain and radiated down his right leg.	Right L5–S1	22 G Quincke-curved tip	0.5 mL of 1% lidocaine	Triamcinolone	1 mL of 1% lidocaine with 80 mg triamcinolone.	Paraplegia
Desai and Dua (2014)	Case report	1	F	72	Lower back and right anterior thigh pain extended to the knee.	Right L3–L4 and L4–L5	22 G	No	Methylprednisolone	4 mL mixture containing 2 mL of methylprednisolone 40 mg/mL and 2 mL of 1% lidocaine.	Progressive right lower extremity weakness, worsening sensory loss, and ambulatory dysfunction. Perineural Hematoma L4–5.
Glaser and Shah (2010)	Cases report	3	i. F ii. M iii. No data (sub judice)	i. 83 ii. 62 iii. ?	? ? ?	i. Right L2–L3 ii. Right L4–L5 iii. ?	? ? ?	? ? ?	? ? ?	? ? ?	i. Paraplegia. ii. Paraplegia (partially recovery). iii. ?
Glaser and Falco (2005)	Case report	1	F	67	Chest wall pain following a T-12 compression fracture.	Left T12–L1	22 G	No	Triamcinolone	3 mL mixture consisting of 2 mL of triamcinolone with 1 mL of 1% ropivacaine.	Paraplegia
Gungor and Aiyer (2017)	Cases report	1	M	48	Right lower extremity radicular symptoms in the distribution of L4 and L5 nerve roots.	Right L4 and L5	22 G	No	Triamcinolone	2 mL lidocaine 1% and triamcinolone 40 mg.	Paraparesia. Epidural hematoma. Total recovery.
Houten and Errico (2002)	Cases report	3	i. F ii. F iii. M	i. 64 ii. 51 iii. 42	i. Low back pain, bilateral buttock and leg pain and numbness in her left leg after falling on her back. ii. Left L3 radiculopathy. iii. Low back pain and episodic left lower extremity pain.	i. Right L3–4 and L4–5 ii. Left L3–4 iii. Left S1	i. 25 G ii. 20 G iii. 22 G	i. No ii. 1 cc of Lidocaine 1% iii. 1 cc lidocaine1%	i. Betamethasone Celestone ii. Methylprednisolone iii. Methylprednisolone	i. 3 mL of bupivacaine 0.25% with 12 mg betamethasone. ii. 1 mL of 40 mg/mL methylprednisolone mixed with 0.2 mL contrast dye. iii. 1 mL of 40 mg/mL methylprednisolone.	i. Spinal cord edema. Total recovery. ii. Complete spinal cord injury at the low thoracic level including loss of sphincter function. Paraplegia. No recovery. iii. T10 sensory level, 0/5 function in all lower extremity muscle groups and loss of sphincter tone. No recovery.

(Continues)

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 | (Continued)

Authors	Article	Patients	Male/Female	Age	Lumbar pathology	TFESI side/level	Needle	Dosis test	Steroid	Dilution	Complication
Huntoon and Martin (2004)	Case report	1	M	64	Chronic low-back pain radiated into the left buttock and groin. History of L2-L5 arthrodesis with extensive laminectomy.	Left T12-L1	25 G and 22 G	No	Triamcinolone	5 mL of 0.125% bupivacaine and 40 mg of triamcinolone.	Paraplegia
Kabbara et al. (2004)	Case report	1	M	44	Intractable back and radiculopathic pain.	Right L4-L5 and L5-S1	?	No	¿	?	Epidural abscess. Total recovery
Kennedy et al. (2009)	Cases report	2	i. F ii. M	i. 83 ii. 79	i. Left "hip" and lateral knee pain. ii. Left radicular pain.	i. Left L3-L4x2 ii. Left L3–L4	i. 26 G ii. 22 G	i. No ii. No	i. Betamethasone ii. Methylprednisolone	i. mL of bupivicaine (0.75%) and 1 mL betamethasone. ii. 2 mL of methylprednisolone (160 mg) and 6cc of bupivacaine 0.375%.	i. Paraplegia ii. Paraplegia
Kim et al. (2019)	Case report	1	M	82	Lower back pain and bilateral buttock pain. Lumbar spinal stenosis at L1–L3 was found.	Right L2–3	20 G	No	Dexamethasone	6 mL of 10 mg of 0.5% bupivacaine, 3 mL of normal saline, and 5 mg of dexamethasone.	Epidural hematoma. Total recovery
Lyders and Morris 2009	Case report	1	F	55	Acute-on-chronic disk herniation at L1–L2.	Right L2–3	22 G	No	Triamcinolone	1 mL of triamcinolone and 0.25% bupivacaine.	Paraplegia. No recovery
Quintero et al. (2006)	Case report	1	M	40	Low-back pain and symptoms of L4 radiculopathy.	Left L4-L5	20G	No	Hydrocortisone	125 mg of hydrocortisone.	Paraplegia
Somayaji et al. (2005)	Case report	1	F	71	Low back pain radiating to her left groin/anterior thigh.	Left L2-L3	21 G	No	Triamcinolone	1 mL 0.5% bupivacaine and 40 mg triamcinolone.	Paraplegia
Wybier et al. (2010)	Cases report	5	i. M ii. M iii. F iv. M v. M	i. 46 ii. 43 iii. 78 iv. 63 v. 64	i. Left L5 radiculopathy. ii. Bilateral L3 and L4 radiculopathy. iii. Left femoral radiculopathy. iv. Low back and right buttock pain. v. Left leg pain.	i. Left L5–S1 ii. Left L1–L2 iii. Left L3–4 iv. Right L5–S1 v. Left L4–5	?	?	Methylprednisolone	?	i. T10 paraplegia ii. T12 paraplegia iii. T12 paraplegia iv. Transient paraplegia with severe right motor L5 deficit v. T12 paraplegia
Levi et al. (2023)	Case report	1	M	76	Low back pain referring into buttocks. Severe L1–L2 stenosis.	Bilateral L1–L2	25 G	1 mL of 1% lidocaine bilateral	Dexamethasone	7.5 mg undiluted dexamethasone in each side.	Transient (30 min) paraplegia
Gharibo et al. (2016)	Case report	1	M	60	Right back and radicular pain.	Right L4–L5	22 G	No	Dexamethasone	1.5 mL dexamethasone and 1.5 mL of normal saline.	Paraplegia

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

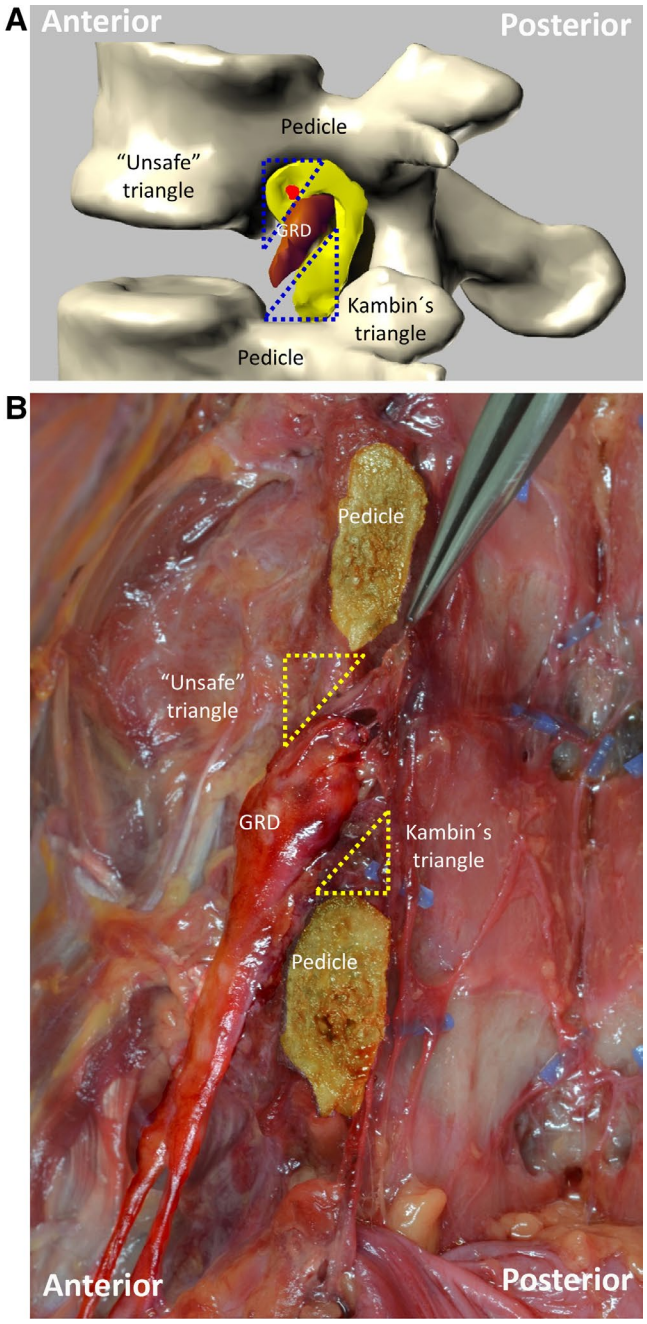

FIGURE 3 | The schematic representation of the subpedicular triangle (classically called the "safe triangle" and today considered "unsafe") and the suprapedicular triangle (Kambin's triangle) is shown in a sagittal section at the intervertebral foramen level. This is based on a 3D reconstruction of a patient's spine from magnetic resonance imaging (A) and a fresh cadaver (B).

they occur more frequently below L3 than at T12–L2. This paradox could reflect the rarity of these complications alongside the high volume of TFESIs performed at lower lumbar levels.

4.4 | Optimal Approach to the IVF

Three main anatomical zones have been proposed as potential "safe" approaches for accessing the IVF: (1) the subpedicular or "safety" triangle (Bogduk 2004), (2) Kambin's

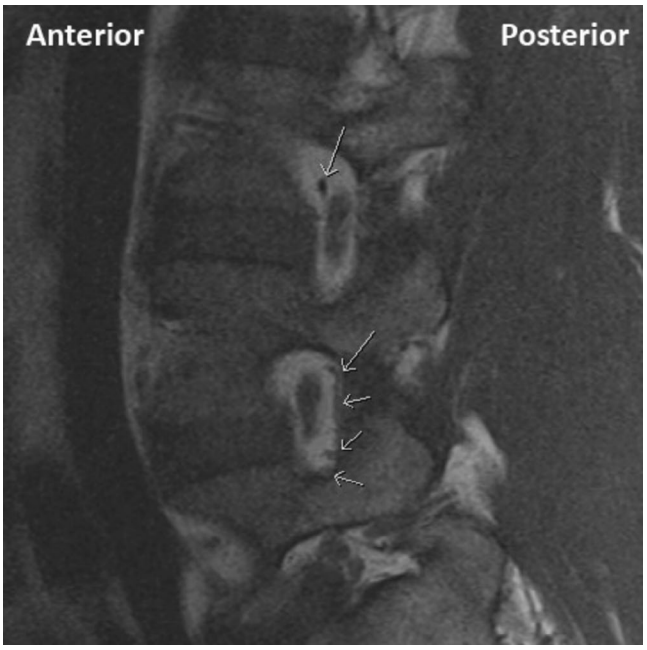

FIGURE 4 | Magnetic resonance imaging in T1 mode. Sagittal view at the level of the lumbar intervertebral foramen showing multiple venous vessels (arrows).

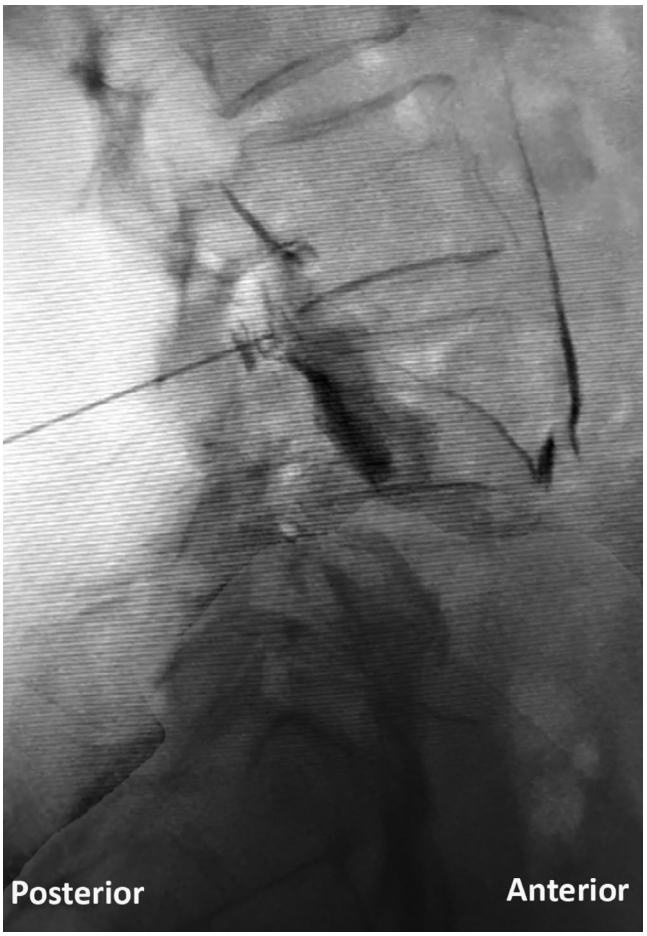

FIGURE 5 | A transforaminal block was performed at the L3–L4 level using a suprapedicular approach (Kambin's triangle), which showed anterior epidural and radicular contrast diffusion and venous diffusion to the inferior vena cava. Aspiration testing was negative.

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

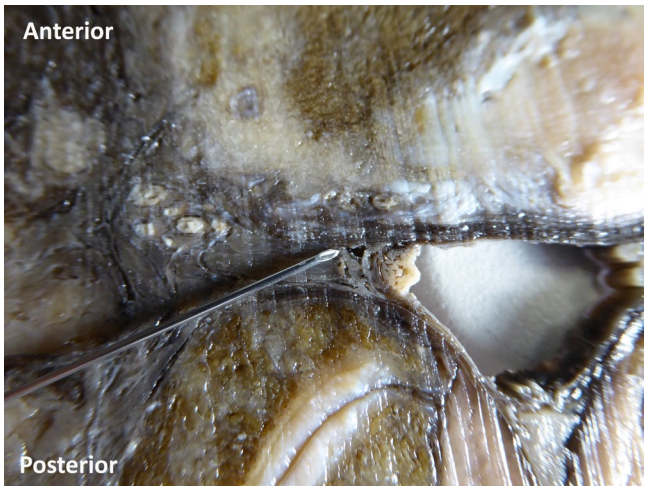

FIGURE 6 | A 22-gauge (Quincke) spinal needle is shown superimposed with a venous vessel in the intervertebral foramen in an axial section of a cadaver at the L3–L4 level.

triangle (suprapedicular) (Park et al. 2011), and (3) the posterior middle third of the IVF (Khalaf et al. 2020). However, most case reports do not specify the exact needle placement within the IVF, making it difficult to draw firm conclusions. Anatomical studies indicate that the upper third of the IVF, especially at T12–L3, carries the highest risk for arterial puncture. Therefore, the subpedicular triangle should no longer be considered a "safe" zone at these levels (Ruan and Chiravuri 2011).

Kambin's triangle, or the retrodiscal foraminal approach, targets the caudal IVF below the nerve root. It appears to be the safest option to avoid contact with arterial structures. Although it can slightly increase the risk of intradiscal injection, careful targeting beneath the nerve root helps reduce this risk. This approach also facilitates anterior epidural spread and precise delivery to areas of disc/nerve root interaction (Figure 3).

The posterior middle third of the IVF could carry a low risk of arterial puncture (Khalaf et al. 2020). Nevertheless, it tends to limit contrast distribution to the posterior epidural space and may involve venous structures, increasing the risk of hematoma formation (Figure 4).

4.5 | Non-Ischemic Vascular Complications (Hematomas)

Hematomas are another serious complication of lumbar TFESI, though outcomes are generally favorable. Three cases with severe neurological symptoms (paraparesis) have been documented, all of which recovered fully (McGrath et al. 2011; Gungor and Aiyer 2017; Kim et al. 2019). Fluoroscopically guided TFESIs show venous contrast injection in 10% to 15% of procedures, while aspiration tests are positive in only 20% to 47% of cases (Furman et al. 2000; Smuck et al. 2007; Lyders and Morris 2009; Hong et al. 2013). This highlights the limited sensitivity of aspiration testing and the importance of real-time imaging (Figure 5).

Venous punctures, which often appear as contrast leakage into the vena cava, require needle repositioning and fluoroscopic confirmation of avascularity before injection. Regardless of the suspected venous origin, a non-particulate corticosteroid such as dexamethasone should be used, and the patient must be monitored for signs of hematoma.

4.6 | Influence of Needle Type

There is insufficient evidence to link needle type (Quincke, Whitacre, Chiba) or gauge with the risk of ischemic or compressive complications (Smuck et al. 2010). However, smaller-gauge needles are generally believed to be less likely to cause vascular injury. Of the 25 reported severe cases, 22 involved needles ranging from 20G to 22G (Figure 6).

Blunt-tip needles are thought to reduce the risk of vascular penetration and arterial wall impingement, but they can be more difficult to maneuver, especially in patients undergoing lumbar surgery and with fibrosis, and typically require larger gauges. Pencil tip spinal needles cannot be considered blunt needles and can enter the artery. Blunt needles usually allow more ventral placement in the foramen and better anterior spread (Heavner et al. 2003). Sharp-tipped Coudé radiofrequency needles could increase the risk of vascular or nerve injury if rotated within the IVF and should be avoided. Only blunt-tipped Coudé needles should be employed during IVF.

An extension line attached to the needle hub can help decrease unintentional movement during syringe changes (Gregg et al. 2017) and allows the operator to distance him or herself from the radiation source.

4.7 | Corticosteroid Formulation and Safety

The primary hypothesis for ischemic complications is intravascular injection of particulate corticosteroids (Schultz 2004; Laredo et al. 2023). Methylprednisolone and triamcinolone are the most commonly implicated (Table 1), both containing particles larger than 500 μm even when diluted. Methylprednisolone has the highest proportion of particles larger than 1000 μm, and its profile does not improve with dilution (Benzon et al. 2007; Derby et al. 2008; MacMahon et al. 2011).

Corticosteroids known for their excellent safety profiles include betamethasone and dexamethasone (Furman et al. 2000; Benzon et al. 2007), but triamcinolone is often preferred for its clinical effectiveness. Therefore, conducting a risk–benefit analysis is crucial: there is some clinical evidence that use of dexamethasone increases the need for repeat procedures (Cohen and Rossc 2024).

Importantly, the aggregate size increases with a delay after syringe loading, especially with triamcinolone. Preparations should be injected within 5 min of loading and reagitated if necessary (Orduña-Valls et al. 2020).

Studies also show that lidocaine 1% increases particle aggregation in triamcinolone suspensions, while bupivacaine does not

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

(Benzon et al. 2007; Wahezi et al. 2019). Nevertheless, bupivacaine was used in most cases with complications. Co-injectates and solutions constitute an interesting topic that deserves further investigation.

An alternative hypothesis proposes that particulate corticosteroids cause red blood cell aggregation, unlike dexamethasone (Laemmel et al. 2016). Additionally, three reported cases involved dexamethasone, and one showed no abnormalities on magnetic resonance imaging (Quintero et al. 2006; Gharibo et al. 2016; Lai et al. 2020; Levi et al. 2023), indicating that other mechanisms such as vasospasm, thrombosis, distal embolism, or neurotoxicity could contribute to pathology (Cohen and Rossc 2024).

Current guidelines recommend using nonparticulate steroids at or above the L2–L3 level, while permitting either particulate or nonparticulate options below that level (van de Minkelis et al. 2024).

Interestingly, a recently published RCT regarding a depot formulation of dexamethasone viscous gel delivered by transforaminal injection at lumbosacral level (Miller et al. 2024) could overcome some of the concerns regarding the use of non-particulate steroids for TFESIs.

4.8 | The Use of Test Doses of Local Anesthetic Continues To Be Debated

In one case, 1 mL of 1% lidocaine administered bilaterally to a patient with severe stenosis resulted in transient paraplegia, probably because of temporary epidural anesthesia (Levi et al. 2023). In reported cases, test doses did not prevent complications (Table 1). We do not believe their benefit is proven and caution that they can increase risk through needle displacement. If used, the dose should be kept minimal (Cohen and Rossc 2024).

5 | Conclusion

- Lumbar TFESI ischemic complications are extremely rare, but their consequences are catastrophic and usually irreversible.
- The safest approach is the suprapedicular triangle (Kambin's triangle).
- Contrast-dye control is mandatory at all lumbar levels.
- Dexamethasone must be used at or above the L2–L3 level, but either particulate or nonparticulate options are allowed below that level.
- When using particulate corticosteroids, the solutions should be shaken before injection.
- Other vascular complications such as hematomas have better outcomes, but early surgical treatment can be necessary.
- The needle gauge should be the thinnest that allows the technique to be performed correctly. Blunt needles seem to be safer. Sharp-tipped Coudé needles should be avoided.
- If venous drainage is observed, the needle should be repositioned, and a non-particulate corticosteroid should be used.
- Test dosing has not been shown to reduce the risk of ischemic complications, but it can lead to confusion.
- To prevent unintentional needle movements, use needles attached to an extension catheter and single-use radiofrequency electrodes with a side injection port.

Funding

The authors have nothing to report.

Ethics Statement

The study was approved by the Clinical Research Ethics Committee of Grupo Hospital Madrid (Madrid, Spain) (Code: 17.01.1040-GHM).

Consent

The authors have nothing to report.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

Avellanal, M., G. Diaz-Reganon, A. Orts, L. Gonzalez-Montero, and I. Riquelme. 2019. "Transforaminal Epiduroscopy in Patients With Failed Back Surgery Syndrome." *Pain Physician* 22: 89–95.

Benzon, H. T., T. L. Chew, R. J. McCarthy, H. A. Benzon, and D. R. Walega. 2007. "Comparison of the Particle Sizes of Different Steroids and the Effect of Dilution: A Review of the Relative Neurotoxicities of the Steroids." *Anesthesiology* 106: 331–338. https://doi.org/10.1097/00000542-200702000-00022.

Bogduk, N. 2004. "An Algorithm for the Investigation of Low Back Pain." In *Practice Guidelines for Spinal Diagnostic and Treatment Procedures*, edited by N. Bogduk, 86–94. International Spine Intervention Society.

Borg, N., S. Oushy, L. Savastano, and W. Brinjikji. 2022. "Transvenous Embolization of a Cerebrospinal Fluid-Venous Fistula for the Treatment of Spontaneous Intracranial Hypotension." *Journal of Neurointerventional Surgery* 14: 948. https://doi.org/10.1136/neurintsurg-2021-018160.

Botwin, K. P., R. D. Gruber, C. G. Bouchlas, F. M. Torres-Ramos, T. L. Freeman, and W. K. Slaten. 2000. "Complications of Fluoroscopically Guided Transforaminal Lumbar Epidural Injections." *Archives of Physical Medicine and Rehabilitation* 81: 1045–1050. https://doi.org/10.1053/apmr.2000.7166.

Chang, A., and A. T. Ng. 2020. "Complications Associated With Lumbar Transforaminal Epidural Steroid Injections." *Current Pain and Headache Reports* 24: 67. https://doi.org/10.1007/s11916-020-00900-9.

Chang-Chien, G. C., K. D. Candido, and N. N. Knezevic. 2012. "Digital Subtraction Angiography Does Not Reliably Prevent Paraplegia Associated With Lumbar Transforaminal Epidural Steroid Injection." *Pain Physician* 15: 515–523.

Cohen, S. P., and J. D. Rossc. 2024. "Lumbar Transforaminal Epidural Steroid Injections With Particulate vs. Nonparticulate Steroid: An Evidence-Informed Review on Shifting Gear to a Personalized Medicine Paradigm." *Current Opinion in Anaesthesiology* 37: 565–574. https://doi.org/10.1097/ACO.0000000000001402.

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Demondion, X., G. Lefebvre, O. Fisch, L. Vandenbussche, J. Cepparo, and V. Balbi. 2012. "Radiographic Anatomy of the Intervertebral Cervical and Lumbar Foramina (Vessels and Variants)." *Diagnostic and Interventional Imaging* 93: 690–697. https://doi.org/10.1016/j.diii.2012.07.008.

Derby, R., S. H. Lee, E. S. Date, J. H. Lee, and C. H. Lee. 2008. "Size and Aggregation of Corticosteroids Used for Epidural Injections." *Pain Medicine* 9: 227–234. https://doi.org/10.1111/j.1526-4637.2007.00341.x.

Desai, M. J., and S. Dua. 2014. "Perineural Hematoma Following Lumbar Transforaminal Steroid Injection Causing Acute-On-Chronic Lumbar Radiculopathy: A Case Report." *Pain Practice* 14: 271–277. https://doi.org/10.1111/papr.12047.

Furman, M. B., E. M. O'Brien, and T. M. Zgleszewski. 2000. "Incidence of Intravascular Penetration in Transforaminal Lumbosacral Epidural Steroid Injections." *Spine (Phila Pa 1976)* 25: 2628–2632. https://doi.org/10.1097/00007632-200010150-00014.

Gharibo, C., M. Fakhry, S. Diwan, and A. D. Kaye. 2016. "Conus Medullaris Infarction After a Right L4 Transforaminal Epidural Steroid Injection Using Dexamethasone." *Pain Physician* 19: E1211–E1214.

Gilchrist, R. V., C. W. Slipman, and S. M. Bhagia. 2002. "Anatomy of the Intervertebral Foramen." *Pain Physician* 5: 372–378.

Glaser, S. E., and F. Falco. 2005. "Paraplegia Following a Thoracolumbar Transforaminal Epidural Steroid Injection." *Pain Physician* 8: 309–314.

Glaser, S. E., and R. V. Shah. 2010. "Root Cause Analysis of Paraplegia Following Transforaminal Epidural Steroid Injections: The 'Unsafe' Triangle." *Pain Physician* 13: 237–244.

Gregg, L., D. E. Sorte, and P. Gailloud. 2017. "Intraforaminal Location of Thoracolumbar Radicular Arteries Providing an Anterior Radiculomedullary Artery Using Flat Panel Catheter Angiotomography." *American Journal of Neuroradiology* 38: 1054–1060. https://doi.org/10.3174/ajnr.A5104.

Groen, R. J., H. J. Groenewegen, H. A. M. van Alphen, et al. 1997. "Morphology of the Human Internal Vertebral Venous Plexus: A Cadaver Study After Intravenous Araldite CY 221 Injection." *Anatomical Record* 249: 285–294. https://doi.org/10.1002/(SICI)1097-0185(199710)249:2<285::AID-AR16>3.0.CO;2-K.

Gungor, S., and R. Aiyer. 2017. "Epidural Hematoma Development Contralateral to Dura After Lumbar Transforaminal Epidural Steroid Injection." *Pain Management* 7: 367–375. https://doi.org/10.2217/pmt-2017-0012.

Heavner, J. E., G. B. Racz, B. Jenigiri, T. Lehman, and M. R. Day. 2003. "Sharp Versus Blunt Needle: A Comparative Study of Penetration on Internal Structures and Bleeding in Dogs." *Pain Practice* 3: 226–231. https://doi.org/10.1046/j.1533-2500.2003.03027.x.

Hong, J. H., S. Y. Kim, B. Huh, and H. H. Shin. 2013. "Analysis of Inadvertent Intradiscal and Intravascular Injection During Lumbar Transforaminal Epidural Steroid Injections: A Prospective Study." *Regional Anesthesia and Pain Medicine* 38: 520–525. https://doi.org/10.1097/AAP.0000000000000010.

Houten, J. K., and T. J. Errico. 2002. "Paraplegia After Lumbosacral Nerve Root Block: Report of Three Cases." *Spine Journal* 2: 70–75. https://doi.org/10.1016/s1529-9430(01)00159-0.

Huntoon, M. A., and D. P. Martin. 2004. "Paralysis After Transforaminal Epidural Injection and Previous Spinal Surgery." *Regional Anesthesia and Pain Medicine* 29: 494–495. https://doi.org/10.1016/j.rapm.2004.05.002.

Iwanaga, J., H. J. Kim, K. Akita, et al. 2025. "Ethical Use of Cadaveric Images in Anatomical Textbooks, Atlases, and Journals: A Consensus Response From Authors and Editors." *Clinical Anatomy* 38: 222–225. https://doi.org/10.1002/ca.24258.

Kabbara, A., S. K. Rosenberg, and C. Untal. 2004. "Methicillin-Resistant *Staphylococcus aureus* Epidural Abscess After Transforaminal Epidural Steroid Injection." *Pain Physician* 7: 269–272.

Karaman, H., G. O. Kavak, A. Tufek, et al. 2011. "The Complications of Transforaminal Lumbar Epidural Steroid Injections." *Spine (Phila Pa 1976)* 36: E819–E824. https://doi.org/10.1097/BRS.0b013e3181f32bae.

Kennedy, D. J., P. Dreyfuss, C. N. Aprill, and N. Bogduk. 2009. "Paraplegia Following Image-Guided Transforaminal Lumbar Spine Epidural Steroid Injection: Two Case Reports." *Pain Medicine* 10: 1389–1394. https://doi.org/10.1111/j.1526-4637.2009.00728.x.

Khalaf, A. M., V. Yedavalli, and T. F. Massoud. 2020. "Magnetic Resonance Imaging Anatomy and Morphometry of Lumbar Intervertebral Foramina to Guide Safe Transforaminal Subarachnoid Punctures." *Clinical Anatomy* 33: 405–413. https://doi.org/10.1002/ca.23533.

Kim, S. I., D. H. Lee, S. H. Kim, and Y. H. Cho. 2019. "Spinal Epidural Hematoma Occurring at a Distance From the Transforaminal Epidural Injection Site: A Case Report." *Medicine (Baltimore)* 98: e16654. https://doi.org/10.1097/MD.0000000000016654.

Kroszczynski, A. C., K. Kohan, M. Kurowski, T. R. Olson, and S. A. Downie. 2013. "Intraforaminal Location of Thoracolumbar Anterior Medullary Arteries." *Pain Medicine* 14: 808–812. https://doi.org/10.1111/pme.12056.

Laemmel, E., N. Segal, M. Mirshahi, et al. 2016. "Deleterious Effects of Intra-Arterial Administration of Particulate Steroids on Microvascular Perfusion in a Mouse Model." *Radiology* 279: 731–740. https://doi.org/10.1148/radiol.2015142746.

Lai, M. K. L., P. W. H. Cheung, and J. P. Y. Cheung. 2020. "A Systematic Review of Developmental Lumbar Spinal Stenosis." *European Spine Journal* 29: 2173–2187. https://doi.org/10.1007/s00586-020-06524-2.

Laredo, J. D., M. Wybier, E. Laemmel, and M. Mirshahi. 2023. "Intra-Arterial Injection of Particulate Corticosteroids: Mechanism of Injury." *Skeletal Radiology* 52: 1887–1892. https://doi.org/10.1007/s00256-022-04273-5.

Levi, D., S. Horn, J. Murphy, and J. Levin. 2023. "Safety of Dexamethasone in Transforaminal Epidural Steroid Injections: A Case of Temporary Paraplegia Caused by Injection of Lidocaine and Dexamethasone Into a Lumbar Radiculomedullary Artery, With no Neurologic Sequelae." *Interventional Pain Medicine* 2: 100240. https://doi.org/10.1016/j.inpm.2023.100240.

Lo, D., J. N. Valleé, L. Spelle, et al. 2002. "Unusual Origin of the Artery of Adamkiewicz From the Fourth Lumbar Artery." *Neuroradiology* 44: 153–157. https://doi.org/10.1007/s002340100658.

Lyders, E. M., and P. P. Morris. 2009. "A Case of Spinal Cord Infarction Following Lumbar Transforaminal Epidural Steroid Injection: MR Imaging and Angiographic Findings." *American Journal of Neuroradiology* 30: 1691–1693. https://doi.org/10.3174/ajnr.A1567.

MacMahon, P. J., M. J. Shelly, D. Scholz, S. J. Eustace, and E. C. Kavanagh. 2011. "Injectable Corticosteroid Preparations: An Embolic Risk Assessment by Static and Dynamic Microscopic Analysis." *American Journal of Neuroradiology* 32: 1830–1835. https://doi.org/10.3174/ajnr.A2656.

Manchikanti, L., Y. Malla, B. W. Wargo, et al. 2012. "A Prospective Evaluation of Complications of 10,000 Fluoroscopically Directed Epidural Injections." *Pain Physician* 15: 131–140.

Masson, C., and T. Bardin. 2009. "Desproges-Gotteron Artery, Spinal Cord Infarction, and Transforaminal Glucocorticoid Injections." *Joint Bone Spine* 76: 120–121. https://doi.org/10.1016/j.jbspin.2008.10.003.

McGrath, J. M., M. P. Schaefer, and D. M. Malkamaki. 2011. "Incidence and Characteristics of Complications From Epidural Steroid Injections." *Pain Medicine* 12: 726–731. https://doi.org/10.1111/j.1526-4637.2011.01077.x.

Miller, A., K. D. Candido, N. N. Knezevic, et al. 2024. "A Randomized, Placebo-Controlled Trial of Long-Acting Dexamethasone Viscous Gel Delivered by Transforaminal Injection for Lumbosacral Radicular

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Pain." *Pain* 165: 2762–2773. https://doi.org/10.1097/j.pain.0000000000003287.

Murphy, N. S., T. P. Maus, and C. L. Behrns. 2010. "Intraforaminal Location of the Great Anterior Radiculomedullary Artery (Artery of Adamkiewicz): A Retrospective Review." *Pain Medicine* 11: 1756–1764. https://doi.org/10.1111/j.1526-4637.2010.00948.x.

Orduña-Valls, J. M., D. L. Cedeno, C. Nebreda-Clavo, et al. 2020. "Microscopic Study of Injectable Steroids: Effects of Postmixing Time on Particle Aggregation." *Pain Physician* 23: E417–E424.

Park, J. W., H. S. Nam, S. K. Cho, H. J. Jung, B. J. Lee, and Y. Park. 2011. "Kambin's Triangle Approach of Lumbar Transforaminal Epidural Injection With Spinal Stenosis." *Annals of Rehabilitation Medicine* 35: 833–843. https://doi.org/10.5535/arm.2011.35.6.833.

Pavel, J., E. Kellerova, and J. Snopkova. 2023. "Spinal Cord Vasculature: General Anatomy and Physiology." In *Neuraxial Therapeutics: A Comprehensive Guide*, edited by T. Yaksh and D. Hayek, 121–149. Springer Nature.

Quintero, N., I. Laffont, L. Bouhmidi, et al. 2006. "Paraplégie à la Suite D'une Infiltration Foraminale Lombaire: Revue de la Littérature à Partir D'un Cas. Transforaminal Epidural Steroid Injection and Paraplegia: Case Report and Bibliographic Review." *Annales de Réadaptation et de Médecine Physique* 49: 242–247. https://doi.org/10.1016/j.annrmp.2006.03.004.

Ruan, X., and S. Chiravuri. 2011. "Truly a Critical Review: Root Cause Analysis of Paraplegia Following Transforaminal Epidural Steroid Injections: "Unsafe" Triangle." *Pain Physician* 14: E82–E83.

Schultz, D. 2004. "Risk of Transforaminal Epidural Injections." *Pain Physician* 7: 289–290.

Shav, R. V. 2014. "Paraplegia Following Thoracic and Lumbar Transforaminal Epidural Steroid Injections: How Relevant Are Particulate Steroids?" *Pain Practice* 14: 297–300. https://doi.org/10.1111/papr.12110.

Slavin, R. E., J. C. Gonzalez-Vitale, and O. S. Marin. 1975. "Atheromatous Emboli to the Lumbosacral Spinal Cord." *Stroke* 6: 411–415. https://doi.org/10.1161/01.str.6.4.411.

Smuck, M., B. J. Fuller, B. Yoder, and J. Huerta. 2007. "Incidence of Simultaneous Epidural and Vascular Injection During Lumbosacral Transforaminal Epidural Injections." *Spine Journal* 7: 79–82. https://doi.org/10.1016/j.spinee.2006.06.380.

Smuck, M., A. J. Yu, C. T. Tang, and E. Zemper. 2010. "Influence of Needle Type on the Incidence of Intravascular Injection During Transforaminal Epidural Injections: A Comparison of Short-Bevel and Long-Bevel Needles." *Spine Journal* 10: 367–371. https://doi.org/10.1016/j.spinee.2009.12.018.

Somayaji, H. S., A. Saiffudin, A. T. H. Casey, et al. 2005. "Spinal Cord Infarction Following Therapeutic Computed Tomography-Guided Left L2 Nerve Root Injection." *Spine (Phila Pa 1976)* 30: E106–E108. https://doi.org/10.1097/01.brs.0000153400.67526.07.

Tabira, Y., A. Carrera, F. Reina, et al. 2026. "Humanizing Donor Terminology in Anatomical and Clinical Research: Best Ethical Practice in Anatomy (BEPA) Consensus Statement From the Universal Anatomical Organization (UAO)." *Clinical Anatomy*. https://doi.org/10.1002/ca.70075.

Taterra, D., B. Skinningsrud, P. A. Pękala, et al. 2019. "Artery of Adamkiewicz: A Meta-Analysis of Anatomical Characteristics." *Neuroradiology* 61: 869–880. https://doi.org/10.1007/s00234-019-02207-y.

Uchikado, H., Y. Nishimura, G. Hattori, and Y. Ohara. 2020. "Micro-Anatomical Structures of the Lumbar Intervertebral Foramen for Full-Endoscopic Spine Surgery: Review of the Literatures." *Journal of Spine Surgery* 6: 405–414. https://doi.org/10.21037/jss.2019.10.07.

van de Minkelis, J., L. Peene, S. P. Cohen, et al. 2024. "Persistent Spinal Pain Syndrome Type 2." *Pain Practice* 24: 919–936. https://doi.org/10.1111/papr.13379.

Wahezi, S. E., S. E. Mohamed, A. Lederman, and A. P. Beck. 2019. "Aggregation Properties of Triamcinolone Acetonide Injection in Human Serum: Considerations When Performing Epidural Steroid Injections." *Journal of Pain Research* 20: 1033–1039. https://doi.org/10.2147/JPR.S181038.

Wybier, M., S. Gaudart, D. Petrover, et al. 2010. "Paraplegia Complicating Selective Steroid Injections of the Lumbar Spine: Report of Five Cases and Review of the Literature." *European Radiology* 20: 181–189. https://doi.org/10.1007/s00330-009-1539-7.

Yuan, S. G., Y. L. Wen, P. Zhang, and Y. K. Li. 2015. "Ligament, Nerve, and Blood Vessel Anatomy of the Lateral Zone of the Lumbar Intervertebral Foramina." *International Orthopedics* 39: 2135–2141. https://doi.org/10.1007/s00264-015-2831-6.

10982353, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1002/ca.70102 by dr nicholasbrandon - Chulalongkorn University Faculty of Dentistry Library , Wiley Online Library on [01/03/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License