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Ultrasound assessment of cranial spread during caudal blockade in children: the effect of different volumes of local anaesthetics

L. Brenner[1], P. Marhofer[1*], S. C. Kettner[1], H. Willschke[1], A.-M. Machata[1], U. Al-Zoraigi[1], M. Lundblad[2] and P.-A. Lönnqvist[2]

[1] Department of Anaesthesia, General Intensive Care and Pain Therapy, Medical University of Vienna, Waehringer Guertel 18-20, A-1090 Vienna, Austria, Europe

[2] Astrid Lindgren Children's Hospital, Karolinska University Hospital, Paediatric Anaesthesia and Intensive Care, SE-171 76 Stockholm, Sweden, Europe

* Corresponding author. E-mail: peter.marhofer@meduniwien.ac.at

Editor's key points

- Cranial spread of local anaesthetic during a caudal block in children is not well investigated.
- Correlation between the volume of local anaesthetic and its cranial spread was studied in 75 children.
- Cranial spread increased with the increase in the volume of the local anaesthetic used.
- The correlation, though significant, was not strong enough to allow prediction of cranial spread for a given volume.

Background. Despite the large amount of literature on caudal anaesthesia in children, the issue of volume of local anaesthetics and cranial spread is still not settled. Thus, the aim of the present prospective randomized study was to evaluate the cranial spread of caudally administered local anaesthetics in children by means of real-time ultrasound, with a special focus on the effects of using different volumes of local anaesthetics.

Methods. Seventy-five children, 1 month to 6 yr, undergoing inguinal hernia repair or more distal surgery were randomized to receive a caudal block with 0.7, 1.0, or 1.3 ml kg^{-1} ropivacaine. The cranial spread of the local anaesthetic within the spinal canal was assessed by real-time ultrasound scanning; the absolute cranial segmental level and the cranial level relative to the conus medullaris were determined.

Results. All the blocks were judged to be clinically successful. A significant correlation was found between the injected volume and the cranial level reached by the local anaesthetic both with regards to the absolute cranial segmental level and the cranial level relative to the conus medullaris.

Conclusions. The main finding of the present study was positive, but numerically small correlation between injected volumes of local anaesthetic and the cranial spread of caudally administered local anaesthetics. Therefore, the prediction of the cranial spread of local anaesthetic, depending on the injected volume of the local anaesthetic, was not possible.
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Single-shot caudal anaesthesia is the most commonly used regional anaesthetic technique in children. The spectrum of indications is very broad and a large number of surgical procedures can be performed in caudal anaesthesia with or without concomitant general anaesthesia.

The reason for the popularity of caudal blocks in children is a high success rate, a steep learning curve, and a low incidence of severe complications.[1–3] Complications of the technique are mainly related to toxicity of the local anaesthetic and the pharmacokinetics of caudally administered common local anaesthetic solutions have been well-described.[4–7]

Despite the large amount of literature on caudal anaesthesia in children, the issue of volume of local anaesthetics and cranial spread is still not satisfactorily addressed. Earlier publications using various clinical assessment methods (e.g. pin-prick, skin pinching) to determine the cranial distribution of the block[8–10] report substantially higher dermatomal levels than what has been possible to observe in more recent studies using radiographic visualization of local anaesthetics mixed with a radio-opaque dye.[11 12] In summary, clinical assessment methods often describe that a mid-thoracic level is reached when using more than 1.0 ml kg^{-1} of local anaesthetics, whereas radiographic determinations rarely observe spread above the thoracolumbar junction.

The introduction of real-time ultrasound-guided regional anaesthesia has now made it possible to see the spread of local anaesthetics not only in peripheral nerve blockade but also in neuraxial paediatric regional anaesthetic techniques.[13–16] Thus, it is now possible to see the cranial spread of local anaesthetics in the caudal–epidural space in children using a non-invasive and objective method.

The aim of the present prospective randomized study was to evaluate the cranial spread of caudally administered local anaesthetics in paediatric patients by means of real-time ultrasound, with a special focus on the effects of using different volumes of local anaesthetics.

Methods

After institutional approval and informed parental consent, 75 children, <6 yr, a maximum weight of 25 kg, undergoing penile, anal, or inguinal surgery were included in this prospective, randomized, observer-blinded clinical trial. Children with known blood coagulation disorders, systemic inflammation, inflammation in the area of the site of injection, and anatomical abnormalities of the lumbosacral spine were excluded from the study.

Anaesthesia management

EMLA™ cream and an adhesive sterile tape were placed at the predetermined venous and caudal puncture sites 45 min before premedication with midazolam 1.0 mg kg^{-1} via the rectal or oral route (maximum dose 15 mg). Fifteen min after premedication, the child was transferred to the operation theatre and standard monitoring was applied (ECG, Sp_{O_2}, non-invasive blood pressure). After induction of anaesthesia using face mask (sevoflurane 8 vol% in O_2/air F_{IO_2} 50%), a peripheral venous access was established. Thereafter, sevoflurane was discontinued and sedation continued with i.v. propofol 5 mg kg^{-1} h^{-1}. Spontaneous ventilation with supplemental oxygen (2 litre min^{-1} and F_{IO_2} 50%) using face mask was maintained.

Ultrasound investigation, identification of T12 level, and conus medullaris

The child was placed in the left lateral decubitus 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 SonoSite™ 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 on the skin.

Caudal block under ultrasound observation

After sterile preparation of the injection site and covering the ultrasound probe with a transparent sterile adhesive cover (Safersonic™, Safersonic Medizinprodukte Handels GmbH, Ybbs, Austria), the sacral cornuae and the sacrococcygeal membrane were palpated for the exact identification of the injection site. The sacrococcygeal membrane was punctured with a 24G facette tip cannula (Pajunk Caudal Set according to Marhofer, Pajunk™, Geisingen, Germany) as illustrated in Figure 1.

Fig 1 Performance of the caudal block under ultrasound guidance. The black and white arrows indicate the position of TH-12 and the conus, respectively.

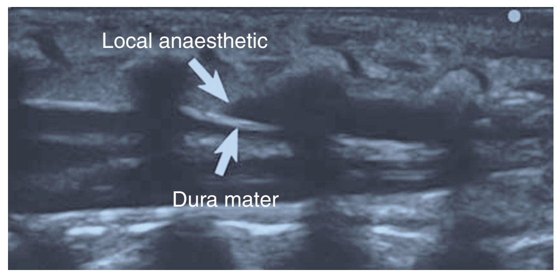

Fig 2 Ultrasound illustration of the spread of local anaesthetic inside the epidural space during caudal injection. The anechogenic area above the dura mater represents the local anaesthetic.

According to a computer-generated random list, the child was randomized to receive a total volume of 0.7 (Group 0.7), 1.0 (Group 1.0), or 1.3 ml kg^{-1} (Group 1.3) of ropivacaine (Naropin™, Astra Zeneca, Wedel, Germany). According to the existing hospital protocol, ropivacaine 2.0 mg ml^{-1} was used in children ≤ 12 months, whereas ropivacaine 3.5 mg ml^{-1} was used in children more than 12 months of age.[17] Thus, the maximum amount of ropivacaine administered was 4.55 mg kg^{-1}, representing a high but still safe dose according to previously published data.[5 6] The local anaesthetic solution was administered using a 10 ml syringe connected to a 30 cm extension tubing and the injection speed was kept at approximately 0.5 ml s^{-1}.

Ultrasound measurements

The spread of the local anaesthetic during the injection was directly observed via ultrasound in a longitudinal paramedian view (Fig. 2). After the completion of the injection, the front of the epidural local anaesthetic was identified and was 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 ultrasound front of the local anaesthetic 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 the 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 the local anaesthetic was recorded via MPEG 2 movies and BMP images and stored on the internal hard drive of the SonoSite™ M-Turbo ultrasound equipment.

One anaesthetist was dedicated to performing the caudal block, including drawing-up and injecting the correct amount of local anaesthetic, whereas a separate person was assigned to perform and evaluate the ultrasound scan. Thus, the ultrasound investigator was blinded with regards to the volume of the local anaesthetic injected.

Skin incision was performed 15 min after injection of the local anaesthetic. A successful block was defined as no motor (movements of extremities) or haemodynamic response (for 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), children received 0.1 mg kg^{-1} nalbuphine (Nalbuphine Orpha™), in which case the block was considered a failure.

The motor function of the lower extremities and the caudal puncture site was assessed in all children on the first postoperative day.

Statistical analysis and sample size calculation

For comparison of patient characteristics and of the differences in the spread of local anaesthetics in the epidural space, testing for normal distribution of the data was performed, followed by an ANOVA or a Kruskal–Wallis test as appropriate. A $P<0.05$ was considered significant. Pearson correlation coefficient was used to correlate the cranial spread of the local anaesthetic relative to the body weight, body height, and body mass index (BMI).

In order to investigate possible age-dependent differences in the cranial spread of the local anaesthetic, all three volume groups were pooled and divided by age (≤12 months and >12 months). Differences in the cranial segmental spread of local anaesthetic and the spread of local anaesthetic relative to the conus medullaris between these groups were analysed using the Kruskal–Wallis test.

A regular sample size calculation was not performed owing to the lack of previously published ultrasound-based data. However, a group size of 15 patients per group has previously been shown to produce statistical difference when using injection of a radio-opaque dye.[12] As it can be argued that ultrasound evaluation of cranial spread is slightly less exact when compared with radiographic examinations, we decided to include 25 patients in each group.

Results

A total of 75 children were included in the study. Relevant patient data and a CONSORT flowchart are shown in Table 1 and Figure 3, respectively. No statistical difference regarding relevant patient data was determined between the study groups. The distribution of the local anaesthetic inside the caudal–epidural space could be seen by ultrasound in all cases, thus, generating an upper level of cranial spread for all patients. Furthermore, all caudal blocks were considered successful as all the surgical procedures could be completed without any indications of insufficient analgesia as outlined in the Methods section.

A significant difference of ultrasound-assessed cranial spread of the local anaesthetic was found between Groups 1.3 and 0.7 (P=0.0002) and Group 1.0 (P=0.03), respectively (Fig. 4). However, no difference in cranial spread could be observed between Groups 0.7 and 1.0 (P=ns). The maximal level of cranial spread observed was T10 (one case in Group 1.3).

The distance of the cranial spread of the local anaesthetic relative to the conus medullaris is illustrated in Figure 5, showing a significant difference between Groups 0.7 and 1.0 (P=0.04) and Group 1.3 (P=0.0005), respectively. However, no difference in spread relative to the conus medullaris could be observed between Groups 1.0 and 1.3 (P=ns). The cranial segmental spread of caudally administered local anaesthetic in children ≤12 months and >12 months was not different (Fig. 6). The spread of caudally administered local anaesthetic relative to the conus medullaris was significantly different with a median (min, max) of −3 mm (+37, −35 mm) and −25 mm (+45, −70 mm) in children ≤12 months and >12 months, respectively (Fig. 7, P=0.003).

A *post hoc* evaluation of the spread of the local anaesthetic relative to weight, height, and BMI found weak inverse correlations with regard to these factors in all study groups (Table 2).

Table 1 Patient-relevant data presented as median (range)

	Group 0.7	Group 1.0	Group 1.3
Age (months)	32 (1–72)	24 (2–70)	21 (1–72)
Weight (kg)	12.8 (2.6–22.0)	11.3 (1.8–24.4)	9.3 (1.9–21.0)
Height (m)	0.88 (0.50–1.20)	0.79 (0.41–1.2)	0.75 (0.43–1.27)
BMI (kg m^{-2})	15.4 (10.6–18.9)	16.1 (9.3–23.5)	14.3 (9.4–18.8)

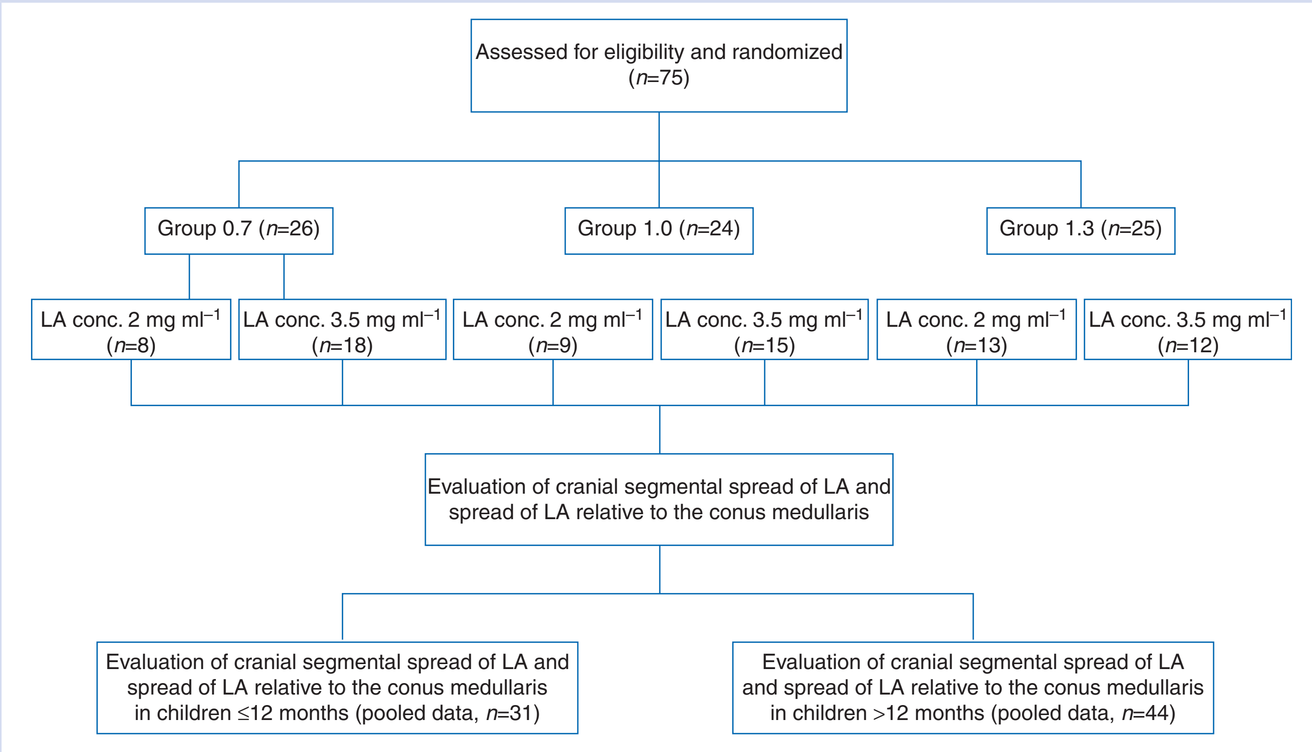

Fig 3 CONSORT statement.

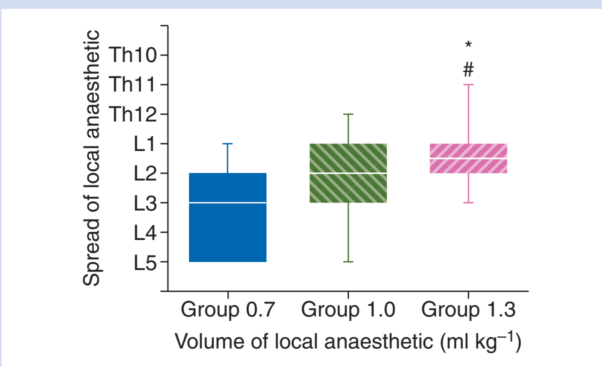

Fig 4 Cranial spread of local anaesthetic after caudal anaesthesia, representing the median, first, and third quartiles (boxes), and the range (whiskers). Asterisk denotes Group 1.3 *vs* Group 0.7, P=0.0002; hash represents Group1.3 *vs* Group 1.0, P=0.03.

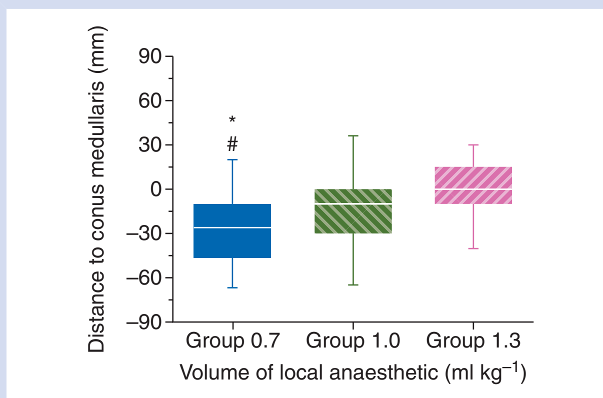

Fig 5 Distance of the spread of local anaesthetic relative to the conus medullaris after caudal anaesthesia, representing the median, first, and third quartiles (boxes), and the range (whiskers). Asterisk denotes Group 0.7 *vs* Group 1.3, P=0.0005; hash denotes Group 0.7 *vs* Group 1.0, P=0.04.

At the follow-up on the first postoperative day, all patients had normal motor function of the lower extremities and no patients had any signs of haematoma or infection at the caudal puncture site.

Discussion

The main finding of the present study was a positive but numerically small correlation between the injected volume of the local anaesthetic and the cranial spread of caudally administered local anaesthetics as assessed by ultrasound. However, the cranial extension of even high volume blocks (1.3 ml kg^{-1}) rarely reached above the thoracolumbar junction, with a maximally observed level of T10. Thus, predicting the cranial spread of the local anaesthetic from the injected volume of the local anaesthetic, with a reasonable degree of precision, was not found possible. No age-dependent differences in the cranial segmental spread of local anaesthetic have been detected, whereas a significant difference in the

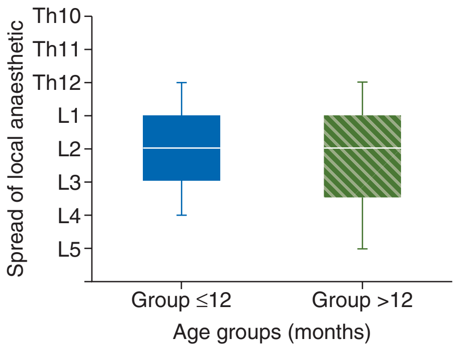

Fig 6 Cranial segmental spread of local anaesthetic after caudal anaesthesia in children ≤12 months and >12 months, representing the median, first, and third quartiles (boxes), and the range (whiskers).

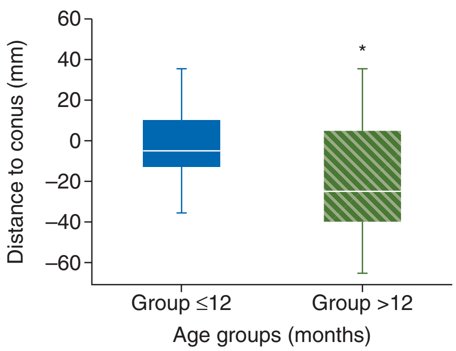

Fig 7 Cranial spread of local anaesthetic relative to the conus medullaris after caudal anaesthesia in children ≤12 months and >12 months, representing the median, first, and third quartiles (boxes), and the range (whiskers). *P=0.003.

cranial spread of local anaesthetic relative to the conus medullaris in children ≤12 months compared with children >12 months could be detected.

Despite the large literature on caudal blockade, dealing for example with intra- and postoperative analgesia, the learning curve for novices, effects of adjunct drugs, pharmacokinetics of different local anaesthetics and the rate of complication,[2 3 7 17–20] the issue of cranial spread of a caudal block in relation to the injected volume of local anaesthetic are still not satisfactorily addressed.

Early studies based on clinical cutaneous testing methods (e.g. pin-prick or skin pinching), performed under halothane anaesthesia about 15–20 min after the injection of local anaesthetics, did result in the publication of different predictive equations that are based on patient characteristics (e.g. age, height, and weight).[9 21] These early studies also suggested that a mid-thoracic level of analgesia could be anticipated if a volume of 1.25 ml kg^{-1} was used.[22]

Table 2 Pearson correlation coefficient for determination of the spread of local anaesthetic relative to weight, height, and BMI

	Group 0.7	Group 1.0	Group 1.3
Weight	−0.45	−0.20	−0.26
Height	−0.42	−0.31	−0.24
BMI	−0.38	−0.05	−0.20

Despite the impact of these early publications, a major point of discussion is the poor description with regards to the sensory testing methodology used in these studies and even to this day there does not exist a validated consensus on how such testing should be performed to allow precision and reproducibility. It is also the authors' clinical experience that even using local anaesthetic volumes in the order of 1.3–1.5 ml kg^{-1} do not consistently allow such procedures as umbilical hernia repair to be performed as an awake regional technique, indicating insufficient cranial spread of the local anaesthetic even when a high-volume caudal block is used.

In recent studies, more objective methods have been used to determine the cranial extension of caudally administered local anaesthetics, for example, radiographic visualization of local anaesthetics mixed with a radio-opaque dye. Using fluoroscopy, Koo and colleagues[11] showed that volumes ranging from 0.5 to 1.25 ml kg^{-1} usually failed to reach higher than the thoracolumbar junction (T10–L2), and similar results were reported by Thomas and colleagues[12] using 0.5–1.0 ml kg^{-1} followed by an anterior–posterior radiogram. Thus, there does exist a substantial discrepancy between the levels reported from the above quoted early studies using cutaneous testing and the more modern studies visualizing the spread by radiographic methods.

In 1994 Kapral and colleagues[23] were the first to describe the use of real-time ultrasound for visualization of the spread of local anaesthetics during peripheral nerve blocks. This new technology has subsequently also been found applicable to verify that the injection of local anaesthetics during a caudal block in fact does result in caudal–epidural deposition.[24]

In the present study, we used ultrasound to determine the cranial spread of caudally administered local anaesthetics in children from 1 month to 6 yr of age using randomized volumes of local anaesthetics related to patient weight (0.7, 1.0, and 1.3 ml kg^{-1}, respectively). Despite finding a significantly higher level of cranial spread when using larger volumes of local anaesthetics, the observed differences were numerically quite small and do not allow for any reasonable prediction of a volume–cranial extension relationship based on volume per kilogram body weight. We also note with interest that the cranial extension of the blocks rarely reached higher than the level of T11, a finding that corroborates the results of the more modern studies using radiographic visualization of spread.[11 12]

The anatomy of the vertebral column is subject to age-dependent changes up to 12 months of age.[25] Therefore, we compared the cranial segmental spread of local anaesthetic in children ≤12 months and >12 months, and did not find an age-dependent difference regarding segmental distribution (Fig. 6). According to these findings, there is no need to adapt the volumes for caudally administered local anaesthetics in different age groups. Contrariwise, we found an age-dependent significant difference in the cranial spread of caudally administered local anaesthetic relative to the conus medullaris (Fig. 7), which might be owing to changes in the relative position of the conus medullaris with age.[15] The clinical relevance of the latter finding should be the subject of further investigations.

Our present results are also in agreement with our own recently published data, where we assessed the cranial spread of a fixed large volume of local anaesthetics (1.5 ml kg^{-1}) in different age groups (neonates, infants, and toddlers) using the same ultrasound technique as described in the present study.[24] In that study, we found that the spread was affected by different patient factors (e.g. age, weight, and height) and that a significantly higher level of local anaesthetic spread was observed in neonates and infants when compared with toddlers. However, the actual difference in cranial spread between the various age groups was on average only one segment (T12 neonates/infants *vs* L1 toddlers) and all blocks except one were confined at or below the segmental area of T11.

As discussed in our recent publication,[24] the discrepancy between the earlier studies based on cutaneous testing and the more recent studies using objective radiographic visualization of spread (e.g. X-ray or ultrasound) can be explained by at least two obvious factors. First, the timing of the assessments differ considerably as the radiographic methods assess the distribution of the local anaesthetics immediately after the injection of the local anaesthetic, whereas the cutaneous testing was typically performed about 15–20 min after the block procedure. Thus, the radiographic methods do not take any secondary spread within the spinal canal into account. Second, the radiographic studies evaluate the visual spread of the local anaesthetic within the spinal canal, whereas the earlier studies tested the pain response to actual nociceptive cutaneous stimulation. Thus, different dimensions are assessed, which makes it very difficult to compare the results of the earlier and the more recent studies on the cranial spread of caudal blocks. Furthermore, it should be noted that the cutaneous testing was performed under 'light' halothane anaesthesia but as end-tidal measurements of volatile agents was not available at the time of these studies, it is very difficult to assess in fact how deeply the children were anaesthetized. This could obviously result in marginally anaesthetized dermatomes being classified as properly blocked dermatomes owing to the additional effect of the halothane anaesthetic, something that would result in an artificially high block level being noted.

From a clinical perspective, all blocks in our present study, regardless of the volume of local anaesthetic used, resulted in successful surgical anaesthesia. In this context it should be noted that our patients received only a moderate concomitant i.v. infusion of propofol during the surgical intervention. A propofol infusion of this magnitude does not provide any significant degree of analgesia, an aspect that considerably differs when compared with the concomitant administration of volatile anaesthetics. Thus, if the anaesthetist can verify that the injection of local anaesthetics does result in the expected spread within the caudal–epidural space, one can reliably expect that inguinal hernia repair and more distal surgery can be successfully performed even using a volume as low as 0.7 ml kg^{-1}.

In conclusion, the ultrasound assessment of local anaesthetic spread after a caudal block showed that cranial spread of the block is dependent on the volume injected into the caudal space. However, the dermatomal difference in cranial spread in the volume range 0.7–1.3 ml kg^{-1} was only minor, with the majority of the blocks below the thoracolumbar junction. This together with the observed variability does not allow for any clinically useful prediction of cranial block level based on the injected volume.

Conflict of interest

None declared.

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