Prospective Evaluation

Intravascular Flow Detection During Transforaminal Epidural Injections: A Prospective Assessment

Omar Hamman El Abd, MD[1], Joao Eduardo Daud Amadera, MD[2], Daniel Camargo Pimentel, MD,[2] and Thais Spacov Camargo Pimentel, MSc[2]

From: [1]HNewton Wellesley Interventional Spine, Wellesley, MA; [2]University of Sao Paulo, Brazil.

Address Correspondence:
Omar El Abd, MD
Director, Newton Wellesley Interventional Spine
378 Washington Street
Wellesley, MA 02481
Email: oelabd@partners.org

Disclaimer: There was no external funding in the preparation of this manuscript. Conflict of interest: Each author certifies that he or she, or a member of his or her immediate family, has no commercial association (i.e., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

Manuscript received: 07-09-2013
Revised manuscript received: 08-25-2013
Accepted for publication: 09-03-2013

Free full manuscript: www.painphysicianjournal.com

Background: Transforaminal epidural steroid injections (TFESI) are a mainstay in the treatment of spine pain. Though this commonly performed procedure is generally felt to be safe, devastating complications following inadvertent intra-arterial injections of particulate steroid have been reported. The use of digital subtraction angiography (DSA) has been suggested as a means of detecting intra-arterial needle placements prior to medication injection.

Objective: To examine the efficacy of DSA in detecting intra-arterial needle placements during TFESI.

Study Design: Prospective cohort study evaluating the impact of DSA on detecting intra-arterial needle placements during TFESI.

Methods: We enrolled 150 consecutive patients presenting to a university-affiliated spine center with discogenic and/or radicular symptoms affecting the cervical, lumbar, and sacral regions. For each injection, prior to imaging with DSA, traditional methods for vascular penetration detection were employed, including the identification of blood in the needle hub (flash), negative aspiration of blood prior to injection, and live fluoroscopic injection of contrast. Once these tests were performed and negative for signs of intra-arterial needle placement, DSA imaging was utilized prior to medication administration for identification of vascular flow.

Results: A total number of 222 TFESI were performed, 41 injections at the cervical levels (18.47%), 113 at the lumbar levels (50.9%), and 68 at the sacral levels (30.36%). Flash was observed in 13 injections performed (5.85% of the total number of injections): one (0.45%) in the cervical, 2 (0.9%) in the lumbar, and 10 (4.5%) in the sacral levels. In 11 TFESI blood aspiration was obtained (4.95% of all injections): 3 (1.3%) in cervical, 4 (1.8%) in lumbar, and 4 (1.8%) in sacral injections. Live fluoroscopy during contrast injection detected 46 (20.72%) intravascular flow patterns: 7 (3.1%) cervical, 17 (7.6%) lumbar, and 22 (9.9%) sacral. DSA identified an additional 5 intravascular injections after all previous steps had resulted in negative vascular penetration signs, which accounted for 2.25% of all injections.

Limitations: This is a prospective, single-center study with a relatively small number of patients and no control group.

Conclusion: DSA detected additional 5.26% intravascular needle placements following traditional methods. Our findings also support other studies that conclude TFESI are generally a safe procedure. We recommend that special attention should be paid to the sacral injections as vascular penetration was statistically higher than at other levels.

Key words: Digital subtraction angiography, transforaminal epidural steroid injections

Pain Physician 2014; 17:21-27

Fluoroscopic guided transforaminal epidural steroid injections (TFESI) are frequently used in the management of spinal pain. The incidence of complications from these procedures is generally felt to be low (1-2). Despite this, various devastating complications have been described in the literature. A particularly catastrophic subset of complications occurs following the inadvertent intra-arterial injection of particulate steroids which is believed to lead to spinal cord (3-11) and cerebral infarcts (12-16).

Meticulous performance of TFESI with adherence to the current procedural recommendations minimizes the risk of complications (17). There is a consensus among interventional spine physicians that avoiding vascular penetration and using non-particulate steroids are vital steps in preventing this complication (18-20). Multiple described injection techniques are believed to aid in the detection of vascular penetration. The traditional methods for vascular penetration detection include the identification of blood in the needle hub (flash), negative aspiration of blood prior to injection, lidocaine challenge, and live fluoroscopic injection of contrast.

The introduction of a digital subtraction angiography (DSA) fluoroscopy technique enables better visualization of intravascular contrast after identifying the contrast's transforaminal epidural flow. Images are generated by subtracting a pre-contrast image from later images so that variations between the pre- and post-contrast images are highlighted. We conducted this prospective cohort study in an effort to evaluate the effectiveness of DSA in the identification of vascular flow following the use of traditional methods.

Study Design

This study was conducted at a major university-affiliated hospital after the protocol was approved by the hospital institutional review board. From August 2010 to January 2011, 150 consecutive patients who were scheduled to undergo TFESI at the cervical, lumbar, or sacral levels were enrolled. Patients who met the inclusion criteria signed an informed consent that described the trial with its risks, benefits, alternatives, and objectives as per the institutional review board protocol.

Inclusion Criteria

- Providing informed consent to participate in the study
- At least 18 years old
- Discogenic axial back or neck pain
- Radicular leg or arm pain
- Lack of response to conservative management that includes medications and/or physical therapy

Exclusion Criteria

- Severe allergy to injectants
- Steroid psychosis
- Tumor or tumor metastasis in the involved area of spine
- Infection at the injection site
- Coagulopathy
- Unstable spinal fracture or spinal instability
- Pregnancy
- Patients unable to provide informed consent

All the injections were performed by the primary author (O.E.A.), a fellowship-trained interventional physiatrist with 9 years of experience performing fluoroscopically guided spine interventions in a practice that frequently utilizes TFESI. Two independent physicians trained in fluoroscopy and DSA images simultaneously observed the procedures and evaluated them for signs of vascular penetration. The procedures were performed under live fluoroscopic guidance using well established techniques (21). No conscious sedation was used.

A 25 gauge 3.5 inch Quincke spinal needle was used for cervical injections. A 22 gauge (3.5 or 5 inches in length depending on subject body habitus) Quincke spinal needle was used for lumbar and sacral injections. A 5 mL Luer lock syringe was used for lumbar and sacral procedures and a 3 mL Luer lock syringe and 5 inch tubing were used during cervical injections. Cervical injections were performed with the patients placed in a lateral position, head supported by a pillow, and placed in a neutral position. The needle was introduced under an oblique view, abutting the superior articular process, and slightly introduced forward into the inferior and posterior portion of the foramen. In lumbar injections, the patients were placed in a prone position and the needles were introduced to the 6 o'clock position under the pedicle and the positioning was confirmed in an antero-posterior view. For sacral injections, the needles were introduced to the foramina using a lateral to medial approach using antero-posterior viewing, and entering the foramina at the superior and lateral quadrant portion. Once the needle was positioned at the neural foramen, the stylet was withdrawn and blood in the hub (flash) was evaluated. This was followed by aspiration. One mL of contrast medium was subsequently injected to confirm needle placement. Once transfo-

raminal flow was identified, careful observation of any sign of vascular flow was initiated. If any of these measures were positive for vascular penetration the needle was repositioned. The same process was repeated until these measures were negative for vascular flow. The goal was to achieve no vascular penetration signs prior to utilizing DSA.

Next, contrast was injected under DSA, evaluating for missed vascular penetration with the conventional methods. As an added layer of safety, lidocaine challenge was used (a test dose of lidocaine 1% was injected 0.5 mL in cervical and one mL in lumbar injections and subjects were monitored for alterations in sensation, motor weakness, or unusual metallic taste) prior to injecting preservative-free non-particulate dexamethasone 10 mg/mL. The independent observers charted the findings during the procedure. Data was categorically computed as "yes" or "no" regarding the presence or absence of blood flow detection in each one of the observed steps. The number of events was quantitatively computed and the frequency was presented in terms of percentage. Univariate analysis using Fisher's exact test with two-tailed P-values was used to evaluate possible differences between levels of injection (cervical, lumbar, or sacral). The significance level (alpha) employed was 0.05 for each comparison. For that, the Stata/SE 10.0 for Windows software (College Station, TX, USA) was used.

Results

One hundred and fifty consecutive patients (97 women, 53 men; mean age 54.09 ± 15.91, ranging from 24 to 86 years old) participated in the study. A total number of 222 TFESI were performed, 41 injections at the cervical levels (18.47%), 113 at the lumbar levels (50.9%), and 68 at the sacral levels (30.36%). Flash was observed in 13 injections performed (5.85% of the total number of injections): one (0.45%) in the cervical, 2 (0.9%) in the lumbar, and 10 (4.5%) in the sacral levels. In 11 TFESI blood aspiration was obtained (4.95% of all injections): 3 (1.3%) in cervical, 4 (1.8%) in lumbar, and 4 (1.8%) in sacral injections. Live fluoroscopy during contrast injection detected 46 (20.72%) intravascular flow patterns: 7 (3.1%) cervical, 17 (7.6%) lumbar, and 22 (9.9%) sacral.

DSA identified an additional 5 intravascular injections after all previous steps had resulted in negative vascular penetration signs, which accounted for 2.25% of all injections. Three of the 5 injections (60%) showed positive intravascular penetration on DSA after traditional methods were completely negative (e.g. there was no need to change the needle position in these injections prior to DSA). The traditional methods were successful in the detection of 94.74% of all the vascular events, while DSA detected 5.26% of vascular events that the conventional methods were unable to identify. Intravascular flow detected either by live fluoroscopy or DSA was venous. There was no intra-arterial flow noted.

The occurrence of "any vascular event" was computed as the presence of any vascular flow sign at any one of the steps performed (flash, aspiration, contrast injection during live fluoroscopy, and contrast injection using DSA). A total of 57 procedures with vascular events were noted, 25.67% of the total TFESI performed. From vascular flow detections, 9 (15.79%) occurred at the cervical level, while 17 (29.82%) and 31 (54.39%) occurred at the lumbar and sacral levels, respectively. Table 1 summarizes the frequencies of vascular events observed.

Table 1. *Frequencies of procedures with vascular events observed in each level of injection.*

	Flash		Aspiration		Live fluoro		DS		TFESI with vascular events*	
Cervical	1	7.69% (1)	3	27.27% (1)	7	15.22% (1)	0	0% (1)	9 (4.05% [5])	15.79% (1)
		2.44% (2)		7.32% (2)		17.07% (2)		0% (2)		21.95% (2)
Lumbar	2	15.38% (1)	4	36.36% (1)	17	36.96% (1)	0	0% (1)	17 (7.66% [5])	29.82% (1)
		1.77% (3)		3.54% (3)		15.04% (3)		0% (3)		15.04% (3)
Sacral	10	76.92% (1)	4	36.36% (1)	22	47.83% (1)	5	100% (1)	31 (13.96% [5])	54.39% (1)
		14.71% (4)		5.88% (4)		32.35% (4)		7.35% (4)		45.59% (4)
Total	13 (5.85% [5])		11 (4.95% [5])		46 (20.72% [5])		5 (2.25% [5])		57 (25.67% [5])	

(1) Percentage of the event in this level as compared to the total number of the same event in all levels
(2) Percentage of the event among all cervical injections
(3) Percentage of the event among all lumbar injections
(4) Percentage of the event among all sacral injections
(5) Percentage of the total number of injections (222)
*Note that some TFESI had more than one vascular sign during the same procedure (i.e. subjects who had both flash and live fluoroscopy signs of vascular uptake during the same procedure counts as one in the "TFESI with vascular event" column).

In patients with positive DSA, the needle was repositioned and DSA was repeated to achieve no vascular uptake. The lidocaine challenge test was performed (injection of lidocaine 1% and subsequently inquiring about any unusual metallic taste or neurological signs unexplained by the injection around the particular nerve root) for each TFESI. This was considered as another sign of intravascular penetration (22), which was not observed in any of our subjects enrolled in the study after using our vascular detection methods.

A greater risk of a vascular event was observed in the injections performed at the sacral level as compared to the lumbar and cervical levels. Odds ratio (OR) of 4.73 (confidence interval [CI]: 2.34 – 9.55; $P < 0.0001$) was observed comparing sacral and lumbar levels, while the OR was 2.97 (CI: 1.23 – 7.18; $P = 0.015$) comparing sacral and cervical levels. There was no statistically significant difference when comparing the risk of a vascular event between cervical and lumbar levels.

Discussion

Since the emergence of complication reports and the publication of Scanlon et al's survey (20) to intervention spine physicians on complications of cervical transforaminal injections, a heightened awareness of the risks of TFESI has developed. Interventionalists considered vascular penetration a central cause of these complications. Many research efforts were geared towards detecting vascular flow during these injections in order to minimize these complications.

In studying vascular flow, Furman et al studied lumbar (23) and cervical (24) TFESI. They prospectively included 671 lumbar TFESI and 504 cervical TFESI in these 2 studies. In both studies the presence of spontaneous blood in the needle hub flash and negative aspiration were compared to subsequent live fluoroscopic contrast injection. DSA was not used. In lumbar injections the overall rate of intravascular injections was 11.2%, flash and blood aspiration were 97.9% specific and 44.7% sensitive. In the cervical TFESI study the overall rate of intravascular penetration was 19.4%, flash and negative aspiration were comparable with 97% specificity and 45.9% sensitivity. In our study, slightly higher rates of intravascular events were found (21.95% for cervical and 15.04% for lumbar TFESI).

Smuck et al (25) evaluated vascular penetration in 121 cervical transforaminal epidural injections. Simultaneous vascular and epidural flow was noted in 18.9%, vascular only injection was noted in 13.9%, and a total vascular injection of 32.8% was noted, strikingly higher than the previous studies by Furman et al (23-24) as well as our present study. They also reported that the higher cervical level correlated with higher possibility of vascular injection without a proposed anatomical explanation. DSA was not used in their study as well.

In a follow-up study by Smuck et al (26), accuracy of vascular detection was compared using intermittent vs. continuous fluoroscopy during transforaminal injections. DSA was not utilized as well. In their prospective trial of 50 epidural injections, pre and post contrast injection static pictures were compared to dynamic fluoroscopic view. Vascular injections were missed in 57% of the static pictures.

Jasper (27) described 3 case reports of atlanto-axial joint, caudal, and cervical transforaminal epidural injections performed with DSA. Vascular flow was detected in these cases with DSA, and the joint injection was aborted, while the epidural injections were performed after the needle repositioning. With the use of DSA technology, Verrills et al (28) demonstrated the presence of cervical radicular artery flow in a C5-6 transforaminal epidural injection. Their DSA images proficiently demonstrate the filling of the cervical radicular artery and its ramification into the anterior spinal artery. Steroids were not injected due to vascular penetration and the patient had no complications.

Yin and Bogduk (29) described the retrograde arterial filling during a left T6-7 transforaminal epidural injection. This was observed first with live fluoroscopy and subsequently confirmed with DSA. The DSA showed the contrast filling a spinal artery toward the ventral and cephalad margin of the intervertebral foramen. A lateral DSA image identified the filling of a medullary artery in the ventral spinal canal. The procedure was terminated with no detrimental consequences to the patient.

Lee et al (30) evaluated the detection of vascular flow with DSA in 87 lumbosacral transforaminal epidural injections in comparison to live fluoroscopy, flash, and aspiration. Procedures with difficult needle placement were excluded, which is a foundation of criticism of this study. Twenty vascular penetration cases were identified (23%) using DSA, 12 of these were predicted by conventional live fluoroscopy and 5 were predicted by flash or aspiration. In this study, on identification of vascular penetration with flash, aspiration, or conventional fluoroscopy, DSA was still performed to assess predictability of the previous

methods. Of interest, they reported the highest incidence at the S1 level (40%) in comparison to lumbar levels (15%), which is replicated in our present study that found an incidence of 45.99% in the sacral level and 15.04% in the lumbar level. There was no difference in the incidence between post-surgical and non-surgical cases.

Nahm et al (31) evaluated risks of intravascular injections in 2,145 injections performed on 1,088 patients. Vascular injection was identified by the visualization of vascular pattern on live fluoroscopy without the use of DSA. The injections were performed on the cervical, thoracic, and lumbosacral levels. The vascular injection incidence was 10.5%, with the highest incidence at the cervical levels, 20.6%, and the lowest at the lumbar levels, 6.1%. They concluded that the level of the injection was the only significant factor in assessing the vascular injection risk, while the interventionalist experience, prior surgery, and injection repetition were not significant. They also concluded that the differentiation between venous and arterial injections was difficult.

Huntoon (32) conducted an evaluation of the cervical foramina to identify arterial branches in the target area of cervical transforaminal injections in 10 cadavers. He concluded that ascending and deep cervical arterial branches enter the external opening of the posterior intervertebral foramen near the target area for injections. These branches occasionally supply anterior radicular and segmental medullary arteries to the spinal cord. Because these arteries are contributors to anterior spinal artery flow, injection into or injury to these vessels may explain the occurrence of ischemic neurologic events in the anterior spinal artery territory. Hoeft et al's (33) cadaveric evaluation of cervical radicular arteries demonstrated that these arteries that join the anterior spinal artery and perfuse the spinal cord enter the cervical foramina at numerous vertebral levels on both sides of the neck. They highlighted the importance of properly identifying vascular flow with or without digital subtraction prior to the injection of particulate steroid.

Spinal cord and cerebral infarcts were reported after transforaminal injections in the past decade (3-16,20). There are multiple theories explaining the different causes of these infarcts (17) with the leading hypothesis being that inadvertent intra-arterial injection of particulate corticosteroid creates an embolus (10,14,17,27) causing a down-stream infarct. Other theories include in the cervical region penetration of the vertebral artery (17,20,24) and vertebral artery trauma (12,20). Needle induced vasospasm (7-8,17) and air embolism (11) were also reported. The role of particulate steroids was also evaluated, with different particle sizes identified (12,34). The injection of particulate steroids in animals highlights the importance of the vascular penetration. In a study by Okubadejo et al (35), 11 pigs underwent intravascular injections of depomedrol, dexamethasone, or prednisolone into the vertebral artery. All the pigs injected with depomedrol failed to gain consciousness, the other 2 groups recovered with no deficits.

A recently published case report discussed the possibility of DSA missing intra-arterial needle placements (36). We recognize that DSA is not a panacea for the prevention of catastrophic complications from intra-arterial steroid injection. However, our findings do suggest that this technology can aid in identifying improper needle placements that conventional methods may miss. In addition, we advise against the use of particulate steroids given the contention surrounding their increased efficacy and the evidence implicating their role in central nervous system infarcts following inadvertent intra-arterial administration.

Another factor that generates discussion as a possible cause of intravascular injections is the type and size of needle used during TFESI, particularly at the cervical level. Quincke needles are usually used, particularly among interventionalists performing cervical transforaminal injections. We performed our study using these needles. Blunt-tip needles were popularized to reduce the chances of arterial penetration. However, there are reports that dispute that blunt needles eliminate intravascular entry or prevent vasospasm or vessel injury (37,38). More recently, in the review by Atluri et al, there was no correlation between the variable type or size of needles and vascular complications in lumbar transforaminal injections (39).

With the recent introduction of DSA, interventionalists are becoming more experienced with its use and sporadic reports of its ability to detect vascular flow were published (23,28). This is the first trial to our knowledge comparing the different methods in vascular detection.

In our study, we demonstrated that meticulous performance of the procedure with the adherence to the 3 traditional methods was the most helpful in avoiding vascular penetration. However, adding an extra 2.25% improvement in vascular penetration detection in comparison to the low incidence of com-

plications of TFESI is clinically and practically relevant. We were not able to evaluate sensitivity or specificity because of the lack of independence among the detection steps. As soon as there was a positive detection of vascular penetration, the needle was repositioned. The following step depended entirely on the previous one. The study was not designed to evaluate the effectiveness of TFESI in managing cervical or lumbar spinal pain. We believe that the establishment of a safe method for performing these injections especially in the cervical spine will pave the way for the performance of larger studies to evaluate effectiveness.

Conclusion

Our study aimed to analyze the utility of DSA in TFESI following other means of detecting intravascular needle placement. In our study, DSA detected additional 5.26% intravascular needle placements following traditional methods. For that reason we recommend the use of DSA to observe dynamic contrast flow during TFESI. Our findings also support that TFESI are safe when performed meticulously with non-particulate steroids. We also recommend that special attention should be paid to the sacral injections as vascular penetration was statistically higher than at other levels.

References

1. McGrath JM, Schaefer MP, Malkamaki DM. Incidence and characteristics of complications from epidural steroid injections. *Pain Med* 2011; 12:726-731.
2. Landa J, Kim Y. Outcomes of interlaminar and transforminal spinal injections. *Bull NYU Hosp Jt Dis* 2012; 70:6-10.
3. Houten JK, Errico TJ. Paraplegia after lumbosacral nerve root block: Report of three cases. *Spine J* 2002; 2:70-75.
4. Huntoon MA, Martin DP. Paralysis after transforaminal epidural injection and previous spinal surgery. *Reg Anesth Pain Med* 2004; 29:494-495.
5. Somayaji HS, Saifuddin A, Casey AT, Briggs TW. Spinal cord infarction following therapeutic computed tomography-guided left L2 nerve root injection. *Spine (Phila Pa 1976)* 2005; 30:E106-E108.
6. Glaser SE, Falco F. Paraplegia following a thoracolumbar transforaminal epidural steroid injection. *Pain Physician* 2005; 8:309-314.
7. Quintero N, Laffont I, Bouhmidi L, C. Rech, A. Even Schneidera, T. Gavardin, O. Dizien. [Transforaminal epidural steroid injection and paraplegia: Case report and bibliographic review]. *Ann Readapt Med Phys* 2006; 49:242-247.
8. Kennedy DJ, Dreyfuss P, Aprill CN, Bogduk N. Paraplegia following image-guided transforaminal lumbar spine epidural steroid injection: Two case reports. *Pain Med* 2009;10: 1389-394.
9. Brouwers PJ, Kottink EJ, Simon MA, Prevo RL. A cervical anterior spinal artery syndrome after diagnostic blockade of the right C6-nerve root. *Pain* 2001; 91:397-399.
10. Ludwig MA, Burns SP. Spinal cord infarction following cervical transforaminal epidural injection: A case report. *Spine (Phila Pa 1976)* 2005; 30:E266-E268.
11. Muro K, O'Shaughnessy B, Ganju A. Infarction of the cervical spinal cord following multilevel transforaminal epidural steroid injection: Case report and review of the literature. *J Spinal Cord Med* 2007; 30:385-388.
12. Rozin L, Rozin R, Koehler SA, Shakir A, Ladham S, Barmada M, Dominick J, Wecht CH. Death during transforaminal epidural steroid nerve root block (C7) due to perforation of the left vertebral artery. *Am J Forensic Med Pathol* 2003; 24:351-355.
13. McMillan MR, Crumpton C. Cortical blindness and neurologic injury complicating cervical transforaminal injection for cervical radiculopathy. *Anesthesiology* 2003; 99:509-511.
14. Tiso RL, Cutler T, Catania JA, Whalen K. Adverse central nervous system sequelae after selective transforaminal block: The role of corticosteroids. *Spine J* 2004; 4:468-474.
15. Suresh S, Berman J, Connell DA. Cerebellar and brainstem infarction as a complication of CT-guided transforaminal cervical nerve root block. *Skeletal Radiol* 2007; 36:449-452.
16. Beckman WA, Mendez RJ, Paine GF, Mazzilli MA. Cerebellar herniation after cervical transforaminal epidural injection. *Reg Anesth Pain Med* 2006; 31:282-285.
17. Glaser SE, Shah RV. Root cause analysis of paraplegia following transforaminal epidural steroid injections: The "unsafe" triangle. *Pain Physician* 2010; 13:237-244.
18. Baker R, Dreyfuss P, Mercer S, Bogduk N. Cervical transforaminal injection of corticosteroids into a radicular artery: A possible mechanism for spinal cord injury. *Pain* 2003; 103:211-215.
19. Karasek M, Bogduk N. Temporary neurologic deficit after cervical transforaminal injection of local anesthetic. *Pain Med* 2004; 5:202-205.
20. Scanlon GC, Moeller-Bertram T, Romanowsky SM, Wallace MS. Cervical transforaminal epidural steroid injections: More dangerous than we think? *Spine (Phila Pa 1976)* 2007; 32:1249-1256.
21. PASSOR Educational Guidelines for the Performance of Spinal Injection Procedures. American Academy of Physical Medicine and Rehabilitation. 2008. (Accessed at www.aapmr.org/practice/guidelines/Documents/edguidelines.pdf.)
22. Smuck M, Maxwell MD, Kennedy D, Rittenberg JD, Lansberg MG, Plastaras CT. Utility of the anesthetic test dose to avoid catastrophic injury during cervical transforaminal epidural injections. *Spine J* 2010; 10:857-864.
23. Furman MB, O'Brien EM, Zgleszewski TM. Incidence of intravascular penetration in transforaminal lumbosacral epidural steroid injections. *Spine (Phila Pa 1976)* 2000; 25:2628-2632.
24. Furman MB, Giovanniello MT, O'Brien EM. Incidence of intravascular penetration in transforaminal cervical epidural steroid injections. *Spine (Phila Pa 1976)* 2003; 28:21-25.
25. Smuck M, Tang CT, Fuller BJ. Incidence of simultaneous epidural and vascular injection during cervical transforaminal epidural injections. *Spine (Phila Pa 1976)* 2009; 34:E751-E755.
26. Smuck M, Fuller BJ, Chiodo A, Benny B, Singaracharlu B, Tong H, Ho S. Accuracy of intermittent fluoroscopy to detect intravascular injection during transforam-

inal epidural injections. *Spine (Phila Pa 1976)* 2008; 33:E205-210.

27. Jasper JF. Role of digital subtraction fluoroscopic imaging in detecting intravascular injections. *Pain Physician* 2003; 6:369-372.
28. Verrills P, Nowesenitz G, Barnard A. Penetration of a cervical radicular artery during a transforaminal epidural injection. *Pain Med* 2010; 11:229-231.
29. Yin W, Bogduk N. Retrograde filling of a thoracic spinal artery during transforaminal injection. *Pain Med* 2009; 10:689-692.
30. Lee MH, Yang KS, Kim YH, Jung HD, Lim SJ, Moon DE. Accuracy of live fluoroscopy to detect intravascular injection during lumbar transforaminal epidural injections. *Korean J Pain* 2010; 23:18-23.
31. Nahm FS, Lee CJ, Lee SH, Kim TH, Sim WS, Cho HS, Park SY, Kim YC, Lee SC. Risk of intravascular injection in transforaminal epidural injections. *Anaesthesia* 2010; 65:917-921.
32. Huntoon MA. Anatomy of the cervical intervertebral foramina: Vulnerable arteries and ischemic neurologic injuries after transforaminal epidural injections. *Pain* 2005; 117:104-111.
33. Hoeft MA, Rathmell JP, Monsey RD, Fonda BJ. Cervical transforaminal injection and the radicular artery: Variation in anatomical location within the cervical intervertebral foramina. *Reg Anesth Pain Med* 2006; 31:270-274.
34. Benzon HT, Chew TL, McCarthy RJ, Benzon HA, Walega DR. Comparison of the particle sizes of different steroids and the effect of dilution: A review of the relative neurotoxicities of the steroids. *Anesthesiology* 2007; 106:331-228.
35. Okubadejo GO, Talcott MR, Schmidt RE, Sharma A, Patel AA, Mackey RB, Guarino AH, Moran CJ, Riew KD. Perils of intravascular methylprednisolone injection into the vertebral artery. An animal study. *J Bone Joint Surg Am* 2008; 90:1932-1938.
36. GC, Chang Chien, K. D. Candido, and N. N. Knezevic. Digital subtraction angiography does not reliably prevent paraplegia associated with lumbar transforaminal epidural steroid injection. *Pain Physician* 2012; 15:515-523.
37. Smuck M, Leung D. Inadvertent injection of a cervical radicular artery using an atraumatic pencil-point needle. *Spine* 2011; 36:E220-223.
38. C Gharibo, C Koo, J Chung, A Moroz. Epidural steroid injections: An update on mechanisms of injury and safety. *Reg Anes Pain Manag* 2009; 13:266-271.
39. Atluri S, Glaser SE, Shah RV, Sudarshan G. Needle position analysis in cases of paralysis from transforaminal epidurals: Consider alternative approaches to traditional technique. *Pain Physician* 2013; 16:321-334.