CME Factors Affecting the Distribution of Neural Blockade by Local Anesthetics in Epidural Anesthesia and a Comparison of Lumbar Versus Thoracic Epidural Anesthesia

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The spread of sensory blockade after epidural injection of a specific dose of local anesthetic (LA) differs considerably among individuals, and the factors affecting this distribution remain the subject of debate. Based on the results of recent investigations regarding the distribution of epidural neural blockade, specifically for thoracic epidural anesthesia, we noted that the total mass of LA appears to be the most important factor in determining the extent of sensory, sympathetic, and motor neural blockade, whereas the site of epidural needle/catheter placement governs the pattern of distribution of blockade relative to the injection site. Age may be positively correlated with the spread of sensory blockade, and the evidence is somewhat stronger for thoracic than for lumbar epidural anesthesia. Other patient characteristics and technical details, such as patient position, and mode and speed of injection, exert only a small effect on the distribution of sensory blockade, or their effects are equivocal. However, combinations of several patient and technical factors may aid in predicting LA dose requirements. Based on these results, we have also formulated suggested epidural insertion sites that may optimize both analgesia and sympathicolysis for various surgical indications.

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The spread of sensory blockade after epidural injection of a specific dose of local anesthetic (LA) differs considerably among individuals, and the factors affecting this distribution remain the subject of debate. Reviews on the subject date back two decades or more.[1,2] A systematic review of recent investigations may provide new insights into factors that affect the spread of epidural blockade, especially for thoracic epidural anesthesia, and may aid in delivering predictable and safe epidural anesthesia.

Although previous reviews have focused primarily on lumbar epidural anesthesia, the practice of thoracic epidural anesthesia has increased tremendously over the last decade.[3,4] Differences in anatomy, physiology, and techniques to identify the epidural space make extrapolation of data for predicting spread of anesthesia gathered during lumbar epidural anesthesia to thoracic epidural anesthesia problematic. This article reviews recent investigations regarding the distribution of neural blockade, specifically for thoracic epidural anesthesia and, where possible, draws results from research regarding lumbar epidural anesthesia.

For the purpose of this review, we will consider C7–T2 as high-thoracic, T2–6 as mid-thoracic, and T6–L1 as low-thoracic. This classification reflects the different fields of surgery for which these epidural sites are typically used (cardiac, thoracic and abdominal surgery, respectively). In addition, most studies mentioned in this article have used either LA, or contrast medium, or both, to study the distribution of epidural anesthesia. However, it should be noted that the findings based on the use of contrast medium may not always be congruent to epidural spread of LA.[1,5,6] Although this review will focus on distribution of sensory neural blockade, distribution of sympathetic and motor neural blockade will be briefly discussed.

A comprehensive description of epidural anatomy is beyond the scope of this article. The reader is referred to several excellent reviews.[7–10] In addition, methods used to test sensory block have been reviewed elsewhere.[11] These methods can be categorized as either qualitative (normal or abolished response to the application of stimuli such as cold or pinprick) or quantitative (e.g., pain on electrical stimulation with increasing current). It should be noted that

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studies mentioned in this review have used different modes of sensory testing, and that demonstration of blockade using qualitative testing does not guarantee adequate anesthesia. It should also be noted that, in general, surgical anesthesia has been the focus of investigations concerning bolus doses of LA, whereas postoperative analgesia has been the focus in evaluations regarding continuous infusions.

FACTORS AFFECTING THE DISTRIBUTION OF EPIDURAL NEURAL BLOCKADE

Patient Characteristics

Many studies have investigated patient characteristics to determine differences in spread of neural blockade in epidural anesthesia. Although different factors are examined separately in this review, multivariable analysis has shown that consideration of multiple patient characteristics may better reflect the cross-dependencies, and lead to a more accurate estimate of anesthetic requirements.[12]

Age

From the 1960s onward, the clinical impression that spread of epidural blockade may be greater in elderly patients has spawned a host of studies investigating this subject. In lumbar epidural anesthesia, Bromage was the first to report a strong correlation between patient age and the epidural segmental dose requirements.[13] However, the validity of these findings has been questioned, as the assumption of linearity between LA dose and extent of anesthesia has later been proven to be a fallacy (see below).[1] Nevertheless, since then, several authors have reported sensory blocks with maximum cephalad spread 3–8 segments higher in patients >60-yr old compared to patients <40-yr old after injection of the same epidural dose of LA.[14–17] A linear relationship between age and spread of blockade is stronger when using volumes up to 10 mL compared to the 10–20 mL range[14,18] and in patients younger than 40 yr, compared to patients over 40-yr old.[12,14] In a study comparing the spread of sensory blockade in high-thoracic, mid-thoracic and lumbar epidural anesthesia, correlation coefficients of spread with age in these three regions were reported to be 0.58, 0.38, and 0.82, respectively.[19] In contrast, other studies have reported either no effect of age on epidural spread,[20–22] or statistically significant, but small correlation coefficients, with differences in spread of sensory blockade that may not be clinically important.[18,23–26]

In contrast with the conflicting reports on lumbar epidural anesthesia, the few studies investigating the effects of age on epidural spread in thoracic epidural anesthesia all suggest a positive correlation between age and spread of blockade. The epidural dose requirement in the elderly (60–79 yr) was demonstrated to be about 40% less than in young adults (20–39 yr).[27] This study demonstrated a correlation coefficient between age and epidural dose requirement of −0.70 (Fig. 1). Low thoracic epidural test doses of lidocaine 2%, 5 and 8 mL, resulted in greater extent of blockade, smaller segmental dose requirements and an increased incidence of hemodynamic instability in patients aged 56–80 yr compared to patients aged 18–51 yr.[28] Furthermore, positive correlation of thoracic epidural spread of contrast medium with the patient's age has been reported.[29,30]

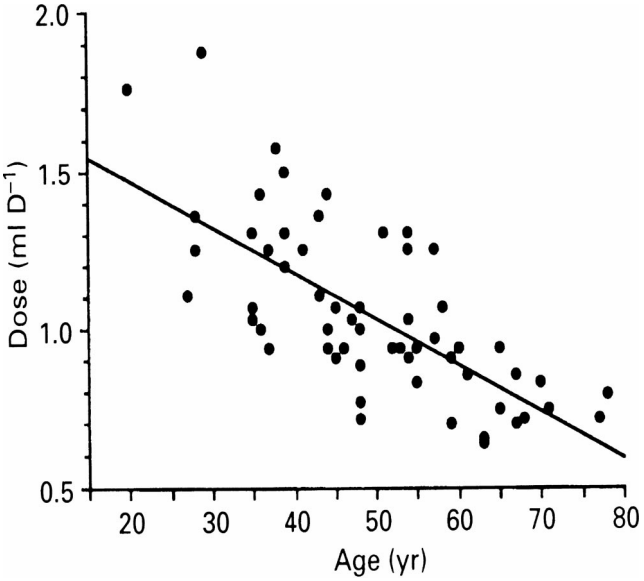

Figure 1. Relationship between age and epidural dose requirement of 2% mepivacaine in thoracic (T9–10) epidural anesthesia ($r = 0.70$, $P < 0.001$, $n = 62$). D = Dermatome. [27]

The mechanism for a positive correlation reported by several investigators between age and spread of blockade remains unclear. Although it has been suggested that this correlation could be explained by decreased leakage of LA through the intervertebral foramina in older patients,[31–34] this has been refuted by others.[30] Alternatively, compliance of the epidural space has been shown to increase with age, and it is positively correlated with spread of sensory blockade.[35] This agrees with the fact that residual pressure after injection of LA is lower in older patients, which, in turn, is associated with wider spread of sensory block.[19] Indeed, it has been demonstrated using epiduroscopy that the epidural space becomes more widely patent after injection of a given amount of air, and the fatty tissue in the epidural space diminishes with increasing age, which may promote the longitudinal spread of LAs in the elderly.[36] Furthermore, with age, the dura becomes more permeable to LA owing to a progressive increase in size and number of arachnoid villi. This provides a large area through which LA can diffuse into the subarachnoid space.[34] Finally, it has been proposed that a decrease in the number of myelinated nerve fibers in the nerve, and a general deterioration of the mucopolysaccharides of the ground substance, allows LA to more easily penetrate nerve roots in older patients.[13,37]

Height

It seems logical to assume that taller patients require more LA to establish a certain level of blockade than shorter subjects. This has been investigated in lumbar

epidural anesthesia, again with conflicting results. Only weak correlation coefficients, ranging from −0.13 to −0.54 have been demonstrated.[18,20,24,38] In thoracic epidural anesthesia, correlation coefficients from −0.25[29] to −0.37[30] have been found between the spread of epidurally injected contrast medium and patient height. To our knowledge, clinical trials evaluating the relationship between height and spread of blockade after epidural administration of LA are lacking in thoracic epidural anesthesia. Therefore, it is not possible to definitively draw conclusions on the significance of patient height in predicting the spread of blockade, except perhaps in extremely short or extremely tall individuals.

Weight and Body Mass Index

Few studies report on the correlation between weight and spread of sensory blockade. In lumbar epidural anesthesia, no correlation was found,[20,22] although a correlation coefficient of 0.41 was demonstrated for the association of body mass index (BMI) with height of sensory block.[20] Weight was not correlated with epidural spread of contrast in thoracic epidural anesthesia.[29]

Apparently, changes that may occur with obesity, such as increased abdominal pressure or increased body fat, are not sufficient to affect the spread of epidural blockade. Indeed, while both weight and BMI are positively correlated with posterior subcutaneous body fat deposition, they are not or only poorly correlated with the amount of posterior epidural fat.[39]

Pregnancy

Due to the lack of studies involving thoracic epidural anesthesia during pregnancy, data on epidural anesthesia in pregnancy concern lumbar epidural anesthesia only. In general, less LA is required to produce a given level of epidural anesthesia in pregnant patients. Engorgement of epidural veins by increased intra-abdominal pressure has often been implied as the mechanism for this phenomenon. Furthermore, both animal[40–42] and clinical studies[43] have shown that during pregnancy, onset of blockade of nerve conduction by LA is faster and blockade is more intense. This may account for the appearance of increased spread of epidural blockade during early pregnancy (8–12 wk) when intra-abdominal pressure is probably still normal, which is similar to that found in pregnant women at term.[44] In contrast, no difference in latency and density of motor and sensory blockade was found when tested with repeated electrical stimulation between pregnant and nonpregnant women receiving lumbar epidural anesthesia.[45] Although cranial extension of blockade was higher in the pregnant group, onset of sensory block in the sacral segments was similar in both groups. In contrast to the general population (see above), epidural LA requirements are further reduced in obese parturients (BMI >30) compared to parturients with BMI ≤30.[46]

Dural Surface Area

It has been demonstrated that the surface area of the lumbosacral dura is correlated with the peak sensory block level in lumbar epidural anesthesia.[47] Although this patient factor may not be clinically useful, future research in this area may further clarify the differences in epidural spread of LAs among patients.

Technical Factors

Choice of Epidural Insertion Site

The length of the lumbar section of the vertebral column is relatively short and the dimensions of the lumbar epidural space are fairly constant. Although statistically significant, only small differences in cranial spread of blockade have been demonstrated after injection of LA at three different lumbar interspaces.[12] In contrast, the thoracic part of the spinal column encompasses more than half the length of the entire spine and adjoins many different anatomical structures and spaces, whereas the thoracic vertebrae and epidural space vary greatly in shape and size. Therefore, it may be speculated that the distribution of neural blockade may vary with the site of epidural injection.

It is alleged that dose requirements are larger in lumbar compared to thoracic epidural anesthesia. Interestingly, while this has also been suggested in several papers,[1,2,18] surprisingly few studies have actually directly compared the differences in spread of blockade between lumbar and thoracic epidural anesthesia. No statistically significant differences in total numbers of segments blocked could be demonstrated after high-thoracic, mid-thoracic, low-thoracic or lumbar epidural injection of contrast medium (Fig. 2).[29,48] Others have reported spread of blockade of 17.3 ± 0.6, 14.3 ± 0.4, and 13.3 ± 0.7 segments after injection of 15 mL of 2% mepivacaine in the cervical, thoracic and lumbar epidural space, respectively.[19] Unfortunately, these data were not statistically analyzed.

Different patterns of sensory blockade were found after a test dose of 3 mL of lidocaine 2% when injected at different sites in the thoracic epidural space. Spread of sensory blockade was primarily caudal after high-thoracic epidural injection, primarily cephalad after low-thoracic injection, and equally distributed caudal and cephalad after mid-thoracic injection (Fig. 2A).[48] These patterns have been confirmed in a series of 90 patients receiving 5 mL of lidocaine 1.5% at vertebral levels ranging from C7 to L5 (Fig. 2B).[29] Differences in epidural pressure (see below), and obstruction of spread of epidural LA by the larger relative volume of the spinal cord and the thecal sac in the cervical and high lumbar areas have been suggested as an explanation for this phenomenon.[48] Also, epiduroscopy has shown that the mid-thoracic epidural space becomes more widely patent after injection of a given amount of air and that the amount of fatty and fibrous tissue is smaller compared to the upper lumbar epidural space.[49] Greater cranial spread (up to C2–3) after epidural injection at the C7–T1 level has been reported when larger doses of LA are being used. However, even in this situation, caudal spread is more extensive

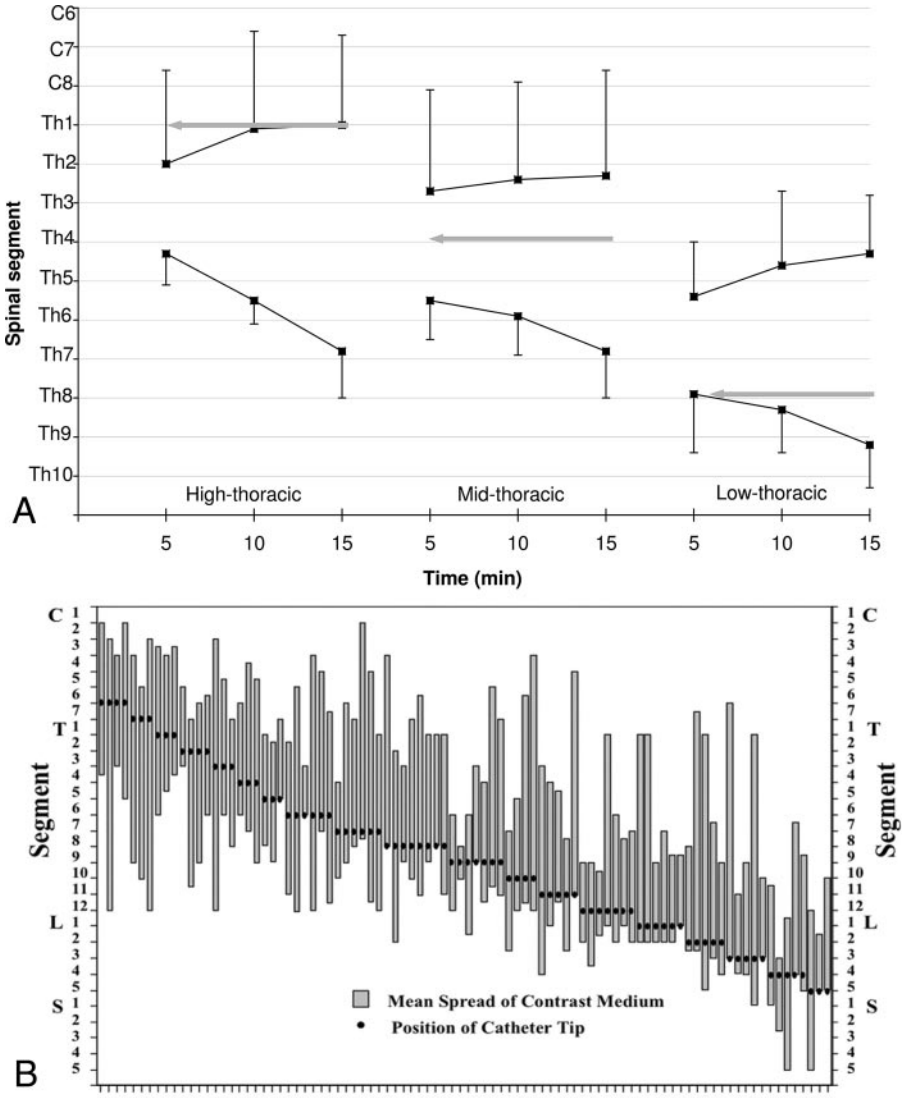

Figure 2. A: Extension of sensory blockade tested by pinprick after administration of 3 mL lidocaine 2% in the high (C7–T2), mid (T2–4) or low (T7–9) thoracic epidural space. Data represent means ± SD. Arrows indicate the level of epidural needle placement. [48] B: Mean contrast spread after injection of 5 mL iotrolan, 240 mg I/mL, in 90 patients. C = cervical segment; L = lumbar segment; S = sacral segment; T = thoracic segment. In this study, there was a strong correlation between radiographic and analgesic spread (r = 0.91–0.97).[29] These figures illustrate two important issues in epidural anesthesia: First, in contrast to common teaching, no statistically significant differences in total number of segments blocked could be demonstrated between patients receiving cervical, high, mid-, or low-thoracic or lumbar epidural injections. Second, the intervertebral level of epidural injection is a statistically significant factor in the distribution of sensory blockade, either in the cranial or caudal direction relative to the injection site.

than cranial spread.[50–52] Despite the differences in spread of blockade in relation to the site of injection, no differences were found in the total number of segments blocked among different regions in the thoracic epidural space,[29,48] indicating that it is safe to use the same initial dose of LA in high-thoracic, mid-thoracic and low-thoracic epidural anesthesia.

Patient Position and Gravity

In lumbar epidural anesthesia, epidural injection of LA with the patient in the lateral position produces sensory block levels approximately 0–3 segments greater on the dependent side compared to injection with the patient in the supine position.[21,53–60] No differences have been reported in maximal cranial spread between groups receiving equal amounts of epidural LA in the sitting or supine position.[21,22,61] Some of these studies report slightly faster onset times in the lateral or sitting positions compared to the supine position.[22,53,54,60]

Head down (Trendelenburg) position of 15° has been shown to result in higher sensory block levels with faster onset times after lumbar epidural injection of LA in pregnant women.[62] There has been one case report in which a high epidural block was diagnosed in an elderly patient, which made mechanical ventilation necessary. This patient had received a continuous epidural infusion through a low-thoracic epidural catheter, while positioned in a 15° head down lithotomy position for 4.5 h.[63]

Once again, studies on the effects of patient position and gravity in thoracic epidural anesthesia are lacking. However, with regard to position only, it has recently been shown that high-thoracic (catheter tip at T1–2) epidural injection of contrast medium with the patient's neck in extension or neutral position results in limited cranial spread, whereas significant cranial spread was observed in patients after injection with the neck flexed.[64]

Needle Direction and Catheter Position

Epidural injection through a Tuohy needle with the bevel oriented to one side[1] or caudal[65,66] has no or only minor effects on the spread of sensory blockade

compared to injection directed cephalad. However, both in lumbar[67,68] and cervical[69] epidural anesthesia, threading an epidural catheter with the Tuohy needle rotated 45° toward the operative side has been shown to produce a preferential distribution of sensory and motor blockade toward this side. In pregnant women, insertion of an epidural catheter with the bevel of the Tuohy needle oriented laterally resulted in greater difficulty passing the catheter and, more frequently, paresthesia.[70] In contrast with the reports mentioned above, no differences were noted in the incidence of asymmetric block.

Orienting the bevel of the Tuohy needle caudad or cranially does not reliably predict final lumbar[71] nor thoracic[48,72,73] epidural catheter position relative to the insertion site. Also, thoracic epidural catheters have been shown to progressively withdraw an average of 1 cm during the first 3 days after insertion.[73] The optimal distance to advance a catheter into the lumbar epidural space is suggested to be 4–6 cm.[74,75] Threading shorter or longer distances may result in inadequate analgesia or increased incidence of venous cannulation and frequency of paresthesias, respectively.[74,75] Fortunately, computed tomography imaging and clinical experience demonstrate that a large variety of lumbar epidural catheter tip positions and solution distribution result in equally satisfactory epidural anesthesia.[76]

Injection Through Needle Versus Injection Through Catheter

Whether injection of LA through a Tuohy needle versus an epidural catheter yields differences in epidural spread remains controversial. Lumbar epidural bolus injection of LA via either a Tuohy needle or a catheter did not result in differences in epidural spread in patients undergoing cesarean delivery[77] or lower extremity surgery.[78] In contrast, injection of 14 mL lidocaine 2% through a lumbar epidural catheter resulted in a spread of sensory blockade four segments greater compared to injection at the same rate through a Tuohy needle.[79] Another study comparing these two modes of injection in pregnant women reported better quality of anesthesia when LA was injected via an epidural catheter.[80] However, injection times differed by a factor of three between groups, which may have affected the results. We are unaware of similar studies in thoracic epidural anesthesia.

Epidural Catheter Design

Epidural catheters may be categorized as either single-orifice or multiorifice designs. *In vitro*, using injection pressures derived from *in vivo* measurements, differential flow has been observed from multiorifice epidural catheters, i.e., the flow appears first at the proximal, then the middle, and finally the distal orifices.[81] With low injection pressures, flow is largest from the proximal orifice, and no flow was observed from the distal orifice, rendering a multiorifice catheter effectively a single-orifice variant.

Comparisons between these two catheter designs are commonly presented as differences in the quality of analgesia, rather than differences in spread of sensory blockade. In this regard, multiorifice catheters have been shown to be superior to single-orifice catheters in obstetric lumbar epidural anesthesia.[82–84] In particular, unilateral analgesia and unblocked segments are reported to occur more frequently when a single-orifice catheter is placed.[84] In contrast, one study did not find any differences in the quality of analgesia between single- and multiorifice catheters.[85] Furthermore, injection of contrast medium resulted in a similar number of segments covered by dye above and below the injection site with both catheter designs.[86] With newer soft-tipped single-orifice catheters, the lower incidence of paresthesias and venous cannulation during placement should be weighed against the higher incidence of inadequate or unilateral analgesia associated with this type of catheter.[87,88] We are unaware of any studies comparing different designs of multiorifice catheters (e.g., longitudinal versus circumferential alignment of orifices).

Fractional Versus Single Bolus Injection

Administration of a specified dose of LA may result in different spread of blockade when injected as a single bolus compared to giving the same dose in smaller fractions.[89] In low-thoracic epidural anesthesia, the effect of timing of fractionated doses of LA on the spread of sensory blockade has been investigated. Administration of two doses of 5 mL of LA with an interval of 5 min produced an epidural block of similar extent as a single injection of 10 mL of LA. However, with an interval of 10 min, the number of segments blocked was smaller compared to the two other modes of injection mentioned.[89] The authors suggested that differences in residual epidural pressures (see below) may explain these differences. Also, prior injection of large volumes (5–10 mL) of saline, e.g., when the loss-of-resistance technique is used, may result in a greater spread of neural blockade after injecting LA.[90] However, this phenomenon has only been observed using mepivacaine 1.5% and not when using mepivacaine 1%, indicating that dilution of the higher concentration by saline may also contribute.[90] Also, this effect is exaggerated when the interval between both injections is short.[91] We are unaware of similar studies in lumbar epidural anesthesia.

Speed of Injection

In lumbar epidural anesthesia, only one study has reported a positive correlation between speed of injection and cranial spread of blockade: Injection through a Tuohy needle of 14 mL lidocaine 2% at a rate of 1.2 mL/s resulted in a spread of sensory blockade four segments greater compared to injection at a rate of

0.24 mL/s.[79] In contrast, rapid injection of mepivacaine 8 mL in 8 s versus 160 s resulted in the same number of dermatomes blocked after 15 min.[92] However, onset of blockade was more rapid in the fast injection group. The number of patients with perineal blockade after 5 min was more than four times higher in the fast injection group compared to the slow injection group. A similar number of dermatomes blocked or maximum cranial level of blockade after 30 min with[66,93] or without faster onset[55] has also been reported by other investigators. Whether speed of injection may exert its effect on the spread of blockade through changes in epidural pressure remains controversial (see below).

Epidural Pressures and Pressures in Adjacent Body Cavities

Epidural Pressures

Pressure gradients within the epidural space, and between this space and adjacent body cavities may play a role in the distribution of LA injected in the thoracic epidural space.[31,48] Since sensory block after both low-thoracic and high-thoracic epidural injection of lidocaine spreads from the site of injection toward the mid-thoracic epidural space,[29,48,64,94] it has been suggested that the latter may harbor a lower pressure.[48] This may facilitate spread of LA toward the mid-thoracic epidural space. Indeed, a small, but statistically significant, difference in epidural pressure has been demonstrated, with the mid-thoracic epidural pressure being slightly lower than the low-thoracic epidural pressure.[95] Also, in this study, subatmospheric pressure was observed more frequently in the mid-thoracic compared to the low-thoracic epidural space. It is difficult to compare studies evaluating epidural pressures because of the many differences in study design, definition of epidural pressure, and lack of homogeneity in the populations studied. It should be noted that debate continues whether epidural pressure is positive or negative (with regard to atmosphere), and whether the pressures reported are true pressures or artifacts.[96] Epidural pressure has been found to be positive by some authors,[95,97–99] but slightly negative by others.[31,96,100,101] In light of the pressures generated by epidural injection,[102] it remains to be investigated whether pressure gradients within the epidural space are sufficient to influence spread of LA. Lumbar epidural pressure after epidural injection of LA may be correlated to the spread of sensory block. However, both positive[19,31,35] and negative[55,102,103] correlations have been reported.

Pressures in Adjacent Body Cavities

Since the epidural space is continuous (or contiguous) with many other body cavities, pressures in these cavities may also influence the spread of sensory blockade. The difference in patency after a given amount of injected air between the thoracic and lumbar epidural spaces, as seen by the epiduroscope, may be influenced by the negative intrapleural and positive intra-abdominal pressures.[36] Increasing airway pressure using a continuous positive airway pressure (CPAP) device increases the number of segments blocked after a low-thoracic epidural injection of lidocaine by 57%, primarily through a more caudad spread of the block.[104] Furthermore, a more cranial extension of sensory blockade was demonstrated after cervico-thoracic (C6–7 or C7–T1) epidural injection of lidocaine in patients breathing on CPAP.[105] Therefore, when airway pressure is increased by the application of CPAP, the distal border of sensory blockade extends further away from the thorax, i.e., more cranially after high-thoracic injection,[105] and more caudad after low-thoracic injection.[104] Although speculative, a similar effect may occur during positive pressure ventilation in anesthetized patients.[104]

Alteration of epidural pressure by CPAP has not been confirmed.[104] Although pneumoperitoneum during laparoscopic procedures[106] and ventilation with positive end-expiratory pressure[107] have been shown to increase epidural pressure, there are no studies that have investigated the effects of these maneuvers on the spread of epidural blockade.

Local Anesthetics

Total Dose, Concentration Versus Volume

Overall, the amount of LA injected influences the spread of epidural blockade. However, the notion that increasing the dose of LA results in a linear increase in the spread of blockade[13] has often been questioned. Although there may be such a linear relationship in patients younger than 40 yr,[14] in patients of 50 yr and older, the relationship between dose and number of segments blocked is dependent on the volume previously injected, i.e., the higher the volume already injected, the higher the dose requirement to block an additional segment (Fig. 3).[14,21,23,108] Indeed, a linear relationship between subsequent segmental dose requirements and dose previously injected has been described.[14,21,108] Given this complex relationship between LA dose and sensory blockade, formulas that have been proposed to predict segmental dose requirements of LA are equally complex.[108] However, simpler formulas derived from cubic polynomial equations have been validated in clinical practice.[109]

Many studies have compared the effects of administering equal doses of LA, in solutions with different concentrations. The conclusion that the same total mass of drug given in different concentrations and volumes produces similar spread of sensory blockade and equally effective analgesia is widely supported in lumbar epidural anesthesia for bolus injections.[2,20,110] In thoracic epidural anesthesia, this has been demonstrated both for single bolus injection[48,111] and for continuous epidural infusion.[112–115] However, some authors have reported cranial block levels 2–4 segments higher with low concentrations compared to higher concentrations of LA, without differences in

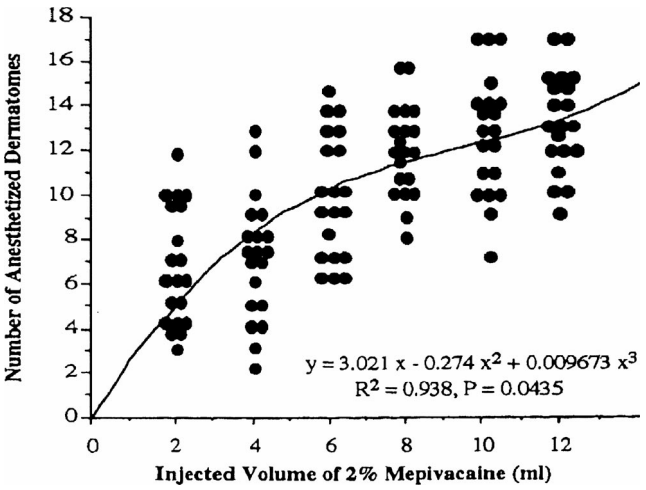

Figure 3. Scattergram and cubic polynomial fit between injected volume of 2% mepivacaine and number of anesthetized dermatomes. This figure illustrates the observation that the spread of epidural anesthesia changes proportionally more after a small volume of local anesthetic is administered than after a larger dose is given.[122]

quality of analgesia or incidence of motor block.[116–119] Others have reported better analgesia with higher volumes of LA.[120] Although administration of the same mass of LAs in different volumes results in similar spread of neural blockade, the intensity of blockade may vary with the concentration of LA. Differences in intensity of sensory blockade using cutaneous electrical stimulation between groups receiving equal amounts of LA in different volumes have both been confirmed[121] and refuted.[119] Most reports on perioperative epidural analgesia using bupivacaine have studied concentrations ranging from 0.1% to 0.5%. Since all studies mentioned above report equally satisfactory analgesia using different combinations of volume and concentration, the potential difference in intensity of blockade appears not to be clinically relevant.

It has been demonstrated that 2% lidocaine diluted with the same volume of saline produces less potent epidural blockade, in terms of number of segments blocked and achievement of perineal blockade, than commercially prepared 1% lidocaine.[122] This may be explained by differences in the concentrations of sodium, chloride, hydroxide, and hydrogen ions.[122]

Additives to Local Anesthetics

Bicarbonate

An increase in pH by adding bicarbonate to a solution of LA results in an increase in the nonionized fraction of the LA and improved nerve penetration.[123,124] Adding bicarbonate increases the pain threshold in blocked dermatomes,[125–127] increases the depth of motor block,[127] and reduces the time to onset of blockade of the first sacral segment.[127] In contrast, spread of sensory blockade as evaluated by pinprick is not affected,[126,127] however, the sample sizes in these studies were based on pain threshold data and may have been too small to demonstrate a difference in spread of blockade.

α_2 Agonists and Opioids

Stimulation of α_2 receptors located in the spinal cord produces antinociception.[128] Both epinephrine and clonidine produce segmental hypoalgesia.[129] The addition of α_2 agonists to LA results in faster onset and longer duration of sensory and motor blockade,[130] decreased plasma LA levels,[131] and improved intraoperative anesthetic quality.[131] However, spread of sensory block has been shown to be similar after injection of levobupivacaine alone, or with various amounts of epinephrine.[131]

Opioids exert their spinal analgesic effects at the level of the dorsal horn.[132] Whether epidurally injected opioids produce analgesia through a spinal or supra-spinal mechanism or both,[132,133] is beyond the scope of this article. However, it is clear that the synergistic action[134,135] between these two types of drugs allows a reduction in the dose and side effects of both LA and opioid, while enhancing the degree of pain relief. Adding opioids to epidural LA has been shown to hasten the onset, but not affect the spread of sensory blockade.[136] No difference in extent of sensory blockade was demonstrated between groups receiving epidural bupivacaine with sufentanil added epidurally versus IV,[137] whereas consumption of sufentanil in the epidural group was half that of the IV group. However, since sample size was based on sufentanil consumption, this study may have been under-powered to demonstrate a difference in spread of blockade.

Sympathetic Block

Over the last 10–15 yr, epidural sympathetic neural blockade has been recognized for its potential to improve outcome in cardiac[138] and colorectal surgery.[139] Sympathicolysis of the cardiac acceleration fibers (T1–4) may contribute to improved cardiac oxygen balance and decreased biochemical markers of perioperative cardiac ischemia,[138] whereas blockade of the splanchnic sympathetic nerves (T6–L1) may protect against perioperative intestinal ischemia,[140] and is associated with quicker return of bowel function and general recovery.[139] Indeed, a future therapeutic role for low-thoracic epidural anesthesia has been suggested in the treatment of septic shock.[140]

Despite the possible presence of a small zone of differential block, spread of sympathetic blockade generally follows the same patterns as sensory blockade.[141,142] Using changes in regional skin temperature in the lower extremities as an indirect indicator of diminished efferent sympathetic nerve activity, both animal[143] and human[144] studies have indicated that the sympathetic blockade associated with segmental high-thoracic epidural anesthesia may extend caudally beyond the area of sensory blockade. However, the change in foot skin temperature is much smaller

Table 1. Recommendations for Epidural Catheter Insertion Site

Type of surgery	Suggested insertion site	Rationale[a]	Typical spread after test dose of LA (3 mL)	Typical spread after loading dose of LA (10–20 mL)	Typical spread with continuous infusion of LA
Cardiac	High-thoracic C7–T2	Sensory blockade primarily caudal of insertion site Sensory blockade covers sternotomy Provides effective sympathetic block of cardiac acceleration fibers T1–4 Documented adequate analgesia Potential for faster recovery, cardiac protection	C7–T1 to T4–7[29,48,64,105]	C7–T1 to T6–11[160,161]	C6–8 to T6–9[151]
Thoracic	Mid-thoracic T2–6	Distribution of sensory blockade equally cranial and caudal Sensory blockade covers thoracotomy Documented adequate analgesia Documented improved outcome	T1–2 to T6–7[29,48,95]	No data	T2–T6[163]
Abdominal	Low-thoracic T6–L1	Sensory blockade primarily cranial of insertion site Sensory blockade covers laparotomy Provides effective splanchnic sympathetic block Documented adequate analgesia Superior analgesia compared to LEA Less motor block compared to LEA Documented improved outcome	T3–5 to T9–11[29,48,89,95,104]	C6–T1 to T11–L4[162]	T4–6 to T10–L2[137,157,164]
Lower extremity Pelvic Peripheral vascular Obstetric analgesia	Lumbar L2–5	Sensory blockade covers incision or labor pain Provides sympathetic block to legs	No data	T8–10 to S5[126,154]	T8–10 to S2[153,154]

Typical spread may vary with concentration and volume of the local anesthetic (LA); LEA = lumbar epidural anesthesia.

[a] See text for details.

compared to that induced by lumbar epidural anesthesia.[144] Furthermore, direct techniques, such as muscle and skin sympathetic nerve activity measurements with microelectrodes, have shown no inhibition of resting sympathetic nerve activity to the lower extremities by thoracic epidural anesthesia limited to the upper thoracic dermatomes.[145] Conversely, lumbar epidural anesthesia induces compensatory vasoconstriction[146] and increased cardiac sympathetic nerve activity[147] in unblocked segments. Therefore, when epidural anesthesia is to be used for both its analgesic and sympathicolytic effects, both these effects should be considered when selecting the site of epidural placement. This means, for example, that to provide complete blockade of the cardiac acceleration fibers, high-thoracic epidural anesthesia should be selected, and to block the splanchnic sympathetic system, low-thoracic epidural anesthesia should be used (Table 1).[29,48]

Degrees of sympathetic blockade in clinical studies are most often derived from changes in hemodynamic variables, e.g., arterial blood pressure, heart rate or cardiac output. These cardiovascular sequelae of epidural anesthesia have been reviewed elsewhere.[141] Specifically, factors that are positively correlated with the occurrence of hypotension and bradycardia during lumbar epidural anesthesia include increasing body weight, spread of sensory blockade, and the addition

of fentanyl to the LA.[148] In high-thoracic epidural anesthesia, no changes in hemodynamic variables were observed when comparing equal volumes of 0.25% bupivacaine to 0.375% in a crossover design.[51]

Motor Block

One of the attractive features of thoracic compared to lumbar epidural anesthesia is its lack of significant motor block of the lower extremities. However, motor block of the phrenic nerve and both upper and lower extremities can occur in thoracic epidural anesthesia, depending on the insertion site.

Phrenic Nerve Motor Block

Phrenic nerve function has been studied in patients receiving cervico-thoracic epidural anesthesia. Injection of 3[105] or 15 mL[52] of 2% lidocaine at the C7–T1 interspace resulted in only mild changes in pulmonary function as measured by forced expiratory volume in 1 min, forced vital capacity and maximum inspiratory pressure. In contrast, using the same variables and epidural catheters placed at the same interspace, a clinically important impairment of pulmonary function was observed in a concentration-dependent manner after injection of both bupivacaine 0.25% or 0.375%[50] and lidocaine 0.5%, 1% and 2%.[149] In an older study, inspiratory capacity, vital capacity, total lung capacity, and forced expiratory volume in 1 min were reduced by thoracic epidural anesthesia using 10 mL of mepivacaine 2% at both the C7–T1 and T12–L1 levels.[150] These changes were significantly greater with high-thoracic compared to low-thoracic epidural anesthesia. In contrast, functional residual capacity decreased after low-thoracic, but not after high-thoracic epidural anesthesia. Changes in Po_2 and Pco_2 were only minor. The authors concluded that motor block of both the diaphragm and the intercostal muscles may play a role in the ventilatory changes.

Upper Extremity Motor Block

A concentration-dependent decrease of hand strength has been demonstrated in cervico-thoracic epidural anesthesia.[50] Mild hand weakness occurred in 16% of patients receiving continuous high-thoracic epidural anesthesia for cardiac surgery.[151] Using a scoring scale for arm movements, decreased upper extremity motor function was demonstrated in 30% of patients with epidural catheters between C7 and T4.[152] Indeed, this scale has been proposed to serve as a simple and reliable method for the early detection of cephalad spread of thoracic epidural anesthesia, before this affects phrenic nerve function.[152]

Lower Extremity Motor Block

Some degree of lower extremity motor block is common in lumbar epidural anesthesia. With continuous infusion of LA, increasing degrees of motor blockade have been reported with increasing infusion rates while the concentration of the LA is held constant,[153] or when the concentration of LA is increased while the infusion rate is held constant.[115,154] Therefore, similar to the spread of sensory blockade, total mass of LA appears to be the most important factor concerning the degree of lower extremity motor block. This has been confirmed in volunteers receiving different concentrations and volumes of equal doses of LA.[119] Adding opioids to the LA accelerates the onset of motor blockade in lumbar epidural anesthesia.[136] The intensity of motor block is not influenced by the speed of epidural injection,[92] whereas it is increased when bicarbonate is added to the LA[127] and in older patients.[15,25,26,155] The decrease in conduction velocity in older patients affects motor nerves in particular,[37] which may explain why there is less controversy on the effect of age on motor blockade compared to the effect of age on sensory blockade. Lumbar epidural injection in the lateral position results in more profound motor block on the dependent side.[18,60] While not a clinically useful variable, posterior epidural fat volume is inversely correlated with the degree of motor block.[47]

In thoracic epidural anesthesia, lower extremity motor block can often be avoided, or is present in only mild degrees.[113,114,116–118,156] A high concentration of LA in a low volume may cause less motor block to the lower extremities in thoracic epidural anesthesia,[114] although this could not be confirmed in other studies by the same[117] and other authors.[156] Placement of catheters in proximity to lumbar spinal segments increases the risk of motor block when compared to a more cephalad placement.[117,157,158] The severity of lower extremity motor block in thoracic epidural anesthesia may also be decreased by using patient-controlled epidural analgesia instead of continuous infusion of LA, as this results in smaller amounts of drugs used, while maintaining equally satisfactory levels of analgesia.[113,156,159]

CONCLUSION

Factors Affecting the Distribution of Epidural Block

Distribution of sensory blockade after epidural injection of LA varies widely among individuals, and may only be partially predicted based upon known factors. Based on this review, the total mass of LA appears to be most important factor in determining the extent of sensory, sympathetic, and motor neural blockade, while the site of epidural needle/catheter insertion governs the pattern of distribution of sensory blockade relative to the injection site. Age may be positively correlated with the spread of sensory blockade, although the evidence is somewhat stronger for thoracic than for lumbar epidural anesthesia. Other patient characteristics and technical details such as patient position and mode and speed of injection have all been shown to exert only a small effect on the distribution of sensory blockade, or their effects are controversial. However, combinations of several patient and technical factors may aid in predicting LA

Table 2. Summary of Factors Affecting the Spread of Epidural Neural Blockade

	Sensory	Sympathetic	Motor	Notes	References
Patient characteristics					
Age	+	++	+++	Conflicting results between the various studies. 3–8 segments more, dose requirement 40% less when >60 yr. Correlation stronger in thoracic than in lumbar epidural anesthesia, and stronger for autonomic and motor block than for sensory block	Positive correlation:[12–17,27–30]. No or small correlation:[18,20–26]
Height	0/+	?	?	No or small correlations	No relation:[20,22,29] Positive relation:[30]
Pregnancy	++	++	++	Generally higher block levels	[45]
Dural surface area	+	?	?	Inverse correlation between dural surface area and peak sensory block	[47]
Posterior epidural fat volume	?	?	+	Inverse correlation between posterior epidural fat volume and degree of motor block	[47]
Anesthesiologist determined					
Epidural insertion site					
High-thoracic	Caudal Spread	?	?	Does not have effect on number of segments blocked, but does influence direction of spread	[29,48,50–52,64]
Mid-thoracic	Even distribution	?	?		[29,48]
Low-thoracic	Cephalad Spread	?	?		[29,48]
Patient positioning					
Sitting or laterally recumbent versus supine	+	?	+	Quicker onset and blockade 1–2 segments greater than supine	[21,53–60]
Head down	+	?	?	Quicker onset times, slightly higher block levels	[62]
Local anesthetics					
Total mass of local anesthetic	++++	++++	++++	Non-linear relationship between total mass of local anesthetic and number of segments blocked, linear relationship between segmental dose requirements and dose already injected	[2,14,18,20,21,23,109]
Volume/ concentration relationship	0/+	0	0		[2,20,48,110–115,120]
Additives (bicarbonate, α2 agonists, opioids)	0	0	+	Quicker onset of blockade, no change in segments blocked; more pronounced motor block with bicarbonate	[126,127,130,131]
Method of injection					
Needle versus catheter	0/+	?	?	Possibly higher block level after injection through catheter compared to needle	[77–80]
Speed of injection	0/+	?	?	Quicker onset of blockade; possibly higher block levels after rapid injection	[55,79,92,93]
Fractional injection versus single bolus	+	?	?	Fractional injection resembles single shot injection when intervals are shorter	[89–91]
Needle direction and catheter position	+/0	?	?	No or only minor effects	[65,66]
Threading of catheter to side	++	+	?	Preferential distribution of sensory and motor block with threading of catheter to one side	[67–69]

There is an ordinal indication of various factor correlation to the spread of neural blockade [from low (+) to high (++++), no correlation evident (0), no information available (?)]. Conjecture or additional notes included, and reference to pertinent literature indicated.

dose requirements. Also, maneuvers such as rapid injection, placing the patient in the lateral position, or adding bicarbonate to LA solutions may be applied to quicken the onset of blockade. The influence of the factors mentioned above may be summarized in a semi-quantitative fashion as presented in Table 2.

Selection of Epidural Insertion Site

It has been suggested that epidural catheters should be sited at an intervertebral space that represents the middle of the area of surgical incision.[115] However, we feel this advice does not consider the different patterns of distribution after single injection or continuous infusion of LA. Also, with the recent recognition of the beneficial effects of sympathicolysis, sympathetic epidural blockade in a particular area of the body may be considered as important as satisfactory analgesia. Based on this review, we have formulated suggested epidural insertion sites for various surgical indications that may serve to accomplish both goals (Table 1).

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