Lumbosacral Cerebrospinal Fluid Volume Is the Primary Determinant of Sensory Block Extent and Duration during Spinal Anesthesia

Randall L. Carpenter, M.D.,* Quinn H. Hogan, M.D.,† Spencer S. Liu, M.D.,‡ Bert Crane, M.D.,§ James Moore, M.D.‖

Background: Injection of local anesthetic into cerebrospinal fluid (CSF) produces anesthesia of unpredictable extent and duration. Although many factors have been identified that affect the extent of spinal anesthesia, correlations are relatively poor and the extent of spread remains unpredictable. This study was designed to determine whether variability in the volume of lumbosacral CSF among individuals is a contributing factor in the variability of spinal anesthesia.

Methods: Spinal anesthesia was administered to 10 healthy volunteers with 50 mg lidocaine in 7.5% dextrose. The technique was standardized to minimize variability in factors known to affect the distribution of spinal anesthesia. The extent of sensory anesthesia was assessed by pin-prick and by transcutaneous electrical stimulation. Motor blockade was assessed in the quadriceps and gastrocnemius muscles by force dynamometry. Duration of anesthesia was assessed by pin-prick, transcutaneous electrical stimulation, and duration of motor blockade. Lumbosacral CSF volumes were calculated from low thoracic, lumbar, and sacral axial magnetic resonance images obtained at 8-mm increments. Volumes of CSF were correlated with measures of extent and duration of spinal anesthesia using the Kendall rank correlation test.

Results: Lumbosacral CSF volumes ranged from 42.7 to 81.1 ml. Volumes of CSF correlated with pin-prick assessments of peak sensory block height ($P = 0.02$) and duration of surgical anesthesia (as assessed by the duration of tolerance to transcutaneous electrical stimulation at the ankle ($P < 0.05$).

Conclusions: Variability in lumbosacral CSF volume is the most important factor identified to date that contributes to the variability in the spread of spinal sensory anesthesia. (Key words: Cerebrospinal fluid volume; duration of anesthesia; lidocaine; magnetic resonance imaging; motor block; spinal anesthesia; spread of anesthesia; subarachnoid; surgical anesthesia.)

> This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 5A.

* Associate Professor, Department of Anesthesiology, Bowman Gray School of Medicine at Wake Forest University.

† Associate Professor, Department of Anesthesiology, Medical College of Wisconsin, Milwaukee, Wisconsin.

‡ Staff Anesthesiologist, Virginia Mason Medical Center.

§ Staff Radiologist, Virginia Mason Medical Center.

‖ Dan Moore-Don Bridenbaugh Fellow in Regional Anesthesia.

SUBARACHNOID injection of local anesthetic produces anesthesia of unpredictable extent and duration. For example, injection of 50 mg hyperbaric lidocaine in one study resulted in peak sensory block height ranging from T3-T9.[1] Similarly, duration of surgical anesthesia for arthroscopic knee surgery after injection of 75 mg hyperbaric lidocaine has been reported to range from 60-115 min.[2] On the other hand, repeated spinal anesthesia in the same person produces relatively consistent spread and duration of spinal anesthesia.[3-6] Many studies have been performed in an attempt to understand the reasons for this variability, and at least 25 factors have been suggested to influence the spread of spinal anesthesia.[7] Some of the more important factors that affect the spread of local anesthetic solutions in cerebrospinal fluid (CSF) include baricity and dose of local anesthetic, site of injection, patient position when injecting nonisobaric solutions, patient age, anatomic configuration of the spinal column, and pregnancy.[7-9] Although many factors correlate with the extent of the spread of anesthesia, no single factor explains more than 50% of the variability in patient response.[10-17]

Recent *in vivo* measurement of lumbosacral CSF volume showed a nearly threefold variability of CSF volume

in healthy adults.[18] Because CSF volume is the diluent for local anesthetics injected during spinal anesthesia, we hypothesized that differences in lumbosacral CSF volume among patients may be an important factor that contributes to the variability in interindividual responses to subarachnoid injection of local anesthetics. This study was designed to evaluate the relation between lumbosacral CSF volume and the extent and duration of spinal anesthesia.

Methods

After we obtained approval from the institutional review boards at the Virginia Mason Medical Center and at the Medical College of Wisconsin and informed consent, 10 healthy volunteers participated in the study (nine at Virginia Mason and one at the Medical College of Wisconsin). Lumbar puncture was performed (in the left lateral decubitus position) at the L2–L3 interspace with a 25-gauge Whitacre spinal needle through a 20-gauge introducer with the orifice of the spinal needle turned cephalad. Cerebrospinal fluid (0.2 ml), was aspirated and 50 mg 5% lidocaine in 7.5% dextrose was injected at a rate of approximately 0.25 ml/s. After injection, the volunteers were immediately placed supine and remained so for the rest of the study.

Dermatomal levels of analgesia to pinprick (18-gauge needle) were measured at 1, 2, and 5 min after intrathecal injection of lidocaine, every 5 min thereafter until 40 min after injection, and then every 10 min until recovery of sensation to pin prick at the S2 dermatomal level.

Transcutaneous electrical stimulation (TES) was used to estimate the onset and duration of surgical anesthesia because it has been shown to be as potent a noxious stimulus as surgical incision.[19] The TES leads were placed in the midline at the T10 and T12 dermatomes and bilaterally at L2–L3 (medial aspect above the knee) and L5–S1 (lateral aspect above the ankle). Five seconds of 50-Hz tetanus at 60 mA delivered with a commercially available nerve stimulator (model NS252; Fisher & Paykel, Auckland, New Zealand) was considered equivalent to surgical incision.[19] This particular unit was tested by our bioengineering department to verify sustained delivery of displayed currents. Tolerance to electrical stimulation was assessed 4 min after intrathecal injec-

There is no relation between Hogan Health Industries and author Quinn Hogan.

tion of lidocaine and measured every 10 min thereafter by initially testing with 10 mA and then increasing in 10-mA increments to a maximum of 60 mA for 5 s. Absence of pain during the maximal stimulus was considered equivalent to "surgical anesthesia."[19] Each TES location was tested in sequence moving from distal to proximal sites.

Motor strength in the right quadriceps and gastrocnemius muscles was assessed with a commercially available isometric force dynamometer (Micro FET; Hogan Health Industries, Draper, UT).# Strength was measured during a 5-s isometric maximal contraction of each muscle performed 0 and 10 min after injection of lidocaine and every 10 min thereafter until return to 90% of the baseline strength measurement. Recovery of 90% of baseline motor strength was identified as the duration of motor blockade. Measurements were performed in triplicate and then averaged at each measurement period. Isometric force dynamometry was shown previously to be a reliable quantitative measure of motor block during spinal and epidural anesthesia.[20,21]

Lumbosacral Cerebrospinal Fluid Volumes

Low thoracic, lumbar, and sacral axial magnetic resonance images were obtained at 8-mm increments by fast-spin echo sequence, which highlights CSF (fig. 1). Details of the method have been described before.[18] Briefly, the dural sack and spinal cord areas were determined in a blinded manner for each image using video/digital analysis. Area of the sack minus area of the cord constituted the area of CSF and roots; this area multiplied by 8 mm resulted in CSF/root volume. The level of the disc between the 11th and 12th thoracic vertebrae was determined and the CSF/root volume was measured caudal from this site. Although this calculated volume includes the roots, it is hereafter referred to as the CSF volume.

Nine volunteers had spinal anesthesia performed before analysis of CSF volume. One volunteer had CSF volume measured before performing the spinal anesthesia.

Cerebrospinal fluid volumes were correlated using Kendall rank correlation with (1) the peak sensory block height to pinprick; (2) the time until two-segment regression from the peak sensory level; (3) the time until regression of pinprick analgesia to the L1 (duration of thoracic analgesia) and S2 (lowest dermatome tested) dermatomes; (4) the duration of surgical anesthesia at L2–L3, and L5–S1; and (5) the duration of motor block-
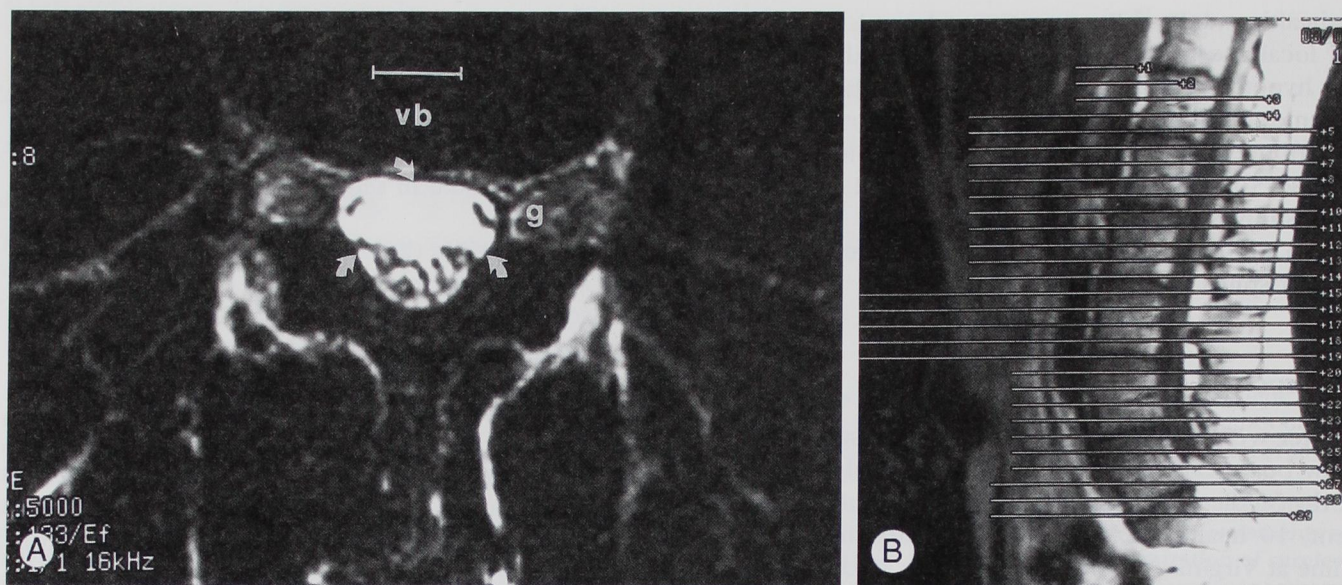
Fig. 1. Examples of magnetic resonance images used to determine cerebrospinal fluid (CSF) volume. (*A*) Axial image at the L4–L5 intervertebral foramen showing bright CSF containing nerve roots seen as gray defects. The area enclosed by the perimeter of the CSF (*arrows*) is measured to determine the dural sack volume. Cord volume (none seen at this level) is subtracted to determine the volume of CSF and roots. (Orientation is anterior up; scale bar = 1 cm; g = posterior root ganglion; vb = vertebral body.) (*B*) Sagittal scout image showing levels of axial images.

ade of the quadriceps and gastrocnemius muscles. Results are reported as means ± SD.

Statistical correlations were assessed by Kendall-Tau analysis. Probability values <0.05 were considered significant. Correlation lines and r values for the figures were identified by linear regression analysis.

Spinal anesthesia was performed before magnetic resonance imaging in nine volunteers. The original statistical analysis revealed a probability value of 0.06 for the correlation between CSF volume and peak block height. Consequently, one volunteer from a previous study that measured CSF volume was approached and consented to receive spinal anesthesia. Data from this volunteer (#10) were added to those of the original nine volunteers and a new statistical analysis was performed.

Results

Volunteers were young and healthy and of average height, weight, and body mass index (weight in kilograms divided by height in meters squared; table 1). Peak sensory block height ranged from T12–T2. Time to achieve peak sensory block height ranged from 10–30 min (20 ± 6 min). Time until two-segment regres-

sion of sensory analgesia to pinprick ranged from 30–80 min (57 ± 16 min), regression to L1 ranged from 35–130 (104 ± 29 min), and regression to S2 ranged from 90–180 min (144 ± 30 min). Duration of surgical anesthesia assessed by TES at T10 ranged from 0–70 min (42 ± 21), at T12 ranged from 0–110 min (68 ± 29 min), at L2–L3 ranged from 10–130 min (80 ± 32 min), and at L5–S1 ranged from 10–130 min (73 ± 39 min). Two volunteers did not develop tolerance to maximal stimulation with TES at the T10 or T12 dermatomes. One volunteer did not develop a detectable motor block of the quadriceps and two did not develop motor block of the gastrocnemius muscles. In those volunteers in whom motor blockade developed, the duration in the quadriceps motor block ranged from 80–140 min (94 ± 26 min) and in the gastrocnemius from 100–150 min (121 ± 17 min).

Volumes of CSF ranged from 42.7 to 81.1 ml and were significantly correlated with the peak sensory block level to pinprick (fig. 2) and the duration of tolerance of TES (surgical anesthesia) in the L_5–S_1 dermatomes (fig. 3, table 2). Volumes of CSF did not correlate with the onset of sensory analgesia or anesthesia, onset of motor blockade, or duration of motor blockade (table 2).

Table 1. Patient Demographics and CSF Volumes

Volunteer No.	Gender	Age (yr)	Height (cm)	Weight (kg)	BMI (kg/m^2)	CSF Volume (ml)
1	F	42	160	50.9	19.9	42.7
2	M	32	173	76.4	25.6	42.8
3	M	29	183	66.8	20.0	46.8
4	F	32	163	65.9	24.9	46.8
5	M	31	185	75.0	21.8	48.4
6	M	28	183	77.3	23.1	50.1
7	F	32	163	55.9	21.2	52.3
8	F	38	158	55.5	22.4	64.8
9	M	32	180	69.5	21.4	81.1
10	M	33	188	76	21.5	61.2
Totals (mean ± SD)		33 ± 4	173 ± 12	66.9 ± 9.8	22.2 ± 1.9	53.7 ± 12.1

BMI = body mass index (weight in kg divided by height^2 in m); CSF = cerebrospinal fluid.

Discussion

This is the first study to determine directly whether variability in lumbosacral CSF volume can explain the wide range of spread of spinal anesthesia observed in clinical practice. We determined that volume of lumbosacral CSF is a critical determinant of the extent and duration of sensory blockade during spinal anesthesia.

For example, differences in peak sensory block levels after injection of lidocaine appear to be explained largely by differences in CSF volume. Differences in CSF volume also correlate with differences in the duration of tolerance to tetanic electrical stimulation (table 2). Similarly, serial intrathecal injections of local anesthetic into the same patient produces spinal anesthesia that is less variable in extent and duration than when the
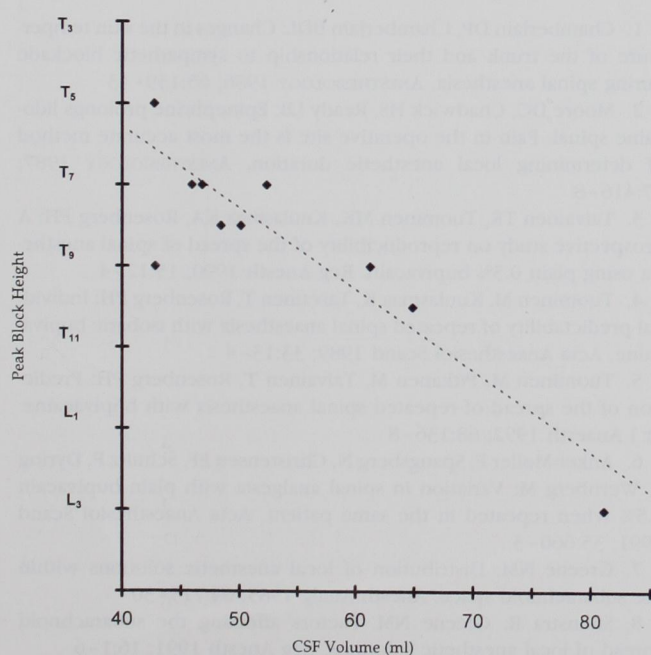

Fig. 2. Correlation between cerebrospinal fluid volume and peak sensory block height (r = 0.91, by linear regression analysis).
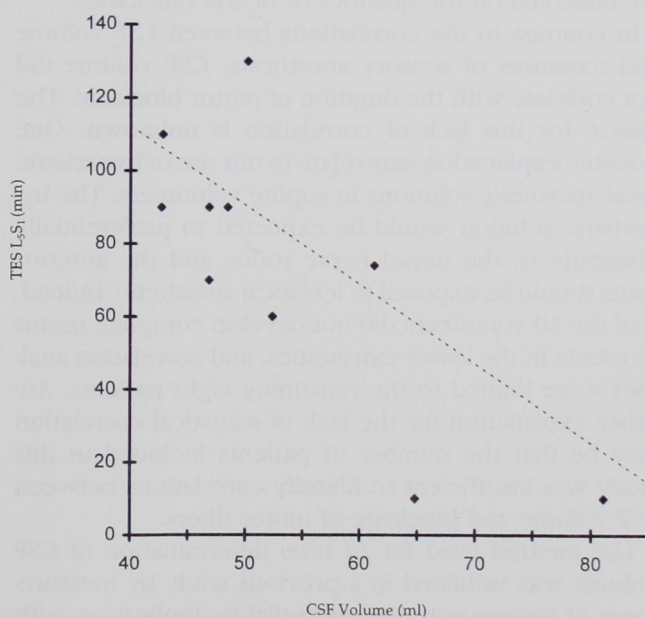

Fig. 3. Correlation between cerebrospinal fluid volume and duration of toleration of transcutaneous electrical stimulation (estimate for duration of surgical anesthesia) at the ankle (L5–S1). (r = 0.83, by linear regression analysis.)

Table 2. Correlations of CSF Volume with Characteristics of Spinal Anesthesia Resulting from 50 mg of Lidocaine*

Characteristic of Spinal Anesthesia	Correlation to CSF Value (*P* value)
Peak sensory block level to pinprick	0.02
Onset time to peak sensory level to pinprick	0.53
Time to 2-segment regression of pinprick sensory level from peak block level	0.09
Time to regression of pinprick to L1	0.06
Time to regression of pinprick to S2	0.28
Tolerance to TES at L2–L3	0.13
Tolerance to TES at L5–S1	0.049
Duration of quadriceps motor blockade	0.99
Duration of gastrocnemius motor blockade	0.54

CSF = cerebrospinal fluid.

* Values were determined by Kendall rank correlation.

same dose of local anesthetic is injected into different patients.[3,4,6,20] Previous authors have suggested that variability in CSF volumes may be an important cause of variability in the spread of spinal anesthesia.[7,22] This suggestion is based on the fact that local anesthetic injected to produce spinal anesthesia will be diluted in the volume of lumbosacral CSF. Because the volume of CSF varies by a factor of three in humans,[18] variable dilution can be expected to have the important effect we observed on the qualities of neural blockade.

In contrast to the correlations between CSF volume and measures of sensory anesthesia, CSF volume did not correlate with the duration of motor blockade. The reason for this lack of correlation is unknown. One possible explanation may relate to our use of hyperbaric local anesthetic solutions in supine volunteers. The hyperbaric solution would be expected to preferentially distribute to the dorsal nerve roots, and the anterior roots should be exposed to less local anesthetic. Indeed, 2 of the 10 volunteers did not develop complete motor blockade in the lower extremities, and correlation analyses were limited to the remaining eight patients. Another explanation for the lack of statistical correlation may be that the number of patients included in this study was insufficient to identify correlations between CSF volume and blockade of motor fibers.

The method used for *in vivo* determination of CSF volume was validated in a previous study by measurement of known volumes and reliable duplication with repeated measurement. Although the volume measured included the cauda equina, this contributes only about 15% of the total volume of the dural sack at this level.[23]

Consequently, uncertainty introduced by a variable nerve root volume should be a relatively small factor.

Our findings help explain the unpredictability of spinal anesthesia in clinical practice and provide valuable insight into mechanisms of spinal anesthesia. However, these findings will probably not be helpful for guiding clinical practice because CSF volume is not measured before anesthesia, is highly variable, and is not easily predicted by patient characteristics. Lumbosacral CSF volume has been shown to correlate with body mass index[18]; however, the correlation is relatively poor (R = 0.4) and, therefore, insufficient to reliably predict CSF volume. Because CSF volume is not easily measured; cannot be predicted by age, height, body mass index, or other readily available patient characteristics; and varies widely among individuals, our results cannot be expected to improve the ability to predict the spread or duration of spinal anesthesia in clinical practice.

In conclusion, variations in lumbosacral volume of CSF largely explain variability in the extent of the spread and duration of spinal anesthesia. Because CSF volume cannot be readily predicted, uncertainty in the extent and duration of spinal anesthesia is inevitable after intrathecal injection of a single local anesthetic dose.

References

1. Chamberlain DP, Chamberlain BDL: Changes in the skin temperature of the trunk and their relationship to sympathetic blockade during spinal anesthesia. ANESTHESIOLOGY 1986; 65:139–43

2. Moore DC, Chadwick HS, Ready LB: Epinephrine prolongs lidocaine spinal: Pain in the operative site is the most accurate method of determining local anesthetic duration. ANESTHESIOLOGY 1987; 67:416–8

3. Taivainen TR, Tuominen MK, Kuulasmaa KA, Rosenberg PH: A prospective study on reproducibility of the spread of spinal anesthesia using plain 0.5% bupivacain. Reg Anesth 1990; 15:12–4

4. Tuominen M, Kuulasmaa K, Taivainen T, Rosenberg PH: Individual predictability of repeated spinal anaesthesia with isobaric bupivacaine. Acta Anaesthesiol Scand 1989; 33:13–4

5. Tuominen M, Pitkanen M, Taivainen T, Rosenberg PH: Prediction of the spread of repeated spinal anaesthesia with bupivacaine. Br J Anaesth 1992; 68:136–8

6. Anker-Møller E, Spangsberg N, Christensen EF, Schultz P, Dyring S, Wernberg M: Variation in spinal analgesia with plain bupivacain 0.5% when repeated in the same patient. Acta Anaesthesiol Scand 1991; 35:660–3

7. Greene NM: Distribution of local anesthetic solutions within the subarachnoid space. Anesth Analg 1985; 64:715–30

8. Stienstra R, Greene NM. Factors affecting the subarachnoid spread of local anesthetic solutions. Reg Anesth 1991; 16:1–6

9. Moore DC: Factors influencing spinal anesthesia. Reg Anesth 1982; 7:20–5

10. Taivainen T, Tuominen M, Rosenberg PH: Influence of obesity

on the spread of spinal analgesia after injection of plain 0.5% bupivacaine at the L3–4 or L4–5 interspace. Br J Anaesth 1990; 64:542–6

11. Pitkänen MT: Body mass and spread of spinal anesthesia with bupivacain. Anesth Analg 1987; 66:127–31

12. McCulloch WJ, Littlewood DG: Influence of obesity on spinal analgesia with isobaric 0.5% bupivacaine. Br J Anaesth 1986; 58:610–4

13. Pitkänen M, Haapaniemi L, Tuominen M, Rosenberg PH: Influence of age on spinal anaesthesia with isobaric 0.5% bupivacaine. Br J Anaesth 1984; 56:279–84

14. Norris MC: Height, weight, and the spread of subarachnoid hyperbaric bupivacaine in the term parturient. Anesth Analg 1988; 67:555–8

15. Watanabe S, Yamaguchi H, Ishizawa Y: Level of spinal anesthesia can be predicted by the cerebrospinal fluid pressure difference between full-flexed and non-full-flexed lateral position. Anesth Analg 1991; 73:391–3

16. Cameron AE, Arnold RW, Choris MW, Jamieson V: Spinal analgesia using bupivacaine 0.5% plain. Variation in the extent of the block with patient age. Anaesthesia 1981; 36:318–22

17. Veering BT, Burm AG, van Kleef JW, Hennis PJ, Spierdijk J: Spinal anesthesia with glucose-free bupivacaine: Effects of age on neural blockade and pharmacokinetics. Anesth Analg 1987; 66:965–70

18. Hogan QH, Prost R, Kulier A, Taylor ML, Liu SS, Mark L: Magnetic resonance imaging of cerebrospinal fluid volume and the influence of body habitus and abdominal pressure. ANESTHESIOLOGY 1996; 84:1341–9

19. Petersen-Felix S, Zbinden AM, Fischer M, Thomson DA: Isoflurane minimum alveolar concentration decreases during anesthesia and surgery. ANESTHESIOLOGY 1993; 79:959–65

20. Chiu AA, Liu S, Carpenter RL, Kasman GS, Pollock JE, Neal JM: The effects of epinephrine on lidocaine spinal anesthesia: A crossover study. Anesth Analg 1995; 80:735–9

21. Nydahl PA, Axelsson K, Hallgren S, Larsson PG, Leissner P, Philipson L: Evaluation of motor blockade by isometric force measurement and electromyographic recording during epidural anaesthesia—A methodological study. Acta Anaesthesiol Scand 1988; 32:477–84

22. Wildsmith JA: Editorial I: Predicting the spread of spinal anaesthesia. Br J Anaesth 1989; 62:353–4

23. Hogan Q: Size of human lower thoracic and lumbosacral nerve roots. ANESTHESIOLOGY 1996; 85:37–42