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SCIENTIFIC ARTICLE

Access routes and reported decision criteria for lumbar epidural drug injections: a systematic literature review

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Abstract
Purpose To review lumbar epidural drug injection routes in relation to current practice and the reported criteria used for selecting a given approach.
Material and methods This was a HIPPA-compliant study. Employing a systematic search strategy, the MEDLINE and EMBASE databank as well as the Cochrane Library were searched for studies on epidural drug injections. The following data were noted: access route, level of injection, use of image guidance, and types and doses of injected drugs. Justifications for the use of a particular route were also noted. Data were presented using descriptive statistics.
Results A total of 1,211 scientific studies were identified, of which 91 were finally included (7.5 %). The interlaminar access route was used in 44 of 91 studies (48.4 %), the transforaminal in 37 of 91 studies (40.7 %), and the caudal pathway in 26 of 91 studies (28.6 %). The caudal pathway was favored in the older studies whereas the transforaminal route was favored in recent studies. Decision criteria related to correct needle placement, concentration of injected drug at lesion site, technical complexity, costs, and potential complications. Injection was usually performed on the level of the lesion using local anesthetics (71 of 91 studies, 78.0 %), steroids (all studies) and image guidance (71 of 91 studies, 78 %).
Conclusions The most commonly used access routes for epidural drug injection are the interlaminar and transforaminal pathways at the level of the pathology. Transforaminal routes are being performed with increasing frequency in recent years.

Keywords Lumbar spine · Stenosis · Epidural · Intervention · Injection

On behalf of the Lumbar Spinal Stenosis Outcome Study (LSOS) Working Group Zurich.

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Introduction

The epidural injection of drugs via different routes is one of the most commonly performed procedures in the treatment of chronic low back pain and has shown a steady increase over the past decades. In the Medicare population, the number of lumbar epidural injections quadrupled within 7 years (1994–2001) [1]. Epidural injections are used to treat lumbosacral radicular pain, but also in patients with lumbar spinal stenosis and other degenerative changes. Local anesthetics and steroids, or steroids alone are commonly used substances. Local

anesthetics are believed to impede the nociceptor transmission and interrupt the pain spasm-cycle whereas steroids are thought to reduce inflammation by inhibiting either synthesis or release of pro-inflammatory mediators [2].

The discussion is still ongoing as to whether epidural injections are effective. Nine systematic reviews have evaluated the benefits and adverse effects of epidural injections. Most of the reviews conclude that epidural injections relieve pain for days or even weeks, whereas long-term pain relief is rarely achieved [3]. As a result, most current guidelines do not recommend epidural injections. However, there are also several ongoing, unpublished trials that might reveal positive long-term effects of epidural injections [3, 4].

Uncertainty also prevails regarding the most appropriate route of access to the lumbar epidural space. The three possible routes are the interlaminar, the transforaminal, and the caudal pathways [5]. Currently, there is no consensus in the literature on which access route should be used. Therefore, this paper aimed to review the current practice for epidural injections as well as the reported decision criteria used for choosing a particular access route into the epidural space.

Materials and methods

This is a structured literature review study compliant with the current Declaration of Helsinki and Health Insurance Portability and Accountability Act (HIPAA). No ethical review board approval was necessary according to local laws and institutional regulations. There was no funding of this study.

Literature search

As a preliminary step, a literature search for all relevant publications about epidural drug injection in patients with low back pain was performed between November 2011 and March 2012, by a professional librarian (initials blinded for the review process, 20 years' experience in literature search with long experience utilizing MEDLINE, EMBASE, and the Cochrane Library). The search attempted to identify all systematic reviews, and experimental and observational studies published in English or German. The librarian developed the search strategy. The focus was on epidural injections of steroids and local anesthetics via interlaminar, transforaminal, or caudal access routes. The search strategy for Medline is shown in Table 1.

Selection criteria

Following the literature search, results from all three databases were combined and duplicate publications were removed. All randomized and observational studies reporting on the site of injection in patients with lower back pain were included, but studies with fewer than ten patients were rejected.

Table 1 Example for the literature search in Medline (Ovid) using a systematic and standardized search strategy that was developed by a professional librarian. Please note that abbreviations are not self-explanatory. These are commands used for searches in Medline or other databases

	Terms	Result
1	Low back pain/	11,565
2	(("low back" or discogenic or ((spinal or lumbar) adj3 radicular)) adj3 pain).ti,ab.	14,526
3	(herniation or radiculitis).ti,ab.	10,977
4	Intervertebral displacement/	14,528
5	Disc adj3 (hernia* or prolapse* or slip*)).ti,ab.	5,465
6	Radiculopathy/	3,039
7	(lumbal adj3 spinal adj3 stenosis).ti,ab.	5
8	(lumbosacral adj3 radiculopathy).to,ab.	191
9	Or/3-8	24,782
10	Pain.mp. or Pain/	400,577
11	9 and 10	7,073
12	1 or 2 or 11	23,326
13	Injections, epidural/	1,853
14	Anesthesia, epidural/	10,684
15	(local* or lumb* or epidural*) adj 3 inject*).ti,ab.	10,774
16	((lumb* or epidural*) adj3 (inject* or anesthetic*)).ti,ab.	3,114
17	Or/13-16	21,969
18	12 and 17	802
19	Limit 18 to "all child (0 to 18 years)"	55
20	Limit 18 to case reports	155
21	18 not (19 or 20)	597
22	Limit 21 to (English or French or German)	575

Data extraction

Year of publication, number of included patients, age and age range of the patients, main patient inclusion criteria, and primary outcome parameters, were extracted by two authors (initials blinded for review process, 1 and 25 years' experience in epidemiological studies, respectively). The access route for drug application, the level of injection for interlaminar and transforaminal route, use of any image guidance or image control during or after the injection (e.g., by fluoroscopy, CT, ultrasound, or others), as well as types and doses of injected drugs, were also extracted. In addition, all included publications were searched in detail for arguments given by the authors for why they selected the given access route for epidural drug application.

Data synthesis and statistical analysis

All data were summarized using spreadsheets (Excel, Microsoft, Seattle, WA, USA), and are presented using descriptive statistics. Access route selection criteria are

described qualitatively. No statistical calculations were performed in this structured literature review study.

Results

Literature

The initial structured literature searches resulted, after de-duplication, in 1,211 papers which referred directly or indirectly to epidural injection. After reading all titles and abstracts, 1,077 of 1,211 publications (88.9 %) were excluded. Full texts from the remaining 134 of 1,211 papers (11.1 %) were ordered. After reading the 134 studies, 91 (7.5 %) fulfilled the inclusion criteria. Of these 91 studies, 59 were randomized controlled trials [6–64] and 32 were observational studies [65–96]. All studies were published between 1971 and 2011, with the majority (60 of 91, 65.9 %) published in the last decade (Fig. 1).

Patient population and inclusion criteria

On average, 85 patients were included per study. The smallest study involved ten patients [75] and the largest study involved 306 [11]. The mean age of the patients over all studies was 50 years. The mean of the youngest study group was 28 years [22] and the mean of the oldest study group was 78 years [69].

Inclusion criteria in these 91 studies were rather homogenous as the majority of studies (75 of 91, 82.4 %) focused on patients with radicular symptoms. Some studies also included patients with lumbar spinal stenosis, chronic back pain refractory to usual analgesics, or complaints after spinal surgery (24, 30, and seven of 91 studies; 26.4, 33.0, and 7.7 %, respectively).

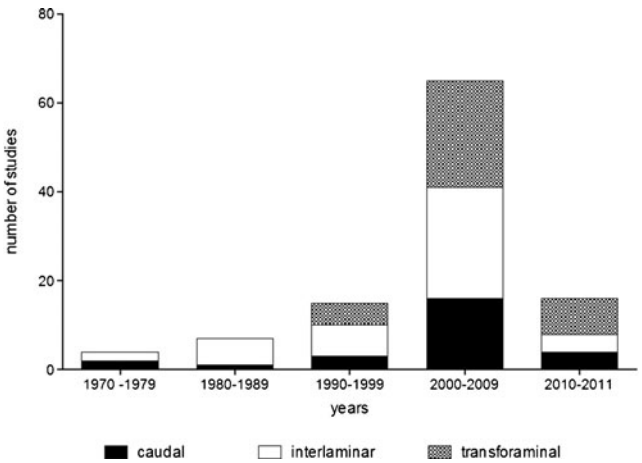

Fig. 1 Bar chart showing the number of publications per decade for each different approach (caudal, interlaminar, and transforaminal injection pathway)

Route of injection

In 44 of 91 studies (48.4 %), drugs were injected via the interlaminar approach (Fig. 2), while 37 (40.7 %) used the transforaminal route (Fig. 3). The caudal approach was chosen in 26 of the 91 (28.6 %) studies (Fig. 4). Two studies applied all three routes to compare the effects [6, 93]. Two other studies compared the effects on the outcome of caudal and transforaminal routes [73, 85], and two studies compared the caudal with the interlaminar approach [42, 50]. A further eight studies compared the transforaminal route to the interlaminar injection site [25, 36, 38, 51, 61, 91, 92, 94].

Level of injection in relation to level of lesion

In 20 of the 44 studies that evaluated the effect of the interlaminar route, the drugs were injected at the level of the lesion. Only three studies performed the injection at a level above (cranial) the level of the lesion [7, 16, 26]. The level of injection in relation to the causal lesion was not declared or remained unclear due to poor description in 21 studies.

In 33 of 37 studies that evaluated the effect of the transforaminal approach, the drugs were injected on the level where the involved nerve left its foramen. In two studies [6, 30], drugs were injected via the preganglionic route, as first described by Lew et al. [97]. One study used a retrodiscal [48] approach, while another used the intradiscal approach [25].

In all 26 studies that investigated the caudal approach, the needle was inserted via the sacrococcygeal ligament through the hiatus sacralis. No technical differences with regard to the site or level of injection were found.

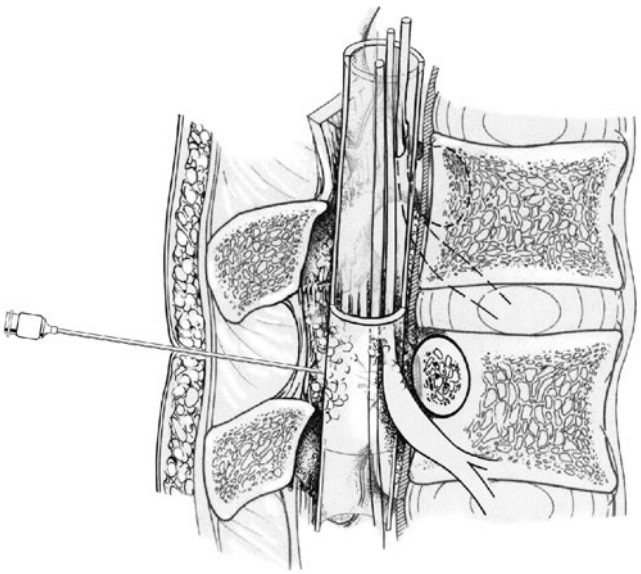

Fig. 2 Anatomic drawing illustrating the access route for interlaminar epidural injections at the lower spine. Sagittal view is provided

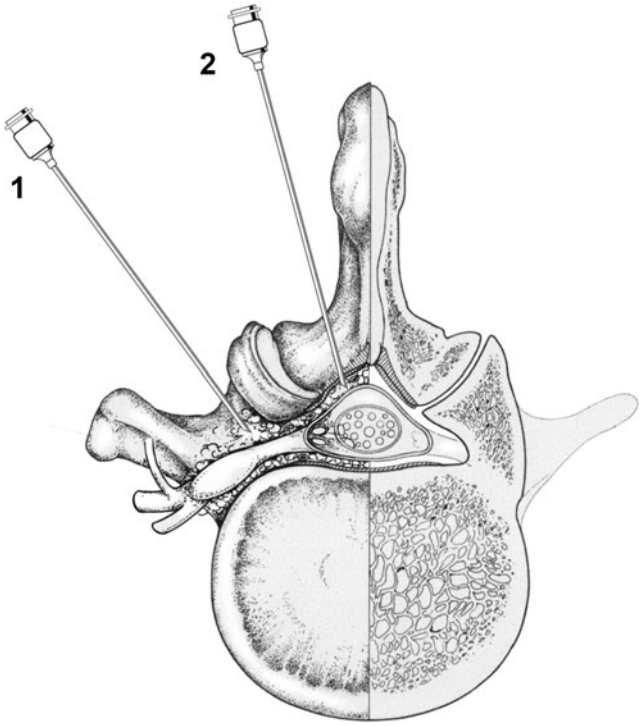

Fig. 3 Anatomic drawing illustrating the access routes for transforaminal epidural injections (1) and interlaminar epidural injections (2) at the lower spine. Transaxial view is provided

Fig. 4 Anatomic drawing illustrating the access route for caudal epidural injections at the lower spine. Sagittal view is provided

Types and doses of injected drugs

Steroids were injected into the epidural space in all studies. Methylprednisolone was the most frequently applied steroid (43 of 91 studies, 47.3 %), followed by triamcinolone (29 of 91 studies, 31.9 %). The dosages ranged from 40–120 mg for methylprednisolone, and 10–80 mg for triamcinolone, per injection. Other steroid preparations included betamethasone (14 of 91 studies, 15.4 %), dexamethasone (four of 91 studies, 4.4 %) and cortivazol (two of 91 studies, 2.2 %).

Local anesthetics were used in 70 of 91 studies (76.9 %). The most often used substances were bupivacaine (31 of 91 studies, 34.1 %) and lidocaine (29 of 91 studies, 31.9 %). Three studies (3.3 %) used non-steroidal analgesics or opioids [7, 55, 86] and two (2.2 %) used an oxygen-ozone gas mixture [11, 25].

Injection under imaging control

In three of 44 studies (6.8 %) using the interlaminar pathway, injections were performed under CT-guidance (Fig. 5) and in 17 of 44 studies (38.6 %) under fluoroscopic control. The remaining 24 studies did not use image guidance. All 37 transforaminal injections were performed under image control, four of them CT-guided (Fig. 6) and 33 of them under fluoroscopic control (10.8 and 89.2 %). For the caudal approach, fluoroscopic guidance was used in 13 of 26 studies (50 %), ultrasound control in two of 26 studies (7.7 %), and no imaging control was used in the remaining 11 of 26 studies (42.3 %).

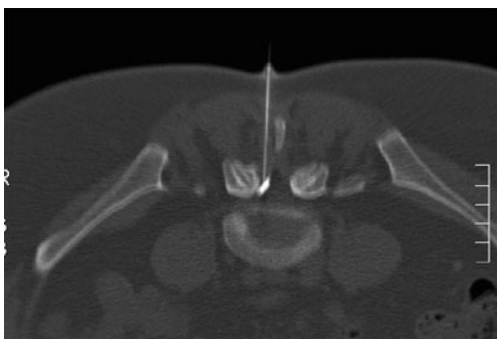

Fig. 5 A 51-year-old male patient with chronic low back pain. Interlaminar access route. Transaxial CT image (slice thickness 3 mm) at the level L4/5 shows needle placement and iodinated contrast within the epidural space. Contrast was injected to proof correct position of needle tip prior to injection of local anesthetics and steroids

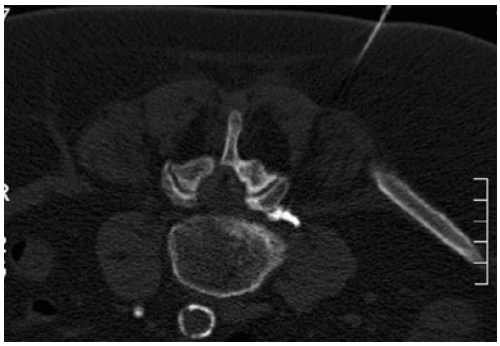

Fig. 6 A 78-year-old female patient with chronic low back pain. Transforaminal access route. Transaxial CT image (slice thickness 3 mm) at the level L4/5 shows iodinated contrast along the left L4 nerve root. Contrast was injected to proof correct position of needle tip prior to injection of local anesthetics and steroids

Primary outcome measures

Changes in pain scores, mainly by VAS (visual analog scale), were measured in 77 of 91 studies (84.6 %). Outcome measures were evaluated via the distribution of contrast media in seven studies (7.7 %) [68, 69, 74, 75, 79, 83, 84], and by degree of disability in another 42 studies (46.2 %).

Arguments for selection of injection route

Fifty-four of 91 (59.4 %) studies provided explanations for the choice of injection route. Decision criteria related to the correct needle placement, concentration of injected drug at lesion site, technical complexity of the procedure, costs, and potential complications (Table 2). Detailed analysis of the studies revealed that the caudal approach was the most frequently chosen injection route in older studies whereas the transforaminal route is the most prevalent today (Fig. 1). The remaining 37 studies (40.7 %) provided no justification for the choice of injection route.

Discussion

The discussion is still ongoing as to whether epidural injections are effective or not and if so, for how long. Recently published data on fluoroscopically guided and blind lumbar epidural injections in the management of low back and lower extremity pain have at least shown good evidence for procedures performed under image guidance [98, 99]. However, to the best of our knowledge, only a few studies have evaluated the different access routes for epidural injections. Benyamin et al. [99] discussed the strengths and limitations of different routes but did not perform a systematic analysis of use frequency or assess the criteria authors used to select a given route [99].

This systematic review found that the interlaminar and the foraminal pathway were used almost equally often, namely in about three fourth of all studies. Interlaminar epidural injections are considered non-specific since the injectate (usually local anesthetics and/or steroids) is free to extend within the posterior epidural space with possible flow anteriorly, cephalad, and caudad [100]. Epidural ligaments or scar tissue might hamper the injectate's extension, but otherwise it can reach multiple areas and nerve roots. Limitations of this access route include extra-epidural needle placement (rare with fluoroscopically guided procedures), preferential flow of the contrast agent towards a non-desired direction, needle deviation to the non-dependent side, difficulty entering the epidural space, potential risk of dural puncture and very rarely, epidural hematoma or spinal cord injury [99, 101]. Transforaminal epidural injections are usually considered to be specific since the injectate is administered in the area where a specific nerve root is leaving the neuroforamen, the typical site of nerve root compression. Using this access route, selected nerves can be targeted. The most commonly cited theory in favor of the transforaminal access route is to place the anti-inflammatory steroid medication as close as possible to the point of nerve root compression. Limitations of the transforaminal access route include misplacement of the needle, intravascular injection, and, when done without fluoroscopic control, the theoretical risk of injuries to the aorta or ureter [102, 103]. Another theoretical risk includes spinal cord injury including severe complications such as paraplegia [104]. Complications of the interlaminar approach are infectious complications, e.g., epidural abscesses, osteomyelitis/discitis and meningitis, and epidural hematomas [105].

As our systematic review showed, the caudal pathway was used the least often, but still in more than one fourth of the studies. Caudal epidural injections are also considered non-specific as the medication is injected very low at the level of the sacrum. Usually a larger amount of injectate is used. Caudal injections allow for multiple areas to be reached with advantageous avoidance of multiple injections. Limitations of this access route include extra-epidural needle placement, preferential flow of the contrast agent towards a non-desired direction, difficulty entering the epidural space, potential risk of dural puncture and epidural hematoma or spinal cord injury [75, 84]. Another limitation of this access route is that the injectate may not always gets as high as desired to reach pathology. This limitation was however not specifically mentioned in the included studies. It would also imply that authors mix contrast with their final injectate to detect how high the injectate passes from a caudal injection. Limitations to all three access routes include radiation exposure infection, (epidural) abscesses, meningitis, osteomyelitis, discitis, adverse or toxic effects of steroids, bleeding, as well as paraplegia, headache and pain [70, 99, 106, 107]. Overall, our findings are in agreement with a previous study, where a questionnaire was sent to 185 centers in the U.S. to record the most commonly used procedural practice [108]. This U.S.-based survey included almost all technical aspects of the procedure itself

Table 2 Arguments for and against the transforaminal (TF), interlaminar (IL), and caudal (C) injection pathway (n = number of studies reporting pros or cons)

Arguments	Transforaminal		Interlaminar		Caudal	
	Pros	Cons	Pros	Cons	Pros	Cons
Needle placement	Drugs at higher concentrations at the site of pathology in the anterior epidural space (n=12), fewer misplacements (n=1)	Difficult in case of foraminal stenosis (n=2)	Correct placement in >90 % (n=3), loss of resistance technique correct in 70–87 % (n=3)	Correct placement in only 60–75 % (n=3)	Correct placement with fluoroscopic guidance in 98 % (n=1)	Incorrect placement in 14–44 % of patients (n=5); intravenous leakage of steroids in up to 40 % of patients (n=1)
Concentration of drugs at site of lesion	Lower dose of drugs needed (n=27), less steroid side effects (n=2)	Spread of the drug over a wide area, not directly at a single affected nerve route (n=1)	Epidural injected drug flows freely (n=1)	Medication might not reach target due to scarring, stenosis (n=1)	Push injection and better diffusion of steroids in the area affected (n=1),	
Complexity of procedure	Higher complexity is justified but fluoroscopic guidance reduces risk for complications (n=3)	Higher complexity (n=11); increased radiation exposure (n=2)	Less than TF (n=6)	Higher than C (n=5)	Complexity of procedures: C < IL < TF (n=5)	
Costs	Lower than surgery (n=1)	Higher than IL or C (n=2)	Lower than TF (n=1)	Higher than C (n=1)	Low (n=1)	
Complication	Minimal adverse reactions (n=3); rate 5–10 % (n=2); Steroid side effects in 10 % (n=1), Fluoroscopy reduces risk for intravascular injection (n=2) and puncture of dura (n=1); risk for dura-puncture: C < TF < IL (n=2)	Potentially severe spinal cord trauma) (n=6); increased risk for intravascular injection, spinal cord trauma at level S1 in 11.2 % (n=1); Post-puncture headache more frequent (n=2),	Rate lower than TF (n=5), post-puncture headache fewer than TF (n=2), puncture of dura rare (n=1), post puncture headache rare (n=1)	Infections and epidural hematomas with severe spinal cord compression and paraplegia	Low complication rate (n=6)	Minor complications vasovagal reaction 2.5 %, pain exacerbation 3.5 %, facial flush 2.5 % (n=1); intravenous needle placement 14 % (n=1)
Special Indication	For neural foraminal stenosis (n=1); for localized nerve root compression (n=1)		Axial pain (n=1), upper lumbar central canal stenosis (n=1)	May not be appropriate for unilateral pain (n=1)	Multilevel or single central canal stenosis (n=2)	

as well as medication used, but found no clear-cut consensus as to the ideal method to perform epidural injections.

Unfortunately, the U.S.-based survey did not provide a detailed evaluation of the three different access routes. Consequently, our study evaluated the level of injection in relation to the pathology and found that the injection was performed at the level of the lesion in most studies. This was true for both interlaminar and transforaminal injections. An exception was the caudal approach. All such studies use the same technique and the injection is inherently performed caudal to the lesion. To our knowledge, no other study has systematically evaluated the level of injection in detail.

An assessment of the choice of access route revealed a change in preferences over time. In the past, the caudal approach was the most frequently chosen injection route whereas the transforaminal route is the most prevalent today.

Our study has limitations. First, all literature search strategies include the inherent risk of failing to detect relevant articles. However, a structured search was performed by a professional librarian and several online libraries were included for maximum coverage of the literature. A total of more than 1,200 articles were identified and analyzed. Second, only articles in English or German were included. This represented a possible selection bias because relevant articles written in other languages (e.g., French, Spanish, Japanese, etc.) were absent. However, this is a minor issue as the bulk of medical literature is written in (or translated into) English. Third, sub-analyses of outcome or efficacy of the different access routes was not performed due to the paucity of such information in the literature. Fourth, information on who performed the procedures was not available in most studies. Thus, differences between practitioners (e.g., radiologists, anesthesiologists, physiatrists and pain management specialists) could not be evaluated. Last, there are more interesting questions regarding spinal injections which were, however, beyond the scope of this work; e.g., about criteria of success, causes of failure, complications dependent to the pathological state, or about the precise indications and efficiency according to the clinical syndrome. Unfortunately, our feeling is that evidence in literature seems to be very weak regarding those questions.

In conclusion, the most commonly used access routes for epidural drug injection are the interlaminar and transforaminal pathways at the level of the pathology. Transforaminal routes are being performed with increasing frequency in recent years.

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References

1. Friedly J, Chan L, Deyo R. Increases in lumbosacral injections in the Medicare population: 1994 to 2001. Spine. 2007;32(16):1754.
2. Boswell MV, Hansen HC, Trescot AM, Hirsch JA. Epidural steroids in the management of chronic spinal pain and radiculopathy. Pain Physician. 2003;6(3):319–34.
3. Chou R, Loeser JD, Owens DK, Rosenquist RW, Atlas SJ, Baisden J, et al. Interventional therapies, surgery, and interdisciplinary rehabilitation for low back pain: an evidence-based clinical practice guideline from the American Pain Society. Spine. 2009;34(10):1066.
4. Spine.org [homepage on the Internet]. North American Spine Society, 7075 Veterans Blvd., Burr Ridge, IL; 2007 [cited March 1, 2013]. Available from: http://www.spine.org/Documents/NASSCG_stenosis.pdf
5. Johnson BA, Schellhas KP, Pollei SR. Epidurography and therapeutic epidural injections: technical considerations and experience with 5334 cases. Am J Neuroradiol. 1999;20(4):697–705.
6. Ackerman WE, Ahmad M. The efficacy of lumbar epidural steroid injections in patients with lumbar disc herniations. Anesth Analg. 2007;104(5):1217–22.
7. Aldrete JA. Epidural injections of indomethacin for postlaminectomy syndrome: a preliminary report. Anesth Analg. 2003;96(2):463–8.
8. Arden NK, Price C, Reading I, Stubbing J, Hazelgrove J, Dunne C, et al. A multicentre randomized controlled trial of epidural corticosteroid injections for sciatica: the WEST study. Rheumatology (Oxford). 2005;44(11):1399–406.
9. Aref AM, Fawzy M, Hamimy W, Shawky M. The effectiveness of volume versus concentration of the epidural steroid injections through transforaminal approach. Egypt J Anaesth. 2011;27(1):61–5.
10. Béliveau P. A comparison between epidural anaesthesia with and without corticosteroid in the treatment of sciatica. Rheumatol Phys Med. 1971;11(1):40–3.
11. Bonetti M, Fontana A, Cotticelli B, Volta GD, Guindani M, Leonardi M. Intraforaminal O(2)-O(3) versus periradicular steroidal infiltrations in lower back pain: randomized controlled study. AJNR Am J Neuroradiol. 2005;26(5):996–1000.
12. Breivik H, Hesla P, Molnar I, Lind B. Treatment of chronic low back pain and sciatica: comparison of caudal epidural injections of bupivacaine and methylprednisolone with bupivacaine followed by saline. Advances in Pain Research and Therapy. New York: Raven Press; 1976.
13. Buchner M, Zeifang F, Brocai DR, Schiltenwolf M. Epidural corticosteroid injection in the conservative management of sciatica. Clin Orthop Relat Res. 2000;375:149–56.
14. Burgher AH, Hoelzer BC, Schroeder DR, Wilson GA, Huntoon MA. Transforaminal epidural clonidine versus corticosteroid for acute lumbosacral radiculopathy due to intervertebral disc herniation. Spine (Phila Pa 1976). 2011;36(5):E293–300.
15. Bush K, Hillier S. A controlled study of caudal epidural injections of triamcinolone plus procaine for the management of intractable sciatica. Spine (Phila Pa 1976). 1991;16(5):572–5.
16. Buttermann GR. Treatment of lumbar disc herniation: epidural steroid injection compared with discectomy. A prospective, randomized study. J Bone Joint Surg Am. 2004;86-A(4):670–9.
17. Carette S, Leclaire R, Marcoux S, Morin F, Blaise GA, St-Pierre A, et al. Epidural corticosteroid injections for sciatica due to herniated nucleus pulposus. N Engl J Med. 1997;336(23):1634–40.
18. Cuckler JM, Bernini PA, Wiesel SW, Booth RE, Rothman RH, Pickens GT. The use of epidural steroids in the treatment of lumbar radicular pain. A prospective, randomized, double-blind study. J Bone Joint Surg Am. 1985;67(1):63–6.
19. Dashfield AK, Taylor MB, Cleaver JS, Farrow D. Comparison of caudal steroid epidural with targeted steroid placement during spinal

endoscopy for chronic sciatica: a prospective, randomized, double-blind trial. Br J Anaesth. 2005;94(4):514–9.
20. Devulder J, Deene P, De Laat M, Van Bastelaere M, Brusselmans G, Rolly G. Nerve root sleeve injections in patients with failed back surgery syndrome: a comparison of three solutions. Clin J Pain. 1999;15(2):132–5.
21. Dilke TF, Burry HC, Grahame R. Extradural corticosteroid injection in management of lumbar nerve root compression. Br Med J. 1973;2(5867):635–7.
22. Dincer U, Kiralp MZ, Cakar E, Yasar E, Dursan H. Caudal epidural injection versus non-steroidal anti-inflammatory drugs in the treatment of low back pain accompanied with radicular pain. Joint Bone Spine. 2007;74(5):467–71.
23. El Zahaar MS. The value of caudal epidural steroids in the treatment of lumbar neural compression syndromes. J Neurol Orthop Med Surg. 1991;12:181–4.
24. Fukusaki M, Kobayashi I, Hara T, Sumikawa K. Symptoms of spinal stenosis do not improve after epidural steroid injection. Clin J Pain. 1998;14(2):148–51.
25. Gallucci M, Limbucci N, Zugaro L, Barile A, Stavroulis E, Ricci A, et al. Sciatica: treatment with intradiscal and intraforaminal injections of steroid and oxygen-ozone versus steroid only. Radiology. 2007;242(3):907–13.
26. Gelalis ID, Arnaoutoglou E, Pakos EE, Politis AN, Rapti M, Xenakis TA, et al. Effect of interlaminar epidural steroid injection in acute and subacute pain due to lumbar disk herniation: a randomized comparison of 2 different protocols. Open Orthop J. 2009;3:121.
27. Ghahreman A, Ferch R, Bogduk N. The efficacy of transforaminal injection of steroids for the treatment of lumbar radicular pain. Pain Med. 2010;11(8):1149–68.
28. Helliwell M, Robertson JC, Ellis RM. Outpatient treatment of low back pain and sciatica by a single extradural corticosteroid injection. Brit J of Clin Pract. 1985:228–31.
29. Iversen T, Solberg TK, Romner B, Wilsgaard T, Twisk J, Anke A, et al. Effect of caudal epidural steroid or saline injection in chronic lumbar radiculopathy: multicentre, blinded, randomised controlled trial. BMJ (Clinical research ed). 2011;343:d5278.
30. Jeong HS, Lee JW, Kim SH, Myung JS, Kim JH, Kang HS. Effectiveness of transforaminal epidural steroid injection by using a preganglionic approach: a prospective randomized controlled study. Radiology. 2007;245(2):584–90.
31. Kang SS, Hwang BM, Son HJ, Cheong IY, Lee SJ, Lee SH, et al. The dosages of corticosteroid in transforaminal epidural steroid injections for lumbar radicular pain due to a herniated disc. Pain Physician. 2011;14:361–70.
32. Karppinen J, Malmivaara A, Kurunlahti M, Kyllönen E, Pienimäki T, Nieminen P, et al. Periradicular infiltration for sciatica: a randomized controlled trial. Spine (Phila Pa 1976). 2001;26(9):1059–67.
33. Kim D, Brown J. Efficacy and safety of lumbar epidural dexamethasone versus methylprednisolone in the treatment of lumbar radiculopathy: a comparison of soluble versus particulate steroids. Clin J Pain. 2011;27(6):518.
34. Klenerman L, Greenwood R, Davenport HT, White DC, Peskett S. Lumbar epidural injections in the treatment of sciatica. Br J Rheumatol. 1984;23(1):35–8.
35. Koc Z, Ozcakir S, Sivrioglu K, Gurbet A, Kucukoglu S. Effectiveness of physical therapy and epidural steroid injections in lumbar spinal stenosis. Spine (Phila Pa 1976). 2009;34(10):985–9.
36. Kolsi I, Delecrin J, Berthelot JM, Thomas L, Prost A, Maugars Y. Efficacy of nerve root versus interspinous injections of glucocorticoids in the treatment of disk-related sciatica. A pilot, prospective, randomized, double-blind study. Joint Bone Spine. 2000;67(2):113–8.
37. Kraemer J, Ludwig J, Bickert U, Owczarek V, Traupe M. Lumbar epidural perineural injection: a new technique. Eur Spine J. 1997;6(5):357–61.
38. Lee JH, An JH, Lee SH. Comparison of the effectiveness of interlaminar and bilateral transforaminal epidural steroid injections in treatment of patients with lumbosacral disc herniation and spinal stenosis. Clin J Pain. 2009;25(3):206.
39. Manchikanti L, Cash KA, McManus CD, Pampati V, Smith HS. One-year results of a randomized, double-blind, active controlled trial of fluoroscopic caudal epidural injections with or without steroids in managing chronic discogenic low back pain without disc herniation or radiculitis. Pain Physician. 2011;14(1):25–36.
40. Manchikanti L, Rivera JJ, Pampati V, Damron KS, McManus CD, Brandon DE, et al. One-day lumbar epidural adhesiolysis and hypertonic saline neurolysis in treatment of chronic low back pain: a randomized, double-blind trial. Pain Physician. 2004;7(2):177–86.
41. Mathews JA, Mills SB, Jenkins VM, Grimes SM, Morkel MJ, Mathews W, et al. Back pain and sciatica: controlled trials of manipulation, traction, sclerosant and epidural injections. Br J Rheumatol. 1987;26(6):416–23.
42. McGregor AH, Anjarwalla NK, Stambach T. Does the method of injection alter the outcome of epidural injections? J Spinal Disord. 2001;14(6):507–10.
43. Meadeb J, Rozenberg S, Duquesnoy B, Kuntz JL, Le Loët X, Sebert JL, et al. Forceful sacrococcygeal injections in the treatment of postdiscectomy sciatica. A controlled study versus glucocorticoid injections. Joint Bone Spine. 2001;68(1):43–9.
44. Ng L, Chaudhary N, Sell P. The efficacy of corticosteroids in periradicular infiltration for chronic radicular pain: a randomized, double-blind, controlled trial. Spine (Phila Pa 1976). 2005;30(8):857–62.
45. Noe CE, Haynsworth Jr RF. Comparison of epidural depo-medrol vs. aqueous betamethasone in patients with low back pain. Pain Practice. 2003;3(3):222–5.
46. Owlia MB, Salimzadeh A, Alishiri GH, Haghighi A. Comparison of two doses of corticosteroid in epidural steroid injection for lumbar radicular pain. Singap Med J. 2007;48(3):241.
47. Park CH, Lee SH, Kim BI. Comparison of the effectiveness of lumbar transforaminal epidural injection with particulate and nonparticulate corticosteroids in lumbar radiating pain. Pain Medicine. 2010;11(11):1654–8.
48. Park CH, Lee SH, Park HS. Lumbar retrodiscal versus postganglionic transforaminal epidural steroid injection for the treatment of lumbar intervertebral disc herniations. Pain Physician. 2011;14:353–60.
49. Pirbudak L, Karakurum G, Oner U, Gulec A, Karadasli H. Epidural corticosteroid injection and amitriptyline for the treatment of chronic low back pain associated with radiculopathy. Pain Clinic. 2003;15(3):247–53.
50. Price CM, Rogers PD, Prosser ASJ, Arden NK. Comparison of the caudal and lumbar approaches to the epidural space. Ann Rheum Dis. 2000;59(11):879–82.
51. Rados I, Sakic K, Fingler M, Kapural L. Efficacy of interlaminar vs transforaminal epidural steroid injection for the treatment of chronic unilateral radicular pain: prospective. Randomized study. Pain Medicine. 2011;12(9):1316–21.
52. Revel M, Auleley GR, Alaoui S, Nguyen M, Duruoz T, Eck-Michaud S, et al. Forceful epidural injections for the treatment of lumbosciatic pain with post-operative lumbar spinal fibrosis. Rev Rhum Engl Ed. 1996;63(4):270–7.
53. Ridley MG, Kingsley GH, Gibson T, Grahame R. Outpatient lumbar epidural corticosteroid injection in the management of sciatica. Br J Rheumatol. 1988;27(4):295–9.
54. Riew KD, Yin Y, Gilula L, Bridwell KH, Lenke LG, Lauryssen C, et al. The effect of nerve-root injections on the need for operative treatment of lumbar radicular pain. A prospective, randomized, controlled, double-blind study. J Bone Joint Surg Am. 2000;82-A(11):1589–93.
55. Rocco AG, Frank E, Kaul AF, Lipson SJ, Gallo JP. Epidural steroids, epidural morphine and epidural steroids combined with morphine in

the treatment of post-laminectomy syndrome. Pain. 1989;36(3):297–303.
56. Rogers P, Nash T, Schiller D, Norman J. Epidural steroids for sciatica. The Pain Clinic. 1992;5(2):67–72.
57. Sayegh FE, Kenanidis EI, Papavasiliou KA, Potoupnis ME, Kirkos JM, Kapetanos GA. Efficacy of steroid and nonsteroid caudal epidural injections for low back pain and sciatica: a prospective, randomized, double-blind clinical trial. Spine. 2009;34(14):1441.
58. Serrao JM, Marks RL, Morley SJ, Goodchild CS. Intrathecal midazolam for the treatment of chronic mechanical low back pain: a controlled comparison with epidural steroid in a pilot study. Pain. 1992;48(1):5–12.
59. Snoek W, Weber H, Jørgensen B. Double-blind evaluation of extradural methyl prednisolone for herniated lumbar discs. Acta Orthop Scand. 1977;48(6):635–41.
60. Teske W, Zirke S, Trippe C, Krämer J, Willburger RE, Schott C, et al. Epidural injection therapy with local anaesthetics versus cortisone in the lumbar spine syndrome: a prospective study. Z Orthop Unfall. 2009;147(2):199–204.
61. Thomas E, Cyteval C, Abiad L, Picot MC, Taourel P, Blotman F. Efficacy of transforaminal versus interspinous corticosteroid injection in discal radiculalgia—a prospective, randomised, double-blind study. Clin Rheumatol. 2003;22(4–5):299–304.
62. Vad VB, Bhat AL, Lutz GE, Cammisa F. Transforaminal epidural steroid injections in lumbosacral radiculopathy: a prospective randomized study. Spine. 2002;27(1):11.
63. Valat JP, Giraudeau B, Rozenberg S, Goupille P, Bourgeois P, Micheau-Beaugendre V, et al. Epidural corticosteroid injections for sciatica: a randomised, double-blind, controlled clinical trial. Ann Rheum Dis. 2003;62(7):639–43.
64. Wilson-MacDonald J, Burt G, Griffin D, Glynn C. Epidural steroid injection for nerve root compression. A randomised, controlled trial. J Bone Joint Surg Br. 2005;87(3):352–5.
65. Andersen KH, Mosdal C. Epidural application of cortico-steroids in low-back pain and sciatica. Acta Neurochir. 1987;87(1):52–3.
66. Banaszkiewicz PA, Kader D, Wardlaw D. The role of caudal epidural injections in the management of low back pain. Bulletin (Hospital for Joint Diseases (New York, NY)). 2003;61(3–4):127.
67. Blanchais A, Le Goff B, Guillot P, Berthelot J-M, Glemarec J, Maugars Y. Feasibility and safety of ultrasound-guided caudal epidural glucocorticoid injections. Joint Bone Spine. 2010;77(5):440–4.
68. Botwin K, Natalicchio J, Brown LA. Epidurography contrast patterns with fluoroscopic guided lumbar transforaminal epidural injections: a prospective evaluation. Pain Physician. 2004;7(2):211–6.
69. Botwin KP, Gruber RD, Bouchlas CG, Torres-Ramos FM, Sanelli JT, Freeman ED, et al. Fluoroscopically guided lumbar transformational epidural steroid injections in degenerative lumbar stenosis: an outcome study. Am J Phys Med Rehabil. 2002;81(12):898–905.
70. Botwin KP, Natalicchio J, Hanna A. Fluoroscopic guided lumbar interlaminar epidural injections: a prospective evaluation of epidurography contrast patterns and anatomical review of the epidural space. Pain Physician. 2004;7(1):77–80.
71. Cooper G, Lutz GE, Boachie-Adjei O, Lin J. Effectiveness of transforaminal epidural steroid injections in patients with degenerative lumbar scoliotic stenosis and radiculopathy. Pain Physician. 2004;7(3):311–8.
72. Cyteval C, Fescquet N, Thomas E, Decoux E, Blotman F, Taourel P. Predictive factors of efficacy of periradicular corticosteroid injections for lumbar radiculopathy. Am J Neuroradiol. 2006;27(5):978–82.
73. Delport EG, Cucuzzella AR, Marley JK, Pruitt CM, Fisher JR. Treatment of lumbar spinal stenosis with epidural steroid injections: a retrospective outcome study. Arch Phys Med Rehabil. 2004;85(3):479–84.
74. Desai MJ, Shah B, Sayal PK. Epidural contrast flow patterns of transforaminal epidural steroid injections stratified by commonly used final needle-tip position. Pain Medicine. 2011;12:864–70.
75. Ergin A, Yanarates O, Sizlan A, Orhan ME, Kurt E, Guzeldemir ME. Accuracy of caudal epidural injection: the importance of real-time imaging. Pain Practice. 2005;5(3):251–4.
76. Furman MB, Kothari G, Parikh T, Anderson JG, Khawaja A. Efficacy of fluoroscopically guided, contrast-enhanced lumbosacral interlaminar epidural steroid injections: a pilot study. Pain Medicine. 2010;11(9):1328–34.
77. Gomez RS, Gusmão S, Silva JF, Bastos MP. Interlaminar epidural corticosteroid injection in the treatment of lumbosciatic pain: a retrospective analysis. Arq Neuro-psiquiatr. 2007;65(4B):1172–6.
78. Lee IS, Kim SH, Lee JW, Hong SH, Choi JY, Kang HS, et al. Comparison of the temporary diagnostic relief of transforaminal epidural steroid injection approaches: conventional versus posterolateral technique. Am J Neuroradiol. 2007;28(2):204–8.
79. Lee JW, Kim SH, Lee IS, Choi J-A, Choi J-Y, Hong SH, et al. Therapeutic effect and outcome predictors of sciatica treated using transforaminal epidural steroid injection. AJR Am J Roentgenol. 2006;187(6):1427–31.
80. Lee JW, Myung JS, Park KW, Yeom JS, Kim K-J, Kim H-J, et al. Fluoroscopically guided caudal epidural steroid injection for management of degenerative lumbar spinal stenosis: short-term and long-term results. Skeletal Radiol. 2010;39(7):691–9.
81. Lutz GE, Vad VB, Wisneski RJ. Fluoroscopic transforaminal lumbar epidural steroids: an outcome study. Arch Phys Med Rehabil. 1998;79(11):1362–6.
82. Maged Mokhemer Mohamed M, Ahmed M, Chaudary M. Caudal epidural injection for L4-5 versus L5-S1 disc prolapse: is there any difference in the outcome? J Spinal Disord Tech. 2007;20(1):49.
83. Manchikanti L, Cash KA, Pampati V, Damron KS, McManus CD. Evaluation of lumbar transforaminal epidural injections with needle placement and contrast flow patterns: a prospective, descriptive report. Pain Physician. 2004;7(2):217–24.
84. Manchikanti L, Cash KA, Pampati V, McManus CD, Damron KS. Evaluation of fluoroscopically guided caudal epidural injections. Pain Physician. 2004;7(1):81.
85. Mendoza-Lattes S, Weiss A, Found E, Zimmerman B, Gao Y. Comparable effectiveness of caudal vs. transforaminal epidural steroid injections. Iowa Orthop J. 2009;29:91.
86. Nawani DP, Agrawal S, Asthana V. Single shot epidural injection for cervical and lumbosaccral radiculopathies: a preliminary study. Korean J Pain. 2010;23(4):254–7.
87. Rivest C, Katz JN, Ferrante FM, Jamison RN. Effects of epidural steroid injection on pain due to lumbar spinal stenosis or herniated disks: a prospective study. Arthritis Rheum. 1998;11(4):291–7.
88. Rosenberg SK, Grabinsky A, Kooser C, Boswell MV. Effectiveness of transforaminal epidural steroid injections in low back pain: a one-year experience. Pain Physician. 2002;5(3):266–70.
89. Runu R, Sinha NK, Pai R, Shankar PR, Vijayabhaskar P. Our experience with epidural steroid injections in management of low back pain and sciatica. Kathmandu Univ Med J (KUMJ). 2005;3(4):349–54.
90. Saravana S, Gillott T. A study on caudal epidural analgesia for low back pain/sciatica. APLAR J Rheumatol. 2007;10(2):137–9.
91. Schaufele MK, Hatch L, Jones W. Interlaminar versus transforaminal epidural injections for the treatment of symptomatic lumbar intervertebral disc herniations. Pain Physician. 2006;9(4):361.
92. Schmid G, Vetter S, Göttmann D, Strecker EP. CT-guided epidural/perineural injections in painful disorders of the lumbar spine: short- and extended-term results. Cardiovasc Interv Radiol. 1999;22(6):493–8.
93. Simotas AC, Dorey FJ, Hansraj KK, Cammisa Jr F. Nonoperative treatment for lumbar spinal stenosis: clinical and outcome results and a 3-year survivorship analysis. Spine. 2000;25(2):197.
94. Smith CC, Booker T, Schaufele MK, Weiss P. Interlaminar versus transforaminal epidural steroid injections for the treatment of

symptomatic lumbar spinal stenosis. Pain Medicine. 2010;11(10): 1511–5.
95. Viton JM, Peretti-Viton P, Rubino T, Delarque A, Salamon N. Short-term assessment of periradicular corticosteroid injections in lumbar radiculopathy associated with disc pathology. Neuroradiology. 1998;40(1):59–62.
96. Weiner BK, Fraser RD. Foraminal injection for lateral lumbar disc herniation. Bone Joint J. 1997;79(5):804.
97. Lew HL, Coelho P, Chou LH. Preganglionic approach to transforaminal epidural steroid injections. Am J Phys Med Rehabil. 2004;83(5):378.
98. McLain RF, Kapural L, Mekhail NA. Epidural steroid therapy for back and leg pain: mechanisms of action and efficacy. Spine J. 2005;5(2):191–201.
99. Benyamin RM, Manchikanti L, Parr AT, Diwan S, Abdi S. The effectiveness of lumbar interlaminar epidural injections in managing chronic low back and lower extremity pain. Pain Physician. 2012;15:E363–404.
100. Whitlock EL, Bridwell KH, Gilula LA. Influence of needle tip position on injectate spread in 406 interlaminar lumbar epidural steroid injections. Radiology. 2007;243(3):804–11.
101. Rosas HG, Lee KS. Performing fluoroscopically guided interlaminar lumbar epidural injections. Am J Roentgenol. 2012;199(2):419–9.
102. Karaman H, Kavak GÖ, Tüfek A, Yldrm ZB. The complications of transforaminal lumbar epidural steroid injections. Spine. 2011;36(13): E819.
103. Smuck M, Fuller BJ, Chiodo A, Benny B, Singaracharlu B, Tong H, et al. Accuracy of intermittent fluoroscopy to detect intravascular injection during transforaminal epidural injections. Spine. 2008;33(7):E205.
104. 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(8):1389–94.
105. Parr AT, Diwan S, Abdi S. Lumbar interlaminar epidural injections in managing chronic low back and lower extremity pain: a systematic review. Pain Physician. 2009;12(1):163–88.
106. Weil L, Frauwirth NH, Amirdelfan K, Grant D, Rosenberg JA. Fluoroscopic analysis of lumbar epidural contrast spread after lumbar interlaminar injection. Arch Phys Med Rehabil. 2008;89(3):413–6.
107. Manchikanti L, Malla Y, Wargo BW, Cash KA, Pampati V, Fellows B. Complications of fluoroscopically directed facet joint nerve blocks: a prospective evaluation of 7,500 episodes with 43,000 nerve blocks. Pain Physician. 2012;15:E143–50.
108. Cluff R, Mehio AK, Cohen SP, Chang Y, Sang CN, Stojanovic MP. The technical aspects of epidural steroid injections: a national survey. Anesth Analg. 2002;95(2):403–8.