Ultrasound assessment of cranial spread during caudal blockade in children: effect of the speed of injection of local anaesthetics

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Editor’s key points

- Cranial spread of local anaesthetic was studied with different speeds of injection during caudal blockade.
- Fifty children were studied using ultrasound to assess cranial spread of the injected anaesthetic solution.
- The solutions were injected at two different speeds.
- Importantly, the speed of injection had no effect on the cranial spread of the local anaesthetic.

Background. Despite caudal blockade being the most widely used regional anaesthetic procedure for infants and children undergoing subumbilical surgery, the question whether the injection velocity of the local anaesthetic itself affects its spread in the epidural space has not yet been investigated. Thus, the aim of the present study was to measure the cranial spread of caudally administered local anaesthetics in infants and children by means of real-time ultrasonography, with a special focus on comparing the effect of using two different speeds of injection.

Methods. Fifty ASA I–II infants and children, aged up to 6 yr, weighing up to 25 kg, undergoing subumbilical surgery, were enrolled in this prospective, randomized, observer-blinded study. Caudal blockade was performed under ultrasound observation using ropivacaine 1 ml kg$^{-1}$ 0.2% or 0.35% and an injection given at either 0.25 ml s$^{-1}$ or 0.5 ml s$^{-1}$, respectively.

Results. Ultrasound observation of the local anaesthetic flow and the extent of cranial spread was possible in all patients. All caudal blocks were considered successful, and all surgical procedures could be completed without any indications of insufficient analgesia. No statistically significant difference could be observed between the two injection speeds regarding the cranial spread of the local anaesthetic in the epidural space.

Conclusions. The main finding of the present study is that the speed of injection of the local anaesthetic does not affect its cranial spread during caudal blockade in infants and children. Therefore, the prediction of the cranial spread of the local anaesthetic, depending on the injection speed, is not possible.

Keywords: children; complications; epidural; infants; regional anaesthesia

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Single-shot caudal blockade has been the most commonly performed regional anaesthetic technique in infants and children scheduled for subumbilical surgery for nearly 50 yr. The reason for its popularity is a high success rate, a steep learning curve, and a low incidence of severe complications. Despite the large amount of literature on caudal blockade, the issue of the spread of caudal analgesia was only described decades ago, using mathematical and statistical models. Recently, only a few studies measured the spread of the local anaesthetic with fluoroscopy and static X-ray examination. Nowadays, real-time ultrasonography not only provides a static picture of the local anaesthetic in the epidural space after injection, but also allows the dynamic assessment of the solution spread during injection, its cranial propagation, and the definite bulk front. Therefore, current investigations started to enlighten previously unanswered questions about the segmental distribution, and the spread of the local anaesthetic during caudal blockade.

The question whether the speed of injection of the local anaesthetic itself influences its spread in the epidural space during caudal blockade in infants and children has not been investigated until now. Previous investigations about local anaesthetic distribution during epidural analgesia in adults showed controversial results.

Thus, the aim of the present prospective, randomized, observer-blinded study was to measure the cranial spread of caudally administered local anaesthetics in infants and children by means of real-time ultrasonography, with a special focus on comparing the effect of using two different speeds of injection.
Methods

After Institutional Ethics Committee approval, 50 ASA I–II infants and children, aged up to 6 yr, weighing up to 25 kg, undergoing penile, anal, or inguinal surgery, were enrolled in this prospective, randomized, observer-blinded study. Informed consent was obtained from the parents of all infants and children. Exclusion criteria were ASA status \( \geq III \), blood coagulation disorders, systemic inflammation, infection at injection site, anatomical abnormalities of the lumbosacral spine, history of allergic reactions to local anaesthetics, and parental refusal to participate in the study.

Anaesthesia management

EMLATM cream was placed with an adhesive sterile tape at the predetermined venous and caudal puncture sites 45 min before premedication. Premedication consisted of midazolam 1 mg kg\(^{-1}\), administered rectally or orally depending on patient’s age and compliance. The total dose of midazolam did not exceed 15 mg.

Fifteen minutes after premedication, the patient was transferred to the operating theatre and standard monitoring was applied (ECG, \( \text{SpO}_{2} \), NIBP). After induction of anaesthesia using face mask (sevoflurane 8 vol% in \( \text{O}_2/\text{air} \) \( \text{FiO}_2 \) 50%), a peripheral venous access was established. Thereafter, sevoflurane was discontinued and sedation was continued with i.v. propofol 5 mg kg\(^{-1}\) h\(^{-1}\) and supplemental oxygen (2 litre min\(^{-1}\) and \( \text{FiO}_2 \) 50%) via face mask.

Ultrasound investigation, identification of T12 level, and conus medullaris

The patient was turned in the left lateral position with flexed lower limbs. The T12 spinous process was identified by palpation of the 12th rib, which was then tracked medially by ultrasound scanning, thereby identifying the 12th vertebral body. Subsequently, an initial neuraxial ultrasound investigation was performed to identify the dura mater, the epidural space, and the conus medullaris using a SonoSiteTM M-Turbo machine (SonoSite Inc., Bothell, WA, USA) and a linear 38 mm 7–13 MHz ultrasound transducer. The levels of the T12 spinous process and the conus medullaris were marked with a skin marking pen.\(^{12}\)

Caudal blockade under ultrasound observation

After sterile preparation of the injection site and covering the ultrasound probe with a transparent sterile adhesive cover (SafersonicTM, Safersonic Medizinprodukte Handelsg.m.b.H., Ybbs, Austria), the sacral cornuae and the sacrococcygeal membrane were palpated for precise identification. The sacrococcygeal membrane was punctured with a 30 mm 24 G Quincke needle connected with a 25 cm injection line (‘immobile needle technique’; Pajunk Caudal Set according to Marhofer, PajunkTM, Geisingen, Germany). The needle and the line were primed with saline 0.9%.

Each patient was randomized via a computer-generated list to receive 1 ml kg\(^{-1}\) ropivacaine (NaropinTM, Astra Zeneca, Wedel, Germany) with an injection speed of either 0.25 ml s\(^{-1}\) (low velocity group) or 0.5 ml s\(^{-1}\) (high velocity group), respectively. According to hospital protocols, ropivacaine 0.2% was administered in infants whereas ropivacaine 0.35% was used in children \( \geq 1 \) yr.\(^{3,16}\) The administration of the local anaesthetic in the predefined speed was performed with a syringe pump (Perfusor SpaceTM, B. Braun, Melsungen, Germany), with the injection line from the needle connected to the perfusor pump after successful caudal puncture.

Ultrasound measurements

During the injection, the ultrasound probe was maintained in the paramedian position and moved cranially for direct observation of the local anaesthetic bulk flow in the epidural space, as evidenced by an anterior displacement of the dura mater, resulting in a reduction in the antero-posterior diameter of the intrathecal space (Fig. 1).\(^{11}\) After completing the injection, the front of the epidural local anaesthetic was identified and positioned in the middle of the ultrasound picture. A skin mark was then made corresponding to the middle of the ultrasound probe and the level reached was determined by counting the spinous processes from the previously indicated T12 spinous process. If the local anaesthetic front on ultrasound was ‘hidden’ behind the bone shadow of the vertebral lamina, the front was approximated to the middle of the corresponding bone shadow.

The level reached by local anaesthetic relative to the conus medullaris (+ ‘ mm’ = local anaesthetic cranial to the conus medullaris and ‘ − mm’ = local anaesthetic caudal to the conus medullaris) was determined by measuring the distance between the skin mark of the conus medullaris and the skin mark representing the cranial extension of the local anaesthetic using a regular measuring tape.

The spread of local anaesthetic was recorded via MPEG 2 movies and BMP images and stored on the internal hard drive of the SonoSiteTM M-Turbo ultrasound equipment.

Blinding

One anaesthetist was dedicated to performing the caudal block, including drawing up and injecting the correct amount of local anaesthetic with the predefined speed,
whereas another anaesthetist was assigned to perform and evaluate the ultrasound scan. Thus, the ultrasound investigator was blinded to the speed of the injected local anaesthetic.

**Further management and evaluation**

Skin incision was performed 15 min after the injection of local anaesthetic. A successful block was defined as no motor (movements of extremities) or haemodynamic response (definition, see below) to skin incision or during the surgical procedure with no need for the administration of supplemental analgesics. In the case of a pain response (defined as: movements of the lower extremities, HR increase >15% from baseline, or other obvious signs of pain) patients received 0.1 mg kg⁻¹ nalbuphine (Nalbuphine Orpha™), in which case the block was considered a failure and excluded from further statistical evaluation.

The urinary and the motor function of the lower extremities and the caudal puncture site were assessed in all patients on the first postoperative day.

**Statistical analysis**

All data are displayed as median [range] or mean (SD) unless otherwise specified. For comparison of the difference in the cranial spread of local anaesthetics between the two velocity groups, a Wilcoxon test was performed. Spearman’s correlation coefficient was calculated to assess correlation of cranial local anaesthetic spread and patient age and weight. A P < 0.05 was considered significant.

**Results**

A total of 50 patients were included in the study. Patient characteristics and morphometric data are shown in Table 1. No statistical difference regarding relevant patient data was determined between both study groups.

The front of the local anaesthetic bulk flow was seen by ultrasonography in all investigations, thus an upper level of cranial spread was measured successfully in all patients. All caudal blocks were considered successful as all surgical procedures could be completed without any indications of insufficient analgesia as outlined in the Methods section.

Ultrasound-assessed median cranial spread was L3 in the low-speed group, and L3/L4 in the high-speed group, respectively. There was no difference between both speed groups (P = 0.2). The maximal level of cranial spread observed was L1 in the low-speed group and L1/L2 in the high-speed group (Fig. 2).

The distance of the cranial spread of the local anaesthetic relative to the conus medullaris is illustrated in Figure 3, showing that there is no statistically significant difference between both study groups.

A post hoc evaluation of the spread of the local anaesthetic in relation to patient age, height, and weight found no correlation with regard to these factors in both study groups.

At the follow-up visit on the first postoperative day, all patients had normal urinary and motor function of the lower extremities. No patient showed any sign of hematoma or infection at the caudal puncture site.

| Table 1 Patient characteristics. Data are given as median [range] |
|---------------------------------|------------------|------------------|
|                                 | Group 0.25 ml s⁻¹ | Group 0.5 ml s⁻¹ |
| Number of patients             | 25               | 25               |
| Age (months)                   | 19 [1–55]        | 12 [2–55]        |
| Age (gestational weeks)        | 40 [32–41]       | 40 [32–41]       |
| Weight (kg)                    | 12 [3.5–19]      | 11.8 [4.2–17]    |
| Height (cm)                    | 89 [52–114]      | 81.5 [55–107]    |
| BMI (kg m⁻²)                   | 15 [8–22.4]      | 15.7 [8–20.7]    |
Discussion

Our data show that the speed of injection of the local anaesthetic does not affect its cranial spread in the caudal epidural space of infants and children (Fig. 4). Both 0.25 and 0.5 ml s\(^{-1}\) epidural injection speed resulted in a similar anatomical extension of the spread as assessed by real-time ultrasonography. A tendency toward lower segmental spread was observed in the higher injection velocity group. Despite the local anaesthetic bulk front not reaching the thoraco-lumbar junction, all blocks resulted in successful surgical analgesia. No relationship between age, height, and weight and cranial segmental spread was detected with both injection speeds.

Previous data about epidural injection velocity and cranial spread of the blockade were only obtained in adults. All studies investigated lumbar or thoracic epidurals and not caudal blocks. Additionally, the end point of all studies was the extent of clinical analgesia determined by cutaneous testing, and not the direct visualization of the local anaesthetic bulk front in the epidural space with ultrasound.

To further discuss our results, we refer to an earlier published relationship between epidural pressure and spread.\(^{16}\) The injection of a local anaesthetic solution in the epidural space increases the epidural pressure with a subsequent return toward preinjection values. The curve of epidural pressure against time exhibits three components: the peak, the descent, and the residual values.\(^{16}\) The first part of the epidural pressure curve is derived from expansion of the epidural space induced by the administration of the local anaesthetic. The younger the patient and the higher the injection speed, the higher is this peak pressure. The second part of the curve is based on intrinsic properties of the epidural space such as compliance and resistance. The high compliance and low resistance of children result in a rapid descent to low residual values even after higher injection speeds. Additionally, the younger the patient, the more the local anaesthetic is seen escaping paravertebrally as a result of the difference in the amount and the characteristics of the epidural fat in childhood.

Summing up, the peak epidural pressure correlates directly with the injection velocity but does not influence the final extent of the block. The final extent of the block is influenced by the residual epidural pressure, which is lower in younger than in the elderly patients.

These results may explain why we did not observe a more cephalad spread of the local anaesthetic in infants than in older children. Contrary to these results, an inverse relationship between age, weight, and height and the number of segments covered by a caudal injection has already been published recently by our group.\(^{11 12}\) We suspect that the 50% higher amount of local anaesthetic administered in this previous study may have contributed to this inverse relationship. Additionally, the higher injection volume may enhance the effects on local anaesthetic spread caused by the absence of the normal spinal curvatures in non-walking children combined with the different amount and characteristics of the epidural fat.

We suspect that the similar cranial spread of the local anaesthetic obtained with both injection speeds in our study may also be explained by the above-mentioned pressure-spread relationship. The higher injection velocity initially causes a higher peak pressure, which subsequently results in a more rapid descent to low residual values because of the specific characteristics of the epidural space in childhood. Therefore, the final extension of both injection speeds may be similar regardless of the applied pressure.

The number of the vertebral segments reached with ropivacaine 1 ml kg\(^{-1}\) in our patients is comparable with recently published data.\(^{9 11 12}\) Our group visualized the cranial spread of the local anaesthetic simultaneously at injection using ultrasonography, whereas Thomas and colleagues, also with similar results, obtained X-ray images 10 min after injection. We agree to the statement of the authors that the caudal solution may still be creeping cranially and has not yet reached its highest level even after several minutes of caudal injection.

The fact that all our blocks were clinically successful underlines the discrepancy between the anatomic height of the caudally injected solution and the extent of analgesia, which has not been fully understood until now.\(^{7}\) It probably may be explained by a further ‘pharmacological spread’ not visible to currently used imaging techniques, representing a significant number of local anaesthetic molecules reaching higher vertebral levels. Furthermore, there is no consensus on how testing should be performed to allow precision and reproducibility. Early studies determined their high analgesic levels with clinical cutaneous testing methods while their patients underwent halothane anaesthesia \(\sim\) 15–20 min after the local anaesthetic injection. However, general anaesthesia with analgesic inhalation agents may obscure incomplete caudal blockade. The light propofol sedation in our patients would immediately unmask insufficient surgical analgesia in contrast to analgesic halothane anaesthesia.

The 30 mm 24 G Quincke needle used in our study represents the standard cannula used in our daily clinical routine for paediatric caudal blockade. An 18 or 22 G needle of the
same length would probably result in higher injection velocities with lower epidural peak pressures because of the rules of the Hagen–Poiseuille equation. Further investigations are needed to elucidate these possible variations. However, we think that a further acceleration of the injection velocity would not extend the spread of the block. Higher injection speeds can only be applied manually and are therefore imprecise and not comparable in a study setting.

In conclusion, the injection speed of the local anaesthetic does not affect its cranial spread during caudal blockade in infants and children. Therefore, the prediction of the cranial spread of the local anaesthetic, depending on the injection speed, is not possible.

Declaration of interest
None declared.

References