Epidural Catheter Placement in Neonates: Sonoanatomy and Feasibility of Ultrasonographic Guidance in Term and Preterm Neonates

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Background: We report the first prospective sonoanatomic study in neonates with the aim to perform ultrasonographic-guided epidural catheter placement in this age group.

Method: One hundred forty-five neonates with a body weight ≤4 kg (0.53-4 kg) were included in this prospective study. The study was divided into 3 consecutive parts. In the first part, the neuraxial sonoanatomy of 60 neonates was evaluated. In the second part, 50 neonates scheduled for major abdominal surgery were enrolled. In this part, the depth of the ligamentum flavum measured with ultrasound was matched up to the depth evaluated clinically with the loss-of-resistance technique. In the third part, ultrasonographic epidural catheter placement was performed in 35 neonates weighing between 620 g and 4 kg.

Results: The ligamentum flavum, the dura mater, and the termination of the spinal cord could be identified in all patients. The first part showed a good correlation between body weight and depth of the ligamentum flavum. The median termination of the spinal cord corresponded to vertebral level L2. The second part confirmed a good correlation between depth of the ligamentum flavum evaluated clinically and the depth predicted with ultrasound. Finally, real-time ultrasound-guided epidural placement was possible in all 35 neonates.

Conclusion: Ultrasound examination of the spinal cord anatomy provides valuable information for epidural catheter placement in neonates. Ultrasonography enables a real-time identification of the tip of the needle within the epidural space and a visualization of the spread of local anesthetic in these patients. Reg Anesth Pain Med 2007;32:34-40.

Key Words: Ultrasound guided regional anesthesia, Neonatal epidural anesthesia.
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immobile patient; this technique carries the risk to hide alarm signals caused by nerve damage or unintended intravascular injection of local anesthetic.8,9

Ultrasoundography adds a new dimension to regional anesthesia in adults and children.10-14 Recently, we showed that ultrasoundography is a useful aid to verify epidural placement of local anesthetic agents and epidural catheters in infants and children up to 6 years. Advantages include real-time visualization of all relevant neuraxial structures and the visualization of the spread of local anesthetic inside the epidural space, a reduction in bone contacts, and rapid epidural placement.15

This is the third in a series of studies evaluating the impact of ultrasoundography on neuraxial anesthesia in children.15,16 The purpose of this study was to evaluate the relevant neuraxial sonoanatomy in term and preterm neonates and to investigate the feasibility of ultrasonographic-guided epidural placement in this age group.

Material and Methods

This study was approved by the ethics committee of the University of Cape Town. After parental consent was obtained, a total of 145 neonates with a body weight ≤4 kg were included in this prospective study. The study consisted of 3 consecutive parts. Data were analyzed after each part, before the subsequent part was started.

Part 1: Descriptive Sonoanatomic Study

Sixty newborns were included in the first part of this study. All neonates were examined within 3 days of birth and were stratified into 4 groups according to weight. Newborns weighing less than 1 kg were assigned to group A, between 1 and 2 kg to group B, between 2 kg and 3 kg to group C, and between 3 kg and 4 kg to group D. Measurements were not performed on those neonates with known, suspected, or identified vertebral malformations.

All ultrasound examinations were performed with the neonates positioned as they would for epidural placement (i.e., in the left lateral position with the hips flexed). No sedation was required. The relevant neuraxial anatomy was then identified by 2 anesthetists, experienced in ultrasound-guided pediatric regional anesthesia, by using a SonoSite 180 plus portable ultrasound unit (SonoSite, Bothell, WA) and a 5- to 10-MHz linear hockey stick probe. Adjustments (depth, probe frequency, and low and far gain) were made to achieve optimal ultrasound images of the neuraxial structures (i.e., vertebrae, spinal canal, spinal cord, ligamentum flavum, dura mater, conus medullaris, and nerve roots of the cauda equina).

First, the spinal canal was studied by using the “acoustic window”17 in both the longitudinal paramedian and cross-sectional planes to identify the spinal cord and the conus medullaris (Figs 1A-C). By using the longitudinal paramedian view, the tip of the hockey stick probe was aligned with the conus. A line was drawn on the skin at the tip of the probe. The conus medullaris was then viewed in cross-section using the transverse plane to confirm this position.

If “ultrasound shadows” cast by ossified posterior vertebral elements prevented a panoramic view of the neuraxial structures, the position of the conus was extrapolated from the views seen through the “acoustic windows” between the vertebra above and below the conus. In other words, if the spinal cord was visible at one level in both longitudinal paramedian and transverse views but only the cauda equina was visible at the next level below, the conus was described as being between these levels (Fig 2).

Second, the intercristal line was used as a landmark from which the spinous processes were counted. In addition the 12th rib, identified clinically by palpation and confirmed by ultrasound, was used to identify the level of T12. In an attempt to avoid errors, the counting of the spinous processes was performed twice by 2 different anesthetists. Third, measurements were made in the cross-sectional plane by using the computer software incorporated in the Sonosite180+. The depth of the ligamentum flavum and the dura mater from the skin were measured at the TH 7/8, L1/2, L2/3, and L3/4 levels (Fig 3).

Part 2: Comparing the Depth Calculated With Ultrasound and the Depth Evaluated Clinically With the LOR Technique

Fifty neonates scheduled for major abdominal surgery who had no contraindication to epidural anesthesia were enrolled into the second part of this study. After induction of anesthesia, the neonates were placed in a left lateral position with the hips flexed and the position of the conus medullaris, and the depth of the ligamentum flavum was calculated by using a SonoSite 180 plus portable ultrasound unit and a 5- to 10-MHz linear hockey stick probe. After aseptic preparation of the puncture site, which was chosen according to the level of the conus medullaris, the epidural puncture was performed with the traditional LOR technique and a 21-gauge Tuohy epidural needle (Pajunk, Geisingen, Germany) with a 25-gauge catheter. The Tuohy needle was introduced...
in the midline in a plane parallel and level to the table. When the LOR to saline was detected, the Tuohy needle was marked at the point where it emerged from the skin. The distance from this point to the tip was measured and recorded as the skin-ligamentum flavum distance. Those epidurals where the catheter did not feed or where failure of the epidural block occurred were not included in the data analysis. The anesthetist who performed the epidural catheter placement was blinded to depth of the ligamentum flavum measured with ultrasound.

Part 3: Ultrasonographic-Guided Epidural Catheter Placement in Preterm Neonates

Ultrasound-guided epidural placement was performed by using real-time imaging in 35 consecutive neonates who were scheduled for major
abdominal surgery. After induction of general anesthesia, the neonates were placed in a left lateral position and the hips flexed. After aseptic preparation of the puncture site and of the ultrasound probe, the epidural puncture was performed under continuous real-time imaging by using a 21-gauge nanoline-coated Tuohy epidural needle (Pajunk) with a 25-gauge catheter. The approach to the epidural space was viewed through the “acoustic window” created by the longitudinal paramedian approach. Once the tip of the needle was identified as being in the epidural space, 0.3 to 0.5 mL/kg levobupivacaine 0.25% was administered. The spread of local anesthetic within the epidural space confirmed correct placement. A 25-gauge epidural catheter was then also introduced under ultrasonography real-time imaging. The procedure was performed by 2 anesthetists experienced in neonatal epidural catheter placement and in the use of ultrasound-guided regional anesthesia in children.

Statistical Analysis

Data are presented as median (range). Linear regression analysis was performed to determine the correlation between skin-ligamentum flavum distance with body weight and height and the ultrasonographic calculated depth of the ligamentum flavum and the corresponding depth of the epidural space evaluated with the LOR technique. After testing for normal distribution of the data, the differences in the skin-ligamentum flavum distances were compared by a single sided t test for independent samples, followed by Bonferoni correction for repeated measurements.

Results

Sixty newborns, 15 in each weight group, were studied in the sonoanatomic part of this study. Demographic data are presented in Table 1. In all newborns, the relevant neuraxial anatomy could be identified. The distances of the skin to the ligamentum flavum and of the skin to the dura at L1/2, L2/3, L3/4, and Th7/8 levels are presented in Table 2. The width of the epidural space was calculated as the difference between skin-ligamentum flavum distance and the skin-dura distance (Table 2). The position of the conus medullaris was also identified in all neonates, and the median termination corresponded to the level L2 (Table 2). The skin-ligamentum flavum distance increased with increasing body weight and was therefore different between groups (Table 3). Overall, the correlation between the skin-ligamentum flavum distance and body weight was good (Fig 4). At the level of L1/L2, the adjusted $r^2$ was 0.8. Similar values were achieved at the other levels of the vertebral column.

Fifty neonates were included in the second part of this study. Epidural catheter placement was possible in all cases, and no clinical signs (i.e., increase in heart rate or blood pressure as a response to skin incision) of a failed epidural occurred in any neonate. No dural puncture occurred, nor was a bloody tap noted. The demographic data of these patients are presented in Table 4. The correlation between the depth of the ligamentum flavum calculated with ultrasound and the depth of the ligamentum flavum evaluated with the LOR technique was 0.64 (adjusted $r^2$).

An ultrasound-guided epidural catheter placement was performed in 35 neonates with a body
weight between 620 g and 4 kg within their first 20 days of life. The median weight of these neonates was 2.8 kg (0.620-4 kg). Three neonates had a body weight less than 1 kg (800 g, 790 g, and 620 g). The tip of the epidural needle and the distribution of local anesthetic could be visualized clearly within the epidural space in all neonates. The epidural catheter per se could not be visualized with certainty. However, tissue movement and the injection of fluid could be used as surrogate markers of the catheter tip. There were no clinical signs (i.e., increase in heart rate and or blood pressure) for a failure of the epidural anesthesia, dural punctures, or traumatic (bloody) tap.

Discussion

This is believed to be the first study evaluating the neuraxial sonoanatomy in neonates with a view to ultrasonographic guidance in epidural catheter placement in this age group. Information with regard to the anatomic relationships of the spinal cord, dura mater, and the epidural space (width and depth) evaluated with ultrasound may be helpful when inserting epidural catheters in the daily practice of pediatric anesthesia.

The sonoanatomic part of this study showed that the termination of the conus medullaris corresponds to the vertebral level L2, when the neonates were positioned as they would be for epidural placement in the left lateral position. Excluding low–birth-weight premature neonates in group 1, the median termination of the spinal cord was between L1 and L2. It is well known that the conus "ascends" from its early fetal position in the sacral canal to the eventual adult position. The precise timing of this ascent has been a matter of debate. Traditionally, the termination of the spinal cord is said to lie at the L3 vertebral body at birth rising to the adult level at L1-2 by 1 year of age. The median level of the termination of the conus medullaris corresponds to the level of L2 vertebra in our study. Similar results have been described by DiPietro, who reported that the median termination of the cord corresponds to the level L1 even in small infants. However, in this study, only few infants and no preterm neonates were investigated. Both results are in contrast to the information supplied by many anesthesia textbooks, which recommend that an epidural should be placed below the termination of the spinal cord (i.e., at L4/L5 or L5/S1 interspace) to reliably avoid neuronal injury. In contrast to these recommendations, epidural infusions are most effective when the catheter tip is placed near the spinal nerves involved in the surgical procedure. A puncture site far more caudal than necessary implicates a cephalad advancement of the catheter over a long distance within the epidural space. This increases the risk of intravenous cannulation, paresthesias, nerve damage, and unilateral sensory analgesia. Furthermore, the risk of catheter coiling seems to increase with increasing insertion depth. Lim et al reported a median coiling length of the epidural catheter at 2.8 cm, independent of whether the bevel of the Tuohy needle is directed cephalad or caudal.

Similar to previous studies in older children, we found a good correlation between the depth of the epidural space and the body weight in term and preterm neonates (adjusted $r^2$, 0.8). Interestingly, whereas the depth of the epidural space is approximately 1 mm per kg body weight in children older than 6 months, this distance is relatively higher in

<table>
<thead>
<tr>
<th>Group</th>
<th>Median Weight (g) (Range)</th>
<th>Median Height (cm) (Range)</th>
<th>Median Gestation Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (&lt;1 kg)</td>
<td>790 (530-970)</td>
<td>31 (27-34)</td>
<td>30 (27-33)</td>
</tr>
<tr>
<td>Group 2 (1-2 kg)</td>
<td>1,380 (1,200-1,950)</td>
<td>41 (38-44)</td>
<td>32 (28-34)</td>
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<tr>
<td>Group 3 (2-3 kg)</td>
<td>2,425 (2,050-2,900)</td>
<td>44 (40-49)</td>
<td>34.5 (31-38)</td>
</tr>
<tr>
<td>Group 4 (3-4 kg)</td>
<td>3,400 (3,100-3,900)</td>
<td>48 (45-56)</td>
<td>39 (35-40)</td>
</tr>
<tr>
<td>All patients</td>
<td>1,965 (530-3,900)</td>
<td>43 (27-56)</td>
<td>33.5 (27-40)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>Median Depth at Th7/8 (Range)</th>
<th>Median Depth at L1/2 (Range)</th>
<th>Median Depth at L2/3 (Range)</th>
<th>Median Depth at L3/4 (Range)</th>
<th>Median Thoracic Width (Range)</th>
<th>Median Lumbar Width (Range)</th>
<th>Median Termination of Cord (Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1 (&lt;1 kg)</td>
<td>4.8 (3.5-7.4)</td>
<td>4.6 (3.5-5.2)</td>
<td>3.8 (2.6-5.0)</td>
<td>1.4 (1.2-2.2)</td>
<td>1.6 (1.3-2.2)</td>
<td>L2 (2-3)</td>
<td></td>
</tr>
<tr>
<td>Group 2 (1-2 kg)</td>
<td>6.3 (5.8-6.5)</td>
<td>4.9 (3.7-8.4)</td>
<td>4.6 (3.5-6.7)</td>
<td>1.7 (1.4-1.9)</td>
<td>2 (1.6-2.2)</td>
<td>L1.5 (1.5-2)</td>
<td></td>
</tr>
<tr>
<td>Group 3 (2-3 kg)</td>
<td>8.35 (7.7-10.8)</td>
<td>6.8 (5.2-8.3)</td>
<td>6.1 (5.2-8.2)</td>
<td>1.7 (1.5-2.6)</td>
<td>2 (1.7-2.5)</td>
<td>L1.5 (1.5-2)</td>
<td></td>
</tr>
<tr>
<td>Group 4 (3-4 kg)</td>
<td>9.3 (7.1-13.8)</td>
<td>7.95 (6.3-9.6)</td>
<td>7.1 (6-8.7)</td>
<td>1.85 (1.5-2.5)</td>
<td>2.25 (1.5-3.1)</td>
<td>L1.5 (1.2)</td>
<td></td>
</tr>
<tr>
<td>All patients</td>
<td>7.25 (3-13.8)</td>
<td>5.5 (2.8-9.6)</td>
<td>5.3 (2.7-8.7)</td>
<td>1.7 (1-2.6)</td>
<td>2 (1.2-3.1)</td>
<td>L2 (1-3)</td>
<td></td>
</tr>
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neonates (Fig 4). However, clinically more relevant than this correlation are the ranges of the depth of the epidural space given in Table 2.

The second part of this study showed that ultrasound can be used accurately to predict the skin epidural distance in neonates. There was a reasonable correlation (adjusted $r^2$, 0.64) between the expected depth of the ligamentum flavum measured with ultrasound and depth of the epidural space evaluated with the LOR technique. There may be different reasons why this correlation was not better. When measuring the skin-ligamentum flavum distance, minimal pressure should be applied to the ultrasound probe. First, it will not improve the image, but more importantly it may result in an inaccurate reading. Similarly, when introducing the Tuohy needle, variable pressure is applied to the skin and the ligamentum flavum may be tented as the needle is advanced. Furthermore, the angle of insertion will have a significant influence over the short distance to the epidural space also. However, in our opinion, one of the main advantages of ultrasound guidance is the knowledge of the depth of the epidural space’s prior puncture. On one hand, it gives an idea at which depth LOR can be expected; on the other hand, it gives confidence about how far the Tuohy needle can be introduced without risk of neurologic damage.

In this study, ultrasound-guided epidural catheter placement was performed successfully in 35 preterm neonates undergoing major abdominal surgery. Before and during the epidural placement, all important neuraxial structures could be delineated clearly. As a result of the incomplete ossification, the hypoechoic spinal cord and hyperechoic nerve roots of the cauda equina are clearly seen in neonates and premature infants. The epidural space is delineated by the hyperechoic images of the ligamentum flavum and the dura mater. Arterial pulsation can also be clearly visualized within the epidural space by using real-time imaging. Real-time needle guidance enabled a safe approach to the epidural space and can help avoid inadvertent puncture of nearby structures. By using ultrasound-guided neonatal epidural puncture, it is possible to visualize the distribution of local anesthetic within the epidural space. By using the paramedian view, the downward movement of the dura is clearly seen. This ability to monitor the spread of local anesthetic in the epidural space, thereby verifying epidural puncture and subsequently correct epidural placement of the catheter, is probably the largest advantage of ultrasound guidance for epidural catheterization in neonates.

The concept of a direct real-time visualization of all neuraxial structures involved in epidural catheter placement is promising. Ultrasound examination of the neuraxial anatomy in newborns can provide valuable information to facilitate epidural placement in this high-risk age group. Because the complication rate in epidural anesthesia in neonates seems to be low, studies to show a significant difference in terms of safety between the LOR and the ultrasound technique would require large numbers of subjects. Ultrasonography can be used to determine the location of the conus and to determine the depth of ligamentum flavum that can then be used as a guide to the depth where LOR can be expected.

Both epidural placement in neonates and ultrasound guidance for epidural catheterization requires experience. Attempting to combine both without proper training and experience could be
risky. As the use of ultrasonography increases and anesthetists feel more comfortable using ultrasound probes for regional anesthesia, the expertise and case of scanning and subsequent placement of epidural catheters in neonates should improve.

References