International Journal of Obstetric Anesthesia (2019) 38, 52–58
0959-289X/$ - see front matter © 2018 Elsevier Ltd. All rights reserved.
https://doi.org/10.1016/j.ijoa.2018.11.005

ORIGINAL ARTICLE

ELSEVIER
www.obstetanesthesia.com

Ultrasound guided L5–S1 placement of labor epidural does not improve dermatomal block in parturients

T. Malik, O. Malas, A. Thompson
Department of Anesthesia and Critical Care, University of Chicago, Chicago, United States of America

ABSTRACT

Background: Based on their experience or training, anesthesiologists typically use the iliac crest as a landmark to choose the L3-4 or L2-3 interspace for labor epidural catheter placement. There is no evidence-based recommendation to guide the exact placement. We hypothesized that lower placement of the catheter would lead to a higher incidence of S2 dermatomal block and improved analgesia in late labor and at delivery.

Methods: One-hundred parturients requesting epidural analgesia were randomly assigned to receive ultrasound-guided L5–S1 epidural catheter placement (experimental group) or non-ultrasound-guided higher lumbar interspace placement (control group). The primary outcome was the incidence of S2 block 30 minutes after administering 10 mL 0.125% bupivacaine. Secondary outcomes were average pain throughout labor and maximum pain during labor or during delivery.

Results: Forty-nine subjects were enrolled in control group and 47 in the experimental group. The primary endpoint did not significantly differ between groups (control group 81% vs experimental group 91%, P=0.24). The secondary endpoints were not significantly different: pain relief after 30 minutes (mean pain score 1.4 in the control group vs 1.9 in the experimental group, P=0.2) and pain at delivery (mean score 4 in the control group vs 3.9 in the experimental group, P=0.6).

Conclusion: Placement of an epidural catheter at the L5–S1 interspace using ultrasound did not improve sacral sensory block coverage when compared with an epidural catheter placed at a higher lumbar interspace, without using ultrasound guidance.

Keywords: Ultrasound; Labor epidural; Labor analgesia; Sacral block

Introduction

Epidural analgesia is the most popular form of pain management for parturients in labor[1–3] due to its established safety and efficacy.[3–6] Despite its widespread use, studies have shown that 0.9–23% of epidural catheters fail to provide adequate analgesia during labor.[2,7–10] Sacral sparing is a possible cause of epidural catheter failure,[4,7,11] and is thought to be caused by poor penetration of analgesic medication into the sacral nerve roots, due to the large number of these roots, the thicker surrounding dura mater and the relatively large distance of the catheter tip from them.[4,11] Although dural puncture has been shown to increase caudad sensory spread, there is no conclusive evidence that it improves labor analgesia when compared to epidural analgesia.[12]

The use of external landmarks to guide epidural catheter placement in a lower lumbar interspace is likely to be ineffective,[13–15] as studies have found that the intercristal line, traditionally thought to intersect with the L4–L5 interspace, is more cephalad in pregnant patients[16] and anesthesiologists correctly identify the interspace of epidural insertion only 14–29% of the time.[17,18] The cephalad displacement of the intercristal line also poses a theoretical risk of injury to the conus medullaris during epidural catheter insertion.[19,20]

Procedural ultrasound can identify the level of epidural catheter insertion, screen for anatomic variations in the spinal column, and demonstrate pregnancy-related tissue changes.[21–24] Pre-puncture ultrasound has been found to decrease the number of puncture attempts, the number of catheter manipulations and pain intensity, as reported using a verbal numeric rating score (VNRS) during labor, while also increasing patient satisfaction.[24–26] No study to date has determined if placing an epidural catheter in a lower interspace, closer to the sacral nerve roots, accurately identified by ultrasound, might lead to decreased sacral block sparing and greater dermatomal coverage.

Accepted November 2018
Correspondence to: T. Malik, Department of Anesthesia and Critical Care, 5841 S. Maryland Ave., MC 4028, Chicago, IL 60637, USA. http://anesthesia.uchicago.edu/.
E-mail address: tmalik@dacc.uchicago.edu

The aim of this study was to evaluate the effectiveness of the sacral dermatomal block when an epidural catheter is placed at the L5–S1 interspace, using pre-puncture ultrasound guidance, compared to placement at the L3-4 or L2-3 interspace, using surface landmarks. The primary endpoint of this study was the incidence of S2 dermatomal block 30 minutes after catheter placement. Cephalad and caudal dermatomal nerve block, the number of interventions required to achieve adequate pain relief, and the pain scores of patients 30 minutes after epidural insertion and during labor, were also assessed.

Methods

This double-blinded randomized controlled trial was conducted at the Mitchell Hospital of the University of Chicago. Institutional Review Board (IRB) approval was obtained and the study was registered at ClinicalTrials.gov (NCT01182220). Inclusion criteria were term pregnancy English-speaking ASA II-III parturients who had requested neuraxial pain relief in labor and were not in acute distress. Exclusion criteria included parturients whose cervix was dilated more than 5 cm, who had a greater than 5/10 pain on a VNRS (0 representing no pain and 10 the worst possible pain), were less than 18 years' old, were expecting premature delivery (at less than 37 weeks' gestation) or who had neuraxial analgesia contraindications.

All parturients who requested neuraxial analgesia during labor and who met inclusion criteria were offered study participation. After obtaining written informed consent, patients were randomized using a computer-generated number list into either the control group (subjects assigned to receive epidural catheters placed at the L3–4 or L2–3 interspace) or the experimental group (subjects assigned to receive epidural catheters placed at the L5–S1 interspace using ultrasound guidance). Participants were blinded to their group assignment.

Sealed envelopes with the group allocation were opened by the primary investigator when epidural analgesia was requested. All procedures were performed by residents under the direct supervision of an anesthesiologist with more than five years' experience with lumbar spine ultrasound scanning. After epidural insertion, all drug administrations and evaluations were performed by an anesthesiologist who was blinded to group allocation and who took no part in data analysis. Outcome data were recorded by an observer who entered the room after the procedure had been completed. The data were analyzed by the principal investigator, who was unaware of group allocation.

In both groups, prior to epidural insertion a low frequency (2–5 Hz) curved array probe (Sonosite Inc, Bothell, WA) was applied to the back, but only in the experimental group was the machine switched on. In this group, spinal interspaces were imaged in the short axis and the paramedian oblique long-axis view, to identify the L5–S1 interspace. The probe was placed in the long axis over the bony contour of the sacrum and was moved cephalad until the first interspace was visualized as a break in the bony outline: this point was marked on the skin. The probe was then turned 90° to visualize the L5–S1 interspace in the short axis, the middle of which was also marked on the skin. This was used as the epidural insertion point for the L5–S1 interspace.

The epidural catheter insertion technique was standardized for both groups. Patients were sitting and had continuous maternal and fetal heart rate and maternal blood pressure monitoring. The back was cleaned and draped in a sterile fashion. In the experimental group, all patients underwent epidural placement in the marked L5–S1 space. In the control group, the intercristal line was used to identify the L4 vertebral body.[27] This landmark was used to place the epidural catheter at the L3–4 or L2–3 interspace as is the current practice at our institution. In both groups, a 17-gauge Tuohy epidural needle (Teleflex Inc., Limerick, PA) accessed the epidural space using the loss-of-resistance to air technique. A 19-gauge FlexTip Plus epidural catheter (Teleflex Inc.) was threaded 4–5 cm into the space. After a test dose of 3 mL lidocaine 1.5% with epinephrine 5 μg/mL, two doses of 5 mL bupivacaine 0.125% were administered five minutes apart.

Upper and lower dermatomal spread, using loss-of-sensation to cold (with ice) and VNRS pain scores were assessed 30 minutes later by an anesthesia resident who was not part of the research team. Sensory levels were assessed starting at the S2 dermatome, then working upward: thoracic levels were assessed in the anterior axillary line. Dermatomal levels were tested by placing ice at the inguinal crease (L1), the front of thigh (L2), the medial side of front of knee (L3), the medial malleolus (L4), the dorsum of the foot just proximal to the first two toes (L5), the lateral margin of foot (S1), and the medial half of the popliteal fossa (S2), xiphoid process (T6) and umbilicus (T10).[28] An epidural infusion of 0.0625% with fentanyl 2 μg/mL at 10 mL/h, with a patient-controlled dose of 5 mL available every 20 minutes, was started.

Patients were reassessed every two hours during labor. A pain score of less than 4/10 was defined as being comfortable. Unilateral block (defined as a difference of more than three dermatomal levels between the right and left side), was managed with two doses of 5 mL bupivacaine 0.125%, administered 10 minutes apart. If pain persisted (score greater than four) with inadequate dermatomal coverage, the catheter was pulled back to leave 3 cm in the epidural space and two further doses of 5 mL bupivacaine 0.125%, 10 minutes apart, were given. If pain relief and coverage remained incomplete, the catheter was replaced. Supplemental interventions were recorded and compared as secondary endpoints. After delivery parturients were

assessed by the resident to determine the pain score during delivery and satisfaction with pain management. The epidural catheter was removed within two hours of delivery.

The following data were collected: age, weight, height, gravida, parity, mode of delivery, presence or absence of S1 and S2 dermatomal sensory blocks on each side 30 minutes after epidural placement, the number of dermatomes blocked on each side, and the number of re-doses, manipulations and replacements of the epidural catheter. Pain scores during contractions, from the time of epidural catheter placement to full cervical dilatation and at the time of delivery, were recorded.

Based on published studies using the same study drug solution, with a baseline incidence of S2 block of less than 25% for epidural labor analgesia, and outcomes reported by Suzuki et al.,[29] the sample size needed to detect a doubling of sacral block to 50% in the experimental group (at 80% power and at a *P*-value of less than 0.05) was 30 per group.[30] The sample size was increased to 50 per group to allow for drop-outs and incomplete data acquisition.

The analysis was performed using SAS version 9.3 (SAS Institute, Cary, NC), and graphs were created using SigmaPlot version 10.0 (Systat Software, San Jose, CA). Basic descriptive statistics were calculated for the control group and the experimental group. Normality of all continuous variables was assessed using the Kolmogorov-Smirnov test. Frequencies with percentages or means with standard deviations (SD) were calculated as appropriate for patient population demographics and epidural characteristics. Pearson chi-square or Fisher exact tests (for categorical variables) and t-tests or Wilcoxon tests (for continuous variables) were used to assess univariate clinical differences between the groups. A *P*-value <0.05 was deemed statistically significant.

Results

Three-hundred-and-fifty women were screened for eligibility: 102 were not eligible, 248 were approached and 130 gave consent to participate. One-hundred subjects were randomized, because 30 patients delivered before requesting labor analgesia. Fifty subjects were randomized to each group but only 96 were eligible for analysis (49 in the control group and 47 in the experimental group, CONSORT diagram, Fig. 1).

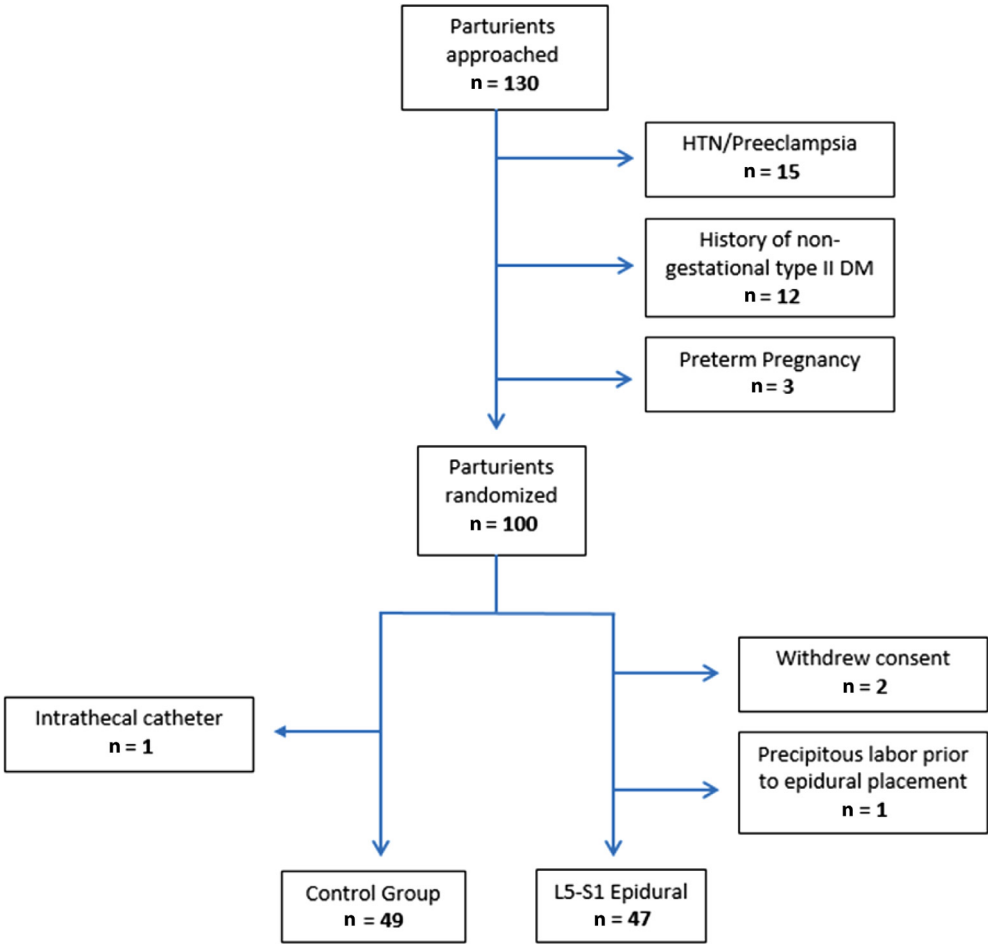

Fig. 1 CONSORT diagram.

Patient characteristics, epidural catheter characteristics and the number of interventions (catheter retraction, solution change, catheter replacement, extra boluses) were similar in both groups (Table 1). The primary endpoint of the study was S2 dermatomal block in the two groups: there was no significant difference between the groups. There was no significant difference in the number of dermatomes blocked on each side, or in the secondary endpoints and pain scores after epidural placement and at delivery. The incidence of catheters requiring manipulation (51% in control group vs 60% in experimental group) or replacement (4.1% in control group vs 2.2% in experimental group) was not statistically different, and there was no difference in the mode of delivery.

For patients in whom inadequate analgesia necessitated administration of a manual bolus, S2 coverage immediately prior to a manual bolus administration was not significantly better in the experimental group compared to the control group (Table 2).

Discussion

In this study, sacral dermatomal spread in parturients with an epidural catheter placed at the L5–S1 interspace based on ultrasound guidance was compared to the

Table 1 Population demographics and epidural analgesia characteristics at 30 minutes.

	Control Group (n=49)	Experimental Group (n=47)	*P*-value
Population Demographics			
Age (y)	26.9 ± 5.4	27.6 ± 6.5	0.543
BMI (kg/m^2)	32.0 ± 7.2	31.8 ± 8.0	0.879
Gravida (n)	2.6 ± 1.7	2.7 ± 2.4	0.808
Parity (n)	0.7 ± 1.1	0.9 ± 1.5	0.620
Mode of delivery (n, %)			0.999
SVD	41 (83.7)	39 (84.8)	
cesarean	8 (16.3)	7 (15.2)	
Epidural Characteristics			
Epidural duration (h)	9.2 ± 5.7	8.1 ± 5.5	0.340
Depth (cm)	6.4 ± 2.0	6.6 ± 1.7	0.548
Threading	10.4 ± 2.2	10.7 ± 1.7	0.571
Need for intervention	25 (51)	27 (60)	0.382
Type of intervention			
Catheter retraction	3 (6.0)	2 (4.4)	0.999
Solution change	11 (22.0)	7 (15.6)	0.442
Catheter replacement	2 (4.1)	1 (2.2)	0.999
Multiple Boluses	23 (46.9)	27 (60.0)	0.205
Analgesic Characteristics			
Bilateral S2 block	40 (81.63)	42 (91.30)	0.243
Mean no. dermatomes blocked	10.7 ± 1.8	10.4 ± 2.4	0.518
Dermatomes blocked			
Right	10.7 ± 1.9	10.5 ± 2.5	0.775
Left	10.8 ± 2.0	10.3 ± 2.6	0.366
Pain 30 min after epidural placement	1.4 ± 1.6	1.9 ± 1.9	0.194
Pain at delivery	4.0 ± 1.5	3.9 ± 2.1	0.656

Values are in mean (SD) or number (%). BMI: body mass index. SVD: spontaneous vaginal delivery.

Table 2 Sacral (S2) dermatomal coverage before and after manual bolus.

	Control group n (%)	Experimental group n (%)	*P*-value
(a) Difference in S2 dermatomal coverage between groups, prior to manual bolus			
Right S2	27 (61.4)	38 (95.0)	<0.001
Left S2	26 (59.1)	39 (97.5)	<0.001
Any S2	28 (56.0)	39 (83.0)	0.004
(b) Difference in S2 dermatomal coverage between groups, 30 minutes after manual bolus			
Right S2	42 (85.7)	44 (95.7)	0.161
Left S2	42 (85.7)	43 (93.5)	0.319
Any S2	45 (90.0)	45 (95.7)	0.437

n: number of patients (%). S: sacral.

spread from an epidural catheter placed at the L3-4 or L2-L3 interspace using intercristal line landmarks. The S2 dermatomal block and spread were similar 30 minutes after epidural drug administration. There was no difference in pain score during labor or at delivery or in the number of interventions between the two groups.

This finding is consistent with a previous study in which L4-5 epidural catheter analgesic characteristics were similar to those for a catheter placed at L1-2, even though better sacral coverage in the group with an L4-5 catheter was shown. Our incidences of catheter manipulation, unilateral blocks and catheter replacement did not significantly differ.[31] Improved sacral coverage has been demonstrated using a 26-gauge spinal needle to puncture the dura before initiating epidural anesthesia,[29] although that study did not evaluate the sacral dermatomal block effect of dural puncture for more than 20 minutes. Chau et al. found 85% S2 dermatomal coverage in the epidural arm of a study 30 minutes after an initial loading dose of local anesthetic.[34] However, epidural catheters were placed at the L2–3 or L3–4 interspace without ultrasound guidance, which may have made localization of the interspaces unreliable, and determination of S2 coverage was not the primary endpoint of that study.

Furthermore, Suzuki et al. [29] used 18 mL mepivacaine 2% in the epidural space while Chau et al. used 20 mL bupivacaine 0.125% with fentanyl 2 μg/mL in the epidural arm and dry-puncture epidural arm of the study, to initiate labor epidural analgesia. Cappiello et al. [30] did not find sustained analgesic benefit despite improved sacral coverage when a 25-gauge spinal needle was used for dural puncture when initiating labor epidural analgesia. Additionally, epidural analgesia was initiated with 12 mL bupivacaine 0.25% and a continuous epidural infusion of bupivacaine 0.125% with fentanyl 2 μg/mL. This made the finding of a sacral block irrelevant in the context of the low concentrations of local anesthetic solutions currently used to maintain labor epidural analgesia.

The reported incidence of failure of labor epidural analgesia is approximately 12%.[2] Sacral-sparing is one cause of inadequate epidural analgesia, especially in the later stages of labor, and may prompt the use of a pudendal block, a combined spinal-epidural (CSE) technique or opioids, to improve analgesia. A CSE technique for catheter placement improves immediate pain relief and sacral coverage[30] but has not been shown to improve labor analgesia. There are no guidelines or recommendations about which interspace to use for epidural placement in order to improve labor analgesia. Typically an anesthesiologist uses an iliac crest landmark, expecting this to be the L2–3 or L3–4 interspace, but this is unreliable and anesthesiologists often end up placing epidural catheters at a higher space than intended.[17,18,32] Solutions injected into the lumbar epidural space tend to spread in a cephalad rather than caudad direction.[33] If the tip of an epidural catheter is placed at or above the L3-4 interspace, the anesthetic solution injected is both further away from the sacral roots and tends to move further cephalad; this may limit its effect on the sacral roots.

This study was intended to assess whether epidural catheters placed at the L5–S1 level can provide improved S2 coverage and hence improve pain control during the late stages of labor. No difference in coverage between the groups was found. Possible explanations may be the influence of the epidural space anatomy and the role of volume and concentration of local anesthetics on the spread of epidural analgesia. The structure of the epidural space is not uniform[34] and this makes spread of, and neural blockade produced by, local anesthetic unpredictable. There is a positive correlation between the volume of local anesthetic and extent of sensory block. Larger volumes of more dilute solutions produce more extensive blockage than smaller volumes, even if the total mass of local anesthetic is the same,[35] but the evidence is not conclusive.[36] In general, when the volume of a lower concentration solution is more than twice the volume of the more concentrated solution, the sensory block will be more extensive in the high-volume group, even if the total dose of local anesthetic is the same.[37] The current study used 13 mL injection volume to establish epidural analgesia and could account for the lack of difference between the study groups. The S2 coverage wore off more often in the control group than the experimental group when the S2 levels were checked prior to a manual bolus, but there was no difference in coverage after the manual bolus. Epidural catheters placed at the L4–5 interspace required fewer boluses in the later stages of labor compared to catheters at the L1–2 interspace,[31] and although this study did not collect data on sacral dermatomal coverage beyond 60 min after initiating epidural analgesia, better sacral coverage might explain fewer manual boluses requested by patients with an L4–5 epidural catheter in later stages of labor.

The only unexpected finding of our study was a high incidence of S2 block in both groups during initiation of epidural analgesia and after a clinician-administered bolus. The baseline incidence of S2 block has been reported as 25%,[25,29] but in this study it was almost 80%. A high incidence was also reported by Chau et al.[38] This may be related to the high volume of local anesthetics used to establish epidural analgesia, the concentration of local anesthetic used to initiate epidural analgesia, or the variability in the S2 dermatome pattern among patients. Since pain in the second stage and the later stages of labor is often felt in the S2–S4 dermatomes, blocking S2 alone may not be enough to make a clinical difference. It is often impractical to test the S3-4 sensory block level clinically because the dermatomes are perianal. The placement of

epidural catheters in the lowest interspace did not increase pain in the early stages of labor because the median number of dermatomes and the upper end of dermatomal block did not significantly differ.

There are some limitations of this study. The control group had an epidural placed using clinical landmarks, which is notoriously unreliable. Since we did not check the interspace level with ultrasound, even at the time of removal of the catheter, the catheter in the control group could have easily been placed at the L4–5 instead of the L2–3 interspace, resulting in a false-negative outcome. The study did not have the power to detect the difference in the number of interventions and in the S2 dermatomal coverage between the two groups towards the later stages of labor. This makes a lower incidence of S2 dermatomal blockage in the control group, when checked in the later stages of labor, less significant. The study did not have a spinal-epidural analgesia arm, this approach being a well-known technique to facilitate sacral sensory block coverage. A future study comparing CSE performed at the L3–4 or L2–3 lumbar interspace, compared to one done at the L5–S1or L4–5 interspace, could indicate the preferred interspace for optimal labor epidural analgesia in late labor.

In summary, epidural catheters placed with ultrasound guidance at the L5–S1 interspace offered no advantage over those placed at L3–4 or at a higher interspace using the intercristal line landmark technique to identify the interspace, when epidural analgesia was initiated with at least a 13 mL volume of local anesthetic.

Funding

No funding source declared.

Declarations of interest

None.

References

1. Eappen S, Blinn A, Segal S. Incidence of epidural catheter replacement in parturients: a retrospective chart review. *Int J Obstet Anesth* 1998;**7**:220–5.
2. Pan PH, Bogard TD, Owen MD. Incidence and characteristics of failures in obstetric neuraxial analgesia and anesthesia: a retrospective analysis of 19,259 deliveries. *Int J Obstet Anesth* 2004;**13**:227–33.
3. Morgan B, Bulpitt CJ, Clifton P, Lewis PJ. Effectiveness of pain relief in labour: survey of 1000 mothers. *Br Med J Clin Res Ed* 1982;**285**:689–90.
4. Jones L, Othman M, Dowswell T, et al. Pain management for women in labour: an overview of systematic reviews. *Cochrane Database Syst Rev* 2012;**3**:CD009234.
5. Hess PE, Pratt SD, Lucas TP, et al. Predictors of breakthrough pain during labor epidural analgesia. *Anesth Anal* 2001;**93**:414–8.
6. Hawkins JL, Koonin LM, Palmer SK, Gibbs CP. Anesthesia-related deaths during obstetric delivery in the United States, 1979–1990. *Anesthesiology* 1997;**86**:277–84.
7. Agaram R, Douglas MJ, McTaggart RA, Gunka V. Inadequate pain relief with labor epidurals: a multivariate analysis of associated factors. *Int J Obstet Anesth* 2009;**18**:10–4.
8. Beilin Y, Zahn J, Bernstein HH, et al. Treatment of incomplete analgesia after placement of an epidural catheter and administration of local anesthetic for women in labor. *Anesthesiology* 1998;**88**:1502–6.
9. Paech MJ, Godkin R, Webster S. Complications of obstetric epidural analgesia and anaesthesia: a prospective analysis of 10,995 cases. *Int J Obstet Anesth* 1998;**7**:5–11.
10. Beilin Y, Bernstein HH, Zucker-Pinchoff B. The optimal distance that a multiorifice epidural catheter should be threaded into the epidural space. *Anesth Analg* 1995;**81**:301–4.
11. Arendt K, Segal S. Why epidurals do not always work. *Rev Obstet Gynecol* 2008;**1**:49–55.
12. Gupta D, Srirajakalidindi A, Soskin V. Dural puncture epidural analgesia is not superior to continuous labor epidural analgesia. *Middle East J Anaesthesiol* 2013;**22**:309–16.
13. Collier CB. Why obstetric epidurals fail: a study of epidurograms. *Int J Obstet Anesth* 1996;**5**:19–31.
14. Wallace DH, Currie JM, Gilstrap LC, Santos R. Indirect sonographic guidance for epidural anesthesia in obese pregnant patients. *Reg Anesth* 1992;**17**:233–6.
15. Le Coq G, Ducot B, Benhamou D. Risk factors of inadequate pain relief during epidural analgesia for labour and delivery. *Can J Anaesth* 1998;**45**:719–23.
16. Margarido CB, Mikhael R, Arzola C, Balki M, Carvalho JCA. The intercristal line determined by palpation is not a reliable anatomical landmark for neuraxial anesthesia. *Can J Anesth* 2011;**58**:262–6.
17. Broadbent CR, Maxwell WB, Ferrie R, et al. Ability of anaesthetists to identify a marked lumbar interspace. *Anaesthesia* 2000;**55**:1122–6.
18. Lee AJ, Ranasinghe JS, Chehade JM, et al. Ultrasound assessment of the vertebral level of the intercristal line in pregnancy. *Anesth Analg* 2011;**113**:559–64.
19. Cook TM, Counsell D, Wildsmith JAW. Royal College of Anaesthetists Third National Audit Project. Major complications of central neuraxial block: report on the Third National Audit Project of the Royal College of Anaesthetists. *Br J Anaesth* 2009;**102**:179–90.
20. Lirk P, Hogan Q. Spinal and epidural anatomy. In: Wong CA, editor. Spinal and Epidural Anesthesia. 1st ed. Chicago: McGraw-Hill Companies Inc.; 2007:1–27.
21. Grau T, Leipold RW, Horter J, et al. The lumbar epidural space in pregnancy: visualization by ultrasonography. *Br J Anaesth* 2001;**86**:798–804.
22. Grau T, Leipold RW, Horter J, et al. Paramedian access to the epidural space: the optimum window for ultrasound imaging. *J Clin Anesth* 2001;**13**:213–7.
23. Grau T, Leipold RW, Conradi R, Martin E. Ultrasound control for presumed difficult epidural puncture. *Acta Anaesthesiol Scand* 2001;**45**:766–71.
24. Grau T, Leipold RW, Conradi R, Martin E, Motsch J. Efficacy of ultrasound imaging in obstetric epidural anesthesia. *Clin Anesth* 2002;**14**:169–75.
25. Carvalho JCA. Ultrasound-facilitated epidurals and spinals in obstetrics. *Anesthesiol Clin* 2008;**26**:145–58.
26. Baldi C, Bettinelli S, Grossi P, et al. Ultrasound guidance for locoregional anesthesia: a review. *Minerva Anestesiol* 2007;**73**:587–93.
27. Render CA. The reproducibility of the iliac crest as a marker of lumbar spine level. *Anaesthesia* 1996;**51**:1070–1.
28. Lee MWL, McPhee RW, Stringer MD. An evidence-based approach to human dermatomes. *Clin Anatomy* 2008;**21**:363–73.
29. Suzuki N, Koganemaru M, Onizuka S, Takasaki M. Dural puncture with a 26-gauge spinal needle affects spread of epidural anesthesia. *Anesth Analg* 1996;**82**:1040–2.

30. Cappiello E, O'Rourke N, Segal S, Tsen LC. A randomized trial of dural duncture epidural technique compared with the standard epidural technique for labor analgesia. *Anesth Analg* 2008;**5**:1646–51.
31. Moore A, Villeneuve V, Bravim B, et al. The labor analgesia requirements in nulliparous women randomized to epidural catheter placement in a high or low intervertebral space. *Anesth Analg* 2017;**125**:1969–74.
32. Lirk P, Messner H, Deibl M, et al. Accuracy in estimating the correct intervertebral space level during lumbar, thoracic and cervical epidural anaesthesia. *Acta Anaesthesiol Scand* 2004;**48**:347–9.
33. Yokoyama M, Hanazaki M, Fujii H, et al. Correlation between the distribution of contrast medium and the extent of blockade during epidural anesthesia. *Anesthesiology* 2004;**100**:1504–10.
34. Savolaine ER, Pandya JB, Greenblatt SH, Conover SR. Anatomy of the human lumbar epidural space: New insights using CT-epidurography. *Anesthesiology* 1988;**68**:217–20.
35. Christiaens F, Verborgh C, Dierick A, Camu F. Effects of diluent volume of a single dose of epidural bupivacaine in parturients during the first stage of labor. *Reg Anesth Pain Med* 1998;**23**:134–41.
36. Hermanides J, Hollmann MW, Stevens MF, Lirk P. Failed epidural: causes and management. *Br J Anaesth* 2012;**109**:144–54.
37. Salinas F. Pharmacology of drugs used for spinal and epidural anesthesia and analgesia. In: Wong CA, editor. Spinal and epidural anesthesia. New York: McGraw-Hill; 2007:75–115.
38. Chau A, Bibbo C, Haung C, et al. Dural puncture epidural technique improves labor analgesia quality with fewer side effects compared with epidural and combined spinal epidural techniques: a randomized clinical trial. *Anesth Analg* 2017;**124**:560–9.