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Single-operator real-time ultrasound-guidance to aim and insert a lumbar epidural needle
Échoguidage en temps réel par opérateur unique afin d'orienter et d'insérer une aiguille péridurale lombaire

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Abstract

Purpose *In conventional practice of epidural needle placement, determining the interspinous level and choosing the puncture site are based on palpation of anatomical landmarks, which can be difficult with some subjects. Thereafter, the correct passage of the needle towards the epidural space is a blind "feel as you go" method. An aim-and-insert single-operator ultrasound-guided epidural needle placement is described and demonstrated.*

Method *Nineteen subjects undergoing elective Cesarean delivery consented to undergo both a pre-puncture ultrasound scan and real-time paramedian ultrasound-guidance for needle insertion. Following were the study objectives: to measure the success of a combined spinal-epidural needle insertion under real-time guidance, to compare the locations of the chosen interspinous levels as determined by*

both ultrasound and palpation, to measure the change in depth of the epidural space from the skin surface as pressure is applied to the ultrasound transducer, and to investigate the geometric limitations of using a fixed needle guide.

Results *One subject did not participate in the study because pre-puncture ultrasound examination showed unrecognizable bony landmarks. In 18 of 19 subjects, the epidural needle entered the epidural space successfully, as defined by a loss-of-resistance. In two subjects, entry into the epidural space was not achieved despite ultrasound guidance. Eighteen of the 19 interspinous spaces that were identified using palpation were consistent with those determined by ultrasound. The transducer pressure changed the depth of the epidural space by 2.8 mm. The measurements of the insertion lengths corresponded with the geometrical model of the needle guide, but the needle required a larger insertion angle than would be needed without the guide.*

Conclusion *This small study demonstrates the feasibility of the ultrasound-guidance technique. Areas for further development are identified for both ultrasound software and physical design.*

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Résumé

Objectif *Dans le positionnement traditionnel de l'aiguille péridurale, l'identification du niveau interépineux et le choix du site de ponction se fondent sur la palpation de points de repère anatomiques, ce qui peut s'avérer difficile chez certains patients. Par la suite, le passage approprié de l'aiguille vers l'espace péridural est réalisé par une méthode en aveugle sur la base de sensation subjective pendant l'insertion. Nous décrivons et démontrons ici le positionnement d'une aiguille péridurale échoguidée par un opérateur unique en 'ciblant et insérant'.*

Méthode *Dix-neuf patientes subissant un accouchement par césarienne non urgent ont consenti à subir un*

échogramme avant la ponction ainsi qu'un échoguidage paramédian en temps réel pour guider l'insertion de l'aiguille. Les objectifs étaient d'évaluer la réussite d'une insertion en temps réel de l'aiguille rachidienne-péridurale par échoguidage, de comparer les sites des niveaux interépineux retenus par échoguidage ou palpation, de mesurer les changements de profondeur de l'espace péridural depuis la surface de la peau lorsqu'on exerce de la pression sur le capteur ultrasonore, et d'explorer les limites géométriques liées à l'utilisation d'un guide fixe de l'aiguille.

Résultats   *Une patiente n'a pas participé à l'étude en raison de points de repères osseux non reconnaissables découverts pendant l'examen échographique réalisé avant la ponction. Chez 18 des 19 patientes, l'aiguille péridurale a bien été insérée dans l'espace péridural tel que défini par une perte de résistance. Chez deux patientes, malgré l'échoguidage, l'entrée dans l'espace péridural n'a pas réussi. Dix-huit des 19 identifications de l'espace interépineux par palpation étaient semblables à celles obtenues par échoguidage. La pression du capteur a modifié la profondeur de 2,8 mm. Les mesures des longueurs d'insertion correspondaient au modèle géométrique du guide d'aiguille, mais l'aiguille a nécessité un angle d'insertion plus large que sans guide.*

Conclusion   *Cette petite étude démontre la faisabilité de la technique échoguidée. Différents domaines où des développements futurs sont possibles sont présentés aussi bien pour les logiciels d'échoguidage que pour la conception physique.*

Epidural needle placement is performed most commonly using an anatomical landmark-based technique for identifying the chosen intervertebral level and site of insertion. This procedure can be difficult for some subjects, such as the obese. Typically, needle insertion is performed using the loss-of-resistance to saline/air, which is a "feel as you go" method to ensure a proper track toward the ligamentum flavum and epidural space. Loss-of-resistance to saline/air is the gold standard method for identifying entry into the epidural space.[1]

Ultrasound pre-puncture scanning can identify the intervertebral level[2,3] and the midline. As a means to improve successful placement, it can also provide information about best angle, direction of approach, and depth to the epidural space.[4-7] The ultimate goal is to plan the trajectory of the needle to achieve successful needle placement in one single attempt without redirections. This is true for both epidural and combined spinal-epidural (CSE) anesthesia. For simplicity in this article, we use the term epidural needle insertion for both cases, although small differences exist as explained in the methods.

In their efforts to achieve the ultimate goal, investigators have described a two-operator real-time ultrasound-guided technique of epidural needle placement.[8,9] In this scenario, one operator would perform a midline epidural needle insertion while observing its entry into the epidural space on a paramedian ultrasound image from a second operator. A single-operator in-plane ultrasound-guided epidural needle insertion method has been described,[10] but it is a free-hand ultrasound technique, i.e., the needle trajectory cannot be superimposed on the ultrasound image for planning before insertion. The free-hand technique allows flexibility in scanning but requires considerable operator expertise.[11] A fixed needle angle facilitates pre-puncture determination of the depth of the needle insertion from a simple measurement along this path, as shown in the ultrasound image as a superimposed line. This superimposed needle trajectory line also helps the anesthesiologist to choose a needle insertion site and angle suitable for a direct path toward the epidural space.

Herein, we present the findings of a single-arm prospective observational cohort study of a systematic method both for ultrasound pre-puncture scanning to identify the lumbar level for selection of the puncture site and for real-time guidance of needle insertion. The primary objective was to determine the feasibility and practicality of performing this aim-and-insert technique with a single operator. Secondary objectives were to compare ultrasound and palpation-based identification of intervertebral space count, to study the effect of transducer pressure on measured distances in the lumbar paramedian plane, to compare the straight-down depth to the epidural space with the diagonal needle trajectory and the relationship to the needle guide geometry, and, finally, to compare the site of insertion selected in the pre-puncture examination with the actual insertion site. We expected the secondary objectives would provide insight into potential limitations of the proposed method.

Methods

Subject selection

This study was approved by the Children and Women's Health Centre of British Columbia and the University of British Columbia's clinical research ethics boards (CW05-0262 / H05-70409). The subjects were recruited throughout March 2008 to May 2008 using informed written consent. Exclusion criteria included the inability to speak English and the standard contraindications for spinal anesthesia. The subjects' age, weight, and height were collected and the body mass index was calculated. As this is a feasibility study, test subjects were those scheduled for Cesarean

delivery so that labour pains did not disrupt the time or subject stability needed to learn the new technique. A CSE procedure was used for such subject. A sample size of 20 was chosen because a minimum of ten subjects was found to give an 85% success rate[4] for other ultrasound guidance studies, and given the nature of our study, we recruited 20 subjects to allow for a more robust statistical analysis.

One sonographer performed all pre-puncture measurements for consistency, and one experienced anesthesiologist (A.K.) performed all epidural needle insertions using ultrasound guidance. All complications were recorded during the course of the procedure (insufficient spinal block, failure to obtain loss-of-resistance, paresthesia, failure to obtain cerebrospinal fluid (CSF) aspirations, and patient discomfort).

Intervertebral level identification

In the pre-surgical assessment area, the anesthesiologist identified and marked the lumbar interspaces, L2-3 and L3-4, using traditional palpation-based techniques and Tuffier's line.[12]

Using our designed systematic approach described below, the sonographer (V.L.) also identified and marked the L2-3 and L3-4 interspaces using a curvilinear 1-5 MHz ultrasound transducer (Model C5-1/60) (Ultrasonix Medical Corporation, Richmond, BC, Canada).

First, with each subject placed in the sitting position, the transducer was placed (with the top of the transducer oriented cephalad) on the subject's back, 5-10 cm lateral to the midline where the 12th rib could be seen ultrasonically superficial to the kidney. Next, the 12th rib was followed medially where the transverse process of L1 could be seen to arise 3-5 cm from the midline, and then the transducer was moved caudad parallel to the midline. The transverse processes (Figure 1a) of L2 to L5 could be identified, and the acoustic shadows appeared like fingers. On moving the transducer medially while maintaining the same orientation, the transverse processes became less defined and were replaced by a wider shadow. This shadow was the intervertebral facet joint (Figure 1b), which looked like a thumb. More medially, the facet joint shadow diminished and a deeper flatter "wavy" pattern was seen (Figure 1c). This was the laminae, situated where the intervertebral spaces were seen as gaps in the wavy line. Next, the transducer was positioned immediately paramedian to the midline spinous processes. By gently angling the transducer towards the midline by 5-10°, the ultrasound beam could be directed at the base of the spinous process where it intersected with the laminae. This technique enabled better definition of the laminae, the foramina, and the ligamentum flavum/dura mater complex (seen as a small white line deep to the foramina) (Figure 1c). This paramedian plane
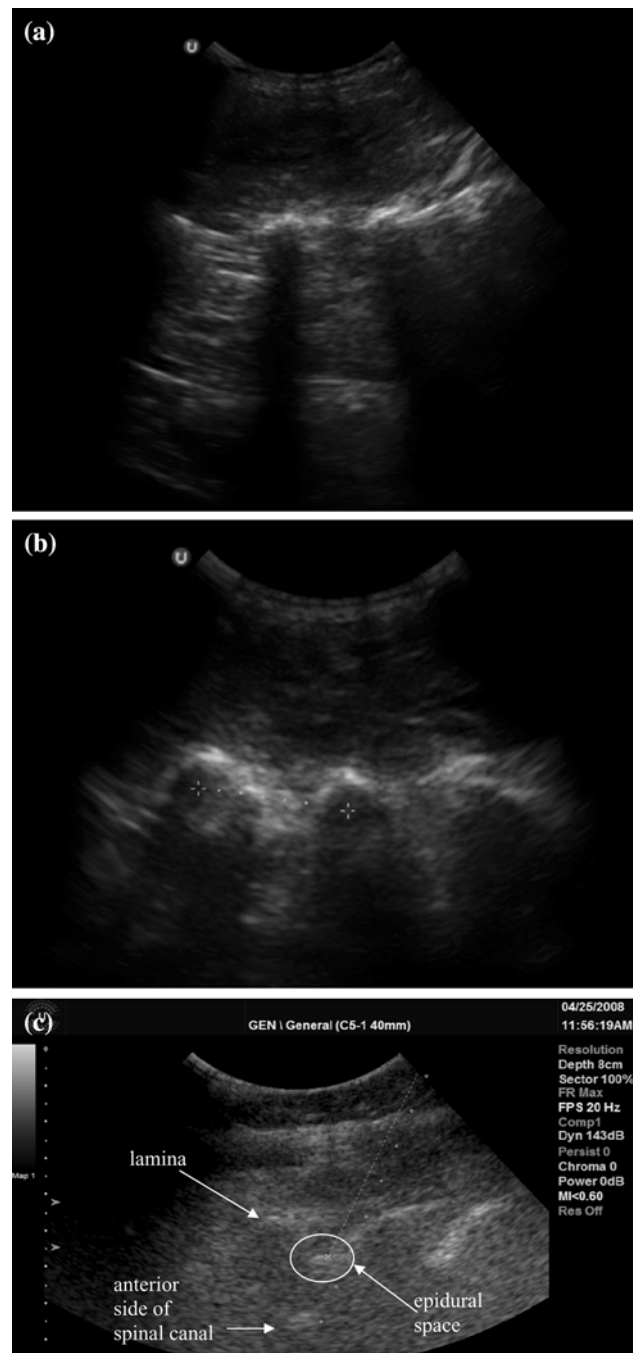

Fig. 1 a Transverse processes (finger-like appearance), **b** facet joints (thumb-like appearance) with the interfacet distance measurement taken from the centre of one facet to the centre of the neighbouring facet, **c** ultrasound image with dashed needle guide line representing the predicted needle path. The wave-like structures are the laminae, and the ligamentum flavum can be seen as a bright reflector at the base of the laminae with the epidural space underneath. The needle guide line is aimed at the visible portion of the ligamentum flavum. Each large white dot represents a 10 mm marking

provided the optimum window for ultrasound images of the lumbar anatomy.[13] The L3-4 vertebral interspace generally was situated directly medial to the L4 transverse process.

The differences between the anesthesiologist's landmarks and the ultrasound skin surface marks were measured using a flexible millimetric ruler. If the difference was greater than one full interfacet distance, it was considered a misidentification of the intervertebral level by the landmark technique, as interspace identification by ultrasound has been shown to be more reliable.[3] Ultrasound remains a more reliable count than palpation, although sometimes it is incorrect in identifying the intervertebral space count (inaccurate by one space in 14.7% of cases). The measurement of the intervertebral spacing (Figure 1b) was calculated as the distance between the facets of L2-3 and L3-4 as measured with ultrasound using software callipers. The difference between the left and right facets of L2-3 and L3-4 were also used to assess the possibility of scoliosis.

Geometric measurement for aim-and-insert technique

A needle guide bracket (Ultrasonix Corp., Richmond, BC, Canada) for the curvilinear 1-5 MHz transducer was mounted (Figure 2). The needle guide sets the needle angle β (as defined in Figure 3) to 23° with respect to the transducer centreline.

Careful analysis of the geometric measurements was required in terms of the use of the needle guide and the compression of tissue by the ultrasound transducer. With the transducer perpendicular to the skin surface, the depth to the epidural space (distance E in Figure 4) was measured when no pressure was applied to the ultrasound transducer, and the depth to the epidural space was measured again
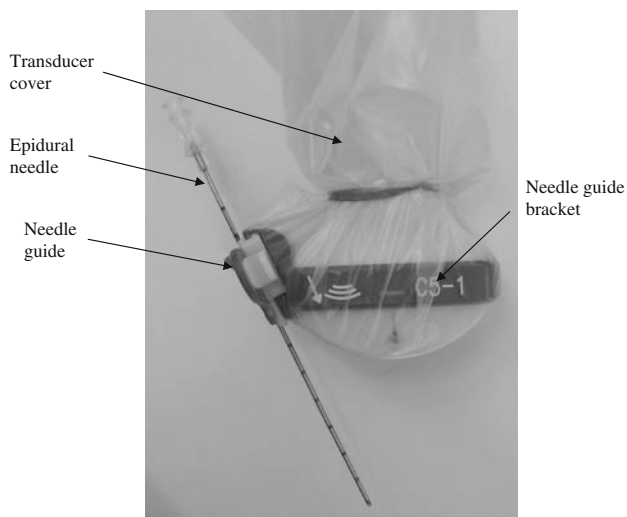

Fig. 2 Assembled sterile transducer with needle guide and epidural needle attached, showing top view. The needle bracket is attached to the ultrasound transducer and the needle guide is attached to the bracket. The epidural needle is then mounted on the needle guide at an angle of 23° with respect to the ultrasound transducer

with a typical contact pressure required by an experienced sonographer (V.L.) to achieve an adequate image. The distance A is the distance between (1) the mark that the centre of the transducer made in the pre-puncture examination (where the needle guide line is aligned with the epidural space) and (2) the actual needle insertion site.

The depiction of the expected needle trajectory was superimposed digitally as a dashed line on the ultrasound image. The transducer was repositioned so the expected needle path echoed the targeted epidural space while ensuring that the bottom of the needle guide apparatus rested on the skin surface. This involved aiming the transducer slightly cephalad by an angle α while maintaining the same scanning plane (Figure 4). Distance B, the diagonal ultrasound-measured needle depth along the guide line, was measured by the software callipers and recorded. The total length required for needle insertion was the ultrasound-measured needle depth, plus the fixed length of the guide (31.9 mm), plus the blind region (8.7 mm), i.e., distances B + D + C, respectively.

As shown in Figures 3 and 4, the distances B, C, E and angles α, β are related geometrically by

$$\cos(\alpha + \beta) = \frac{E}{B + C} \tag{1}$$

or

$$B = \frac{E}{\cos(\alpha + \beta)} - C \tag{2}$$

where the measurement of C is 8.7 mm; α is the 15° transducer tilting angle (the approximate transducer angle so the needle guide touches the subject's skin); and β is the 23° angle of the needle relative to the transducer. Then, eq. 2 can be written as

$$B = 1.27E - 8.7mm \tag{3}$$

The anesthesiologist then marked the vertical and central plane of the ideal transducer position on the subject's skin (Figure 5). These marks were used later for faster placement of the ultrasound transducer at the correct level in the operating room where less time is available for scanning.

Needle insertion and block procedure

The second part of the experiment was conducted in the operating room. Standard aseptic methods were used, i.e., use of a sterile transducer cover (Cone Instruments, Solon, OH, USA) and a sterile disposable needle guide (Protek Medical Products, Coralville, IA, USA). The skin and subcutaneous tissues were anesthesized at the predicted needle insertion site, about 30-40 mm (distance A) below the felt-tipped pen mark corresponding to the centre of the

Fig. 3 Schematic of probe and needle guide geometry, viewed from the side. The distance A is the distance from the felt tip pen mark, indicating the centre of the ultrasound transducer when it is properly positioned for needle insertion in the surgery preparation room, with the needle guide line aligned with the epidural space. The distance B is the distance seen on the ultrasound image along the needle guide line that extends from the ligamentum flavum to the edge of the image
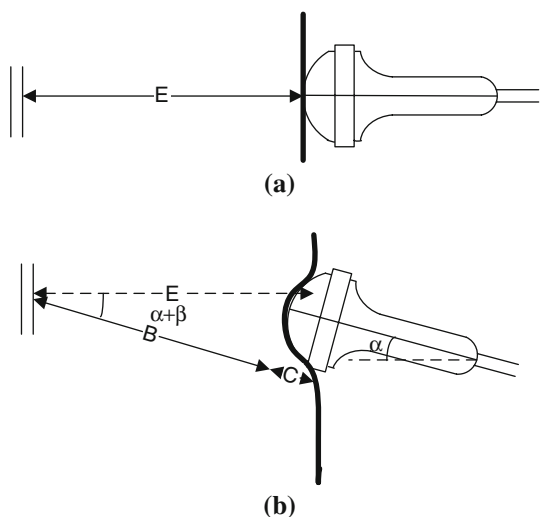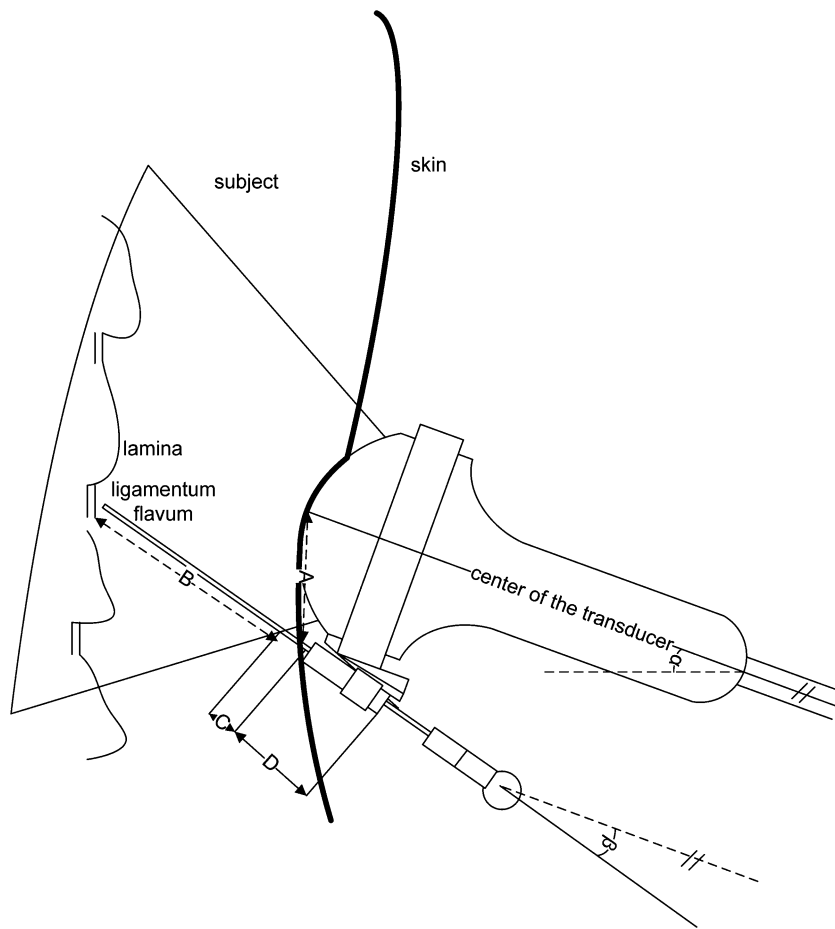
Fig. 4 Geometry showing the measurement of epidural space depth **a** straight down (distance E) and **b** the measurement along the diagonal needle guide line (distance B) where there is a need to angle the transducer by an angle α accounting for tissue deformation at the transducer location and a needle angle β with respect to the transducer axis
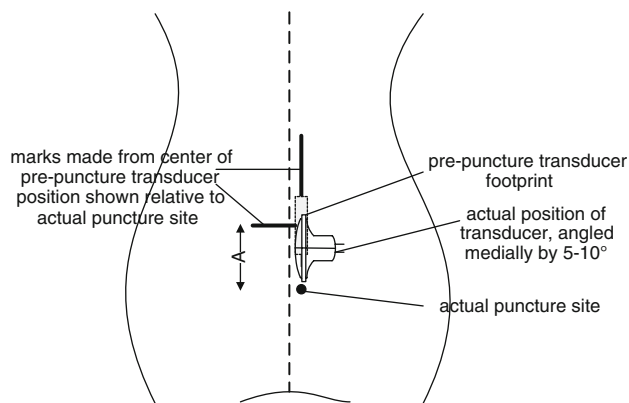
Fig. 5 Schematic of measured distance A, viewed from the back

transducer (Figure 5). The ultrasound transducer was placed on the previously marked locations and was positioned and angled so that the superimposed needle trajectory guide line was aimed at the epidural space on the ultrasound image. A 125 mm New Gertie Marx® CSE-Set epidural needle (IMD Incorporated, Huntsville, UT, USA)

was inserted in-plane with the paramedian plane of the ultrasound. The epidural needle was used because it is more rigid than the spinal needle and, consequently, the actual needle path would follow more closely the predetermined needle path on the ultrasound image. Using this arrangement, the needle could be observed during the entire course of the insertion. Care was taken to ensure that the predicted needle path that was superimposed on the scanned image targeted the epidural space throughout the procedure. With the stylet remaining inside the shaft, the epidural needle was inserted until the tip was seen to be approximately 10 mm away from the expected position of the epidural space. Then, a saline-filled syringe was mounted on the epidural needle, and loss-of-resistance to saline was used to advance the needle through the ligamentum flavum and into the epidural space. To avoid degrading the ultrasound image, care was taken not to inject saline until the needle was about 10 mm from the ligamentum flavum. This is the aim-and-insert technique. Although this study used a CSE, it is expected that the success or failure of single-operator ultrasound guidance would also apply to epidural needle insertion.

The endpoint for a successful procedure under ultrasound guidance is defined as a loss-of-resistance permitting either successful anesthesia or a successful threading of a catheter. A spinal neuraxial block is our standard for elective Cesarean delivery. The spinal anesthesia is then injected into the subarachnoid space. In case of absence of cerebrospinal fluid (CSF), an epidural catheter would be threaded into the epidural space to confirm successful epidural placement of the needle. Then, a standard midline spinal needle insertion would be performed to administer the spinal anesthesia. For regional anesthesia for Cesarean delivery, spinal anesthesia was used to deliver intrathecal hyperbaric bupivacaine (12 mg), fentanyl (10 μg), and morphine (100 μg). Successful subarachnoid block was verified through the standard tests for Cesarean delivery (ice at T4 and pin prick at T6).

Statistical analysis

The Bland-Altman analysis was used to compare the measurement of the actual distance B with the distance B calculated in eq. 3 using the measurement of distance E. The 95% limits of agreement are between 95% of the actual distance B and the calculated distance B according to eq. 3.

Results

Twenty subjects gave written consent; however, one subject did not participate in the study due to unrecognizable bony landmarks. The participating subjects ($n = 19$) were aged 35 ± 5.3 yr, weighed 80.3 ± 13.2 kg, were 160.0 ± 5.6 cm in height, and had a body mass index of 31.5 ± 5.9 kg·m^{-2}. There were 11 obese, five overweight, and three normal subjects (Table 1).

All subjects underwent attempted needle placement using the new real-time ultrasound-guided single-operator aim-and-insert technique. In 18 of the 19 subjects, the epidural needle was successfully guided into the epidural space, as defined by good loss-of-resistance. In one subject (subject 9), loss-of-resistance to saline could not be elicited despite good ultrasound and needle views. There was CSF aspiration in 14 of the 18 subjects confirming that the spinal needle had passed through the epidural space, giving further evidence, though no guarantee, that the needle tip was in the epidural space. In the four subjects with no CSF aspiration, a catheter was threaded easily into the epidural space. Spinal anesthesia provided a satisfactory block in all 18 subjects.

Table 2 shows the differences in measurements between the interspaces identified by palpation and the interspaces identified by ultrasound. In two subjects (subjects 5 and 7), a difference of 25 mm was found. The magnitude of this difference was compared with the respective interfacet distances. The differences for subject 5 (24.1 mm interfacet distance) and subject 7 (23.7 mm interfacet distance) were considered to be miscounts of intervertebral level.

The ultrasound-measured epidural space depths E (Figure 4), with and without contact pressure, were compared in 17 of the 19 subjects. These measurements were not obtained from two of the subjects due to time constraints in the preparation room. The average difference was 2.8 (SD 1.1) mm, and the 95% limits of agreement were 0.4 mm to 5.2 mm according to Bland-Altman analysis.

The measured diagonal distance B ($n = 15$) is compared with the distance B calculated from the measurement of E in eq. 3, and the Bland-Altman plot is shown in Figure 6. The bias is 0.8 mm and the 95% limits of agreement are -4.7 mm to 6.4 mm.

The distance A ($n = 13$), the distance between the actual insertion point and the mark of the middle of the transducer at the pre-puncture examination (Figure 5), is 34 (SD 6) mm on average, with the values ranging from 25 mm to 45 mm. The actual measurement of this distance (Figure 2) from the middle of the transducer to the tip of the needle guide is 35 mm, which agrees closely with the average of 34 mm.

Discussion

This study demonstrates that a single-operator aim-and-insert real-time ultrasound-guided lumbar paramedian epidural technique is feasible, with success achieved in 18

Table 1 Subject biometrics and comments

Subject	Age (yr)	Weight (kg)	Height (cm)	Epidural space: LOR obtained with ultrasound guidance	Comments about success of overall procedure
1	33	59	157	Yes	
2	31	80	155	Yes	
3	43	98	163	Yes	
4	36	93	157	Yes	
5	26	61	163	Yes	
6	41	95	158	Yes	
7	27	99	156	Yes	
8	41	65	161	Yes	
9	25	74	161	No	Loss-of-resistance to saline could not be elicited
10	36	82	160	Yes	
11	33	94	169	Yes	No CSF aspirated, epidural catheter passed, midline spinal performed for Cesarean
12	40	80	170	Yes	
13	41	78	156	Yes	
14	33	80	165	Yes	No CSF aspirated, epidural catheter passed, midline spinal performed for Cesarean
15	37	83	155	Yes	No CSF aspirated, epidural catheter passed, midline spinal performed for Cesarean
16	37	95	150	Yes	
17	37	79	159	Yes	No CSF aspirated, epidural catheter passed, midline spinal performed for Cesarean
18	30	57	155	Yes	
19	31	73	170	Yes	

LOR = loss of resistance; CSF = cerebrospinal fluid

of the 19 subjects. The one failure occurred within the first ten trials, whereas the latter cases were viewed as being considerably smoother and faster, as the operator (anesthesiologist) became increasingly familiar with the technique. We chose loss-of-resistance as the endpoint, similar to previous studies on ultrasound guidance. We used the presence of CSF or insertion of the catheter as additional evidence that the needle reached its target, but, admittedly, these are not perfect measures of successful placement. Our rates of absence of CSF in subjects where loss-of-resistance was felt (4/18) were comparable with previous studies, with the added difficulty of performing the needle-through-needle technique in the paramedian plane.[14] In previous studies, CSEs using a Tuohy epidural needle were noted as having similar rates of failure, i.e., 16%,[15] 25%,[16] and 18%[10] rates of absence of CSF aspirations were reported.

By using a fixed guided needle instead of a free-hand technique, the described technique has the advantage of being performed by a single operator. The fixed needle guide allows the needle to be held in the plane of the ultrasound image and allows the operator to release her/his grip on the needle momentarily without losing its alignment in the plane. Conversely, the free-hand technique requires more operator expertise to see the needle tip in the ultrasound image.[17]

In our study, identification of the interspace level by palpation rather than by ultrasound differed in only two of the 19 subjects. However, since previous studies[3] have suggested that palpation misidentifies the actual space in 58% of the cases, it is recommended that ultrasound guidance continue being used.[3]

In our study, the curved shape of the transducer and the size of footprint presented three practical problems. First, with the subject sitting flexed forward, a better image was obtained by pressing the transducer onto the skin surface rather than resting it lightly. This aspect caused a difference in depth to the epidural space of approximately 2.8 mm. A less curved transducer shape with better skin contact enabling light pressure should reduce this practical error.

Second, our projected needle tract was substantially longer than the more direct midline trajectory used in the

Table 2 Palpation compared with ultrasound: difference (mm) between the anesthesiologist's mark and the sonographer's mark. Data missing due to time constraints are labelled "n/a"

Subject	Difference (mm)	Associated interfacet distance (mm)
1	0	31.5
2	15	27.4
3	0	31.6
4	0	28.7
5	25 (different level)	24.2
6	17.5	27.5
7	25 (different level)	23.7
8	15	27.5
9	10	27.7
10	0	36.6
11	2.5	31
12	2.5	32.6
13	0	32.2
14	7.5	28.0
15	2.5	25.8
16	0	36.5
17	0	29.8
18	10	n/a
19	9	24.1

Fig. 6 Bland-Altman plot of the measured distance B *vs* the distance B calculated by eq. 3, i.e. the predicted distance B

blind technique, as suggested by the 27% longer distance B than distance E in equation. 3. Our measured skin-to-epidural space distance was 88-111 mm, requiring the use of a long 125 mm New Gertie Marx® CSE-Set epidural needle. Future developments will require a transducer with a smaller footprint to reduce the track distance through the subject's tissues.

Third, distance A, the vertical distance between the mark made from the centre of the transducer face during the pre-puncture scan and the actual puncture site, (Figure 3) is 34 mm on average, ranging from 25-45 mm. The magnitude of this distance is important because the puncture site is 35 mm below the desired intervertebral space. This situation necessitates the choice of L2-3 instead of L3-4 to avoid contact with the pelvic bones, and it is entirely due to the limitation of the size of the transducer held parallel to the midline for real-time scanning.

Also, the variability of distance A shows that the pre-puncture ultrasound is useful, but, ultimately, only real-time guidance can ensure the best site and angles, as the transducer position found in the surgical preparation room differs slightly (up to 10 mm) from the position found in the operating room. We believe the pre-puncture ultrasound gives the anesthesiologist time to mark the approximate location of the transducer and to become familiarized, thus saving time in the operating room.
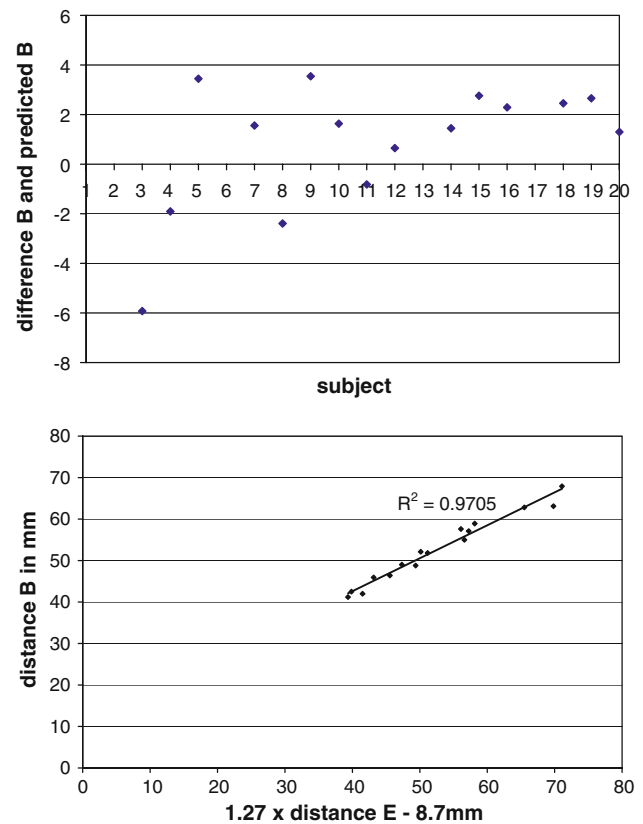
The current protocol requires extra equipment (125 mm CSE set, probe cover, biopsy needle guide, biopsy bracket, ultrasound machine, and curvilinear transducer), additional work for the nurse and the anesthesiologist (the ultrasound transducer must be covered by the sterile cover, and the sterile biopsy guide must be attached prior to the procedure), and extra time for the pre-puncture orientation and skin marking. The extra time may be mitigated by a reduction in the number of needle insertion attempts. Also, as the injection of saline into the subcutaneous tissues obscures the image, the anesthesiologist should minimize the amount of saline injected prior to the needle approaching the ligamentum flavum.

In conclusion, in 18 of the 19 subjects (including obese and overweight subjects), a real-time aim-and-insert ultrasound-guided epidural needle insertion was successfully performed by a single operator. This technique involved a systematic approach for both a pre-puncture scan and ultrasound guidance during needle insertion. Several limitations were also described, mostly related to the needle guide geometry. Current efforts are now underway to design a specialized transducer and needle guide that will improve the clinical practicality of a real-time aim-and-insert ultrasound-guided epidural needle insertion technique.

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