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ORIGINAL ARTICLE

Utility of longitudinal paramedian view of ultrasound imaging for middle thoracic epidural anesthesia in children

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Abstract
Purpose The risk of nerve injury for pediatric thoracic epidural block increases stress for anesthesiologists. The purpose of this study was to investigate the usefulness of longitudinal ultrasound imaging for thoracic epidural block (T5–T6 or T6–T7) in anesthetized children scheduled for the Nuss procedure.
Methods Neuraxial structure in the longitudinal paramedian section was observed using ultrasound imaging before epidural puncture (US group, $n = 10$). In the control group, usual epidural block without ultrasound was performed. Attempts were made to observe epidural catheterization in ultrasound imaging in three cases.
Results Patient age ranged from 5 to 7 years. Time for epidural block in the US group [100 (77–116) s; median value (95% confidence interval)] was significantly shorter than that in the control group [165 (130–206) s; $P = 0.001$]. The difficulty score was significantly lower in the US group than in the control group ($P < 0.001$). Epidural catheterization was observed in all three cases in which the catheter manipulated the dura mater ventrally. There was a high correlation ($r = 0.98$, $P < 0.001$) between needle depth and ultrasound estimation of the skin–dura distance in the US group.
Conclusion We concluded that longitudinal paramedian ultrasound imaging could reduce performance time and the difficulty for anesthesiologists during epidural block.

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Introduction

Epidural block for pediatric patients is commonly performed under general anesthesia with a muscle relaxant, and it may be difficult to detect symptoms of neurological response such as paresthesia or muscle twitch caused by inadequate needle advancement or catheter placement. Risks of nerve injury and inadequate catheterization increase stress for anesthesiologists. Although an ultrasound prescan to observe relevant neuraxial structures should increase successful pediatric epidural block and enable a safe and comfortable epidural puncture [1, 2], there is no report showing the advantages of ultrasound imaging for thoracic epidural anesthesia in pediatric patients under general anesthesia. The purpose of this study was to investigate whether longitudinal paramedian ultrasound imaging could improve the difficulty with thoracic epidural block in anesthetized pediatric patients.

Materials and methods

Ethical approval for the study was provided by the Ethics Committee of our institution, and written informed consent was obtained from all patients and their parents. Twenty patients with ASA physical status classification of I who were scheduled to undergo the minimally invasive Nuss procedure for pectus excavatum were randomly assigned to an ultrasound group (US group, $n = 10$) or a control group ($n = 10$). Patients known or suspected to have neurological diseases, local infection, coagulation abnormality, seizures, allergy to a local anesthetic, or anatomical malformation of centroaxial structures were excluded from the study.

General anesthesia was induced with inhalation of 5% sevoflurane in oxygen. After tracheal intubation with 0.1 mg/kg vecuronium, anesthesia was maintained with 66% nitrous oxide and 1–2% sevoflurane, and children were placed in a right lateral position for epidural anesthesia. We scheduled the T5–T6 intervertebral space as the first order of precedence for epidural puncture. When it was evaluated to be narrower than T6–T7 by ultrasound imaging in the US group or palpation in the control group, T6–T7 was selected for the epidural puncture. In the US group, ultrasound examination was performed by one of two authors (M.Y. or N.T.) with a convex 3–5 MHz probe connected to a portable ultrasound unit (LOGIC Book; GE Healthcare, Norwalk, CT, USA). The ultrasound probe was applied from the sacrum to the thoracic region in longitudinal view to identify the T5–T6 epidural space. Neuraxial structures at T5–T6 were visualized in longitudinal paramedian view (Fig. 1a). The shortest depth from the dura mater to the skin was measured using the relevant "frozen image" of the ultrasound for the epidural puncture. The measured point on the skin was marked as the puncture point. Time for this ultrasound procedure was measured. After aseptic skin disinfection, epidural puncture was performed with reference to the angle of the probe to the skin and the measured distances by ultrasound imaging. In the control group, the puncture point was decided by palpation from the sacrum to T5. In both groups, all epidural punctures were performed by a senior attending anesthesiologist using an 18-gauge Touhy needle (Hakko, Tokyo, Japan), and the epidural space was identified by the loss-of-resistance technique with 2 ml physiological saline. Finally, a catheter was introduced 4 cm into the epidural space through the needle. In patients who had undergone computed tomography (CT) for primary disease, skin to T5–T6 epidural space distances from CT were estimated using computed calculating functions of the imaging system without referring to ultrasound examination or needle depth. Statistical correlation was calculated in gathering every patient's data.

Needle depth from skin to the epidural space, the number of epidural puncture attempts, and time from the start of the first puncture to completion of epidural catheterization were compared between the groups. The number of ventral advances of the needle was counted as puncture attempts. Difficulty in epidural puncture was evaluated by the operator using a five-point scale (1 = very easy, 2 = easy, 3 = conventional, 4 = difficult, 5 = very difficult). In three cases, insertion of the epidural catheter was confirmed by ultrasound imaging. If a patient complained of severe postoperative pain despite sufficient epidural administration of local anesthetics, this case was defined as failed block. The primary outcome of the study was the number of puncture attempts, and secondary outcomes were puncture time and difficulty in epidural puncture. Statistical analysis was performed using the SPSS software package for Windows, version 18.0.0 (SPSS, IBM Company Headquarters, Chicago, IL, USA). Data were analyzed by the Mann–Whitney U test, and $P < 0.05$ was considered statistically significant. Pearson's correlation coefficient between distance from skin to epidural space measured by ultrasound, and needle depth of actual epidural puncture, were also calculated in the US group.

Results

The groups were similar with respect to all demographic variables (Table 1). Epidural catheterization was successful in all children at T5–T6 or T6–T7, and there was no failed block case. There was no significant difference in the number of epidural puncture attempts (Table 2). There were significant difference between the groups in time for epidural block and difficulty score. A high correlation ($r = 0.98$, $P < 0.001$) between needle depth and ultrasound estimation of the skin–dura distance in the US group was demonstrated. A significant correlation ($r = 0.96$,

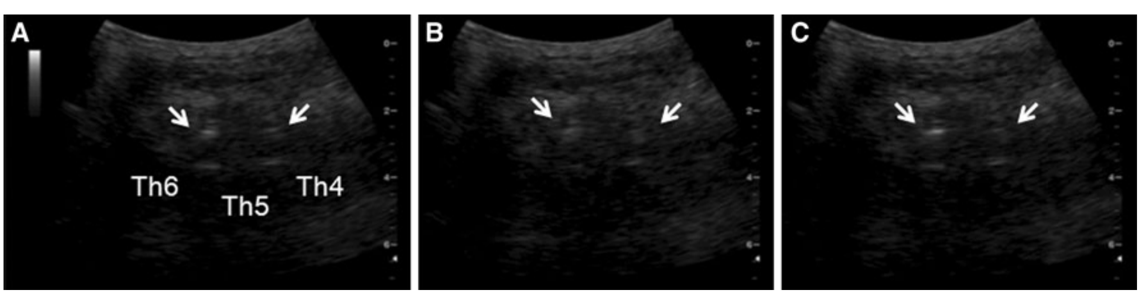

Fig. 1 **a** Longitudinal ultrasound imaging of the T4–T6 (*Th4*, *Th5*, *Th6*) spinal canal in a 5-year-old child. *Arrows*, dorsal dura mater. **a–c** Sequence ultrasound imaging of thoracic epidural catheter in the longitudinal view. The dorsal dura mater and that of the T5–T6 intervertebral space were synchronously shaken (i.e., appeared and disappeared) with insertion of the epidural catheter, expressed as the repetition of appearance (**a**, **c**) and disappearance (**b**) of the dorsal dura mater

$P < 0.001$) was also demonstrated between needle depth and CT estimation of the skin–dura distance in all patients. In three cases in the US group, we succeeded on observing catheterization into the cephalad epidural space by paramedian longitudinal ultrasound imaging. Although the epidural catheter could not be observed in the ultrasound imaging, location of the catheter could be identified by movement of the dura mater synchronizing with gentle manipulation of the catheter in all three cases (Fig. 1). This repetitive movement of the dura mater gradually migrated to the cephalad side by inserting the catheter. No patients experienced severe side effects.

Discussion

We could observe the middle thoracic dura mater in older children and accurately estimate the distance from skin to the epidural space. This technique would facilitate pediatric middle thoracic epidural puncture under general anesthesia.

The minimally invasive Nuss procedure for pectus excavatum causes severe pain [3], and epidural anesthesia with bed rest is useful to reduce postoperative pain and respiratory complications [4]. However, epidural block performed under general anesthesia with a neuromuscular relaxant in pediatric patients has the risk of complications, including dural puncture, subarachnoid or intravascular catheterization, inadequate spread of local anesthetics, and neurological trauma. It seems that most anesthesiologists do not have enough experience to perform thoracic epidural block in pediatric patients and hesitate to perform the block because of anxiety about the complications. The present study showed that an ultrasound prescan made pediatric epidural block easier than simple palpation and would facilitate smooth performance of the thoracic epidural block.

An ultrasound prescan enables easy estimation of the appropriate angle and the distance from skin to the epidural space as well as showing the appropriate puncture point on the skin [5, 6]. Very high correlations between the skin–epidural space distance determined by epidural puncture and that measured by ultrasound ($r = 0.88$–0.92) have been reported in infants and small children [2, 5, 7]. The correlation calculated in the present study was almost the same as those results. Position of an epidural catheter is also identical through the wide acoustic window. Rapp et al. [2] reported ultrasound-guided epidural catheter insertion in children using a linear probe, and longitudinal median, longitudinal paramedian, and short axis levels were visualized [2]. However, it is difficult to use a linear probe for observing the thoracic epidural space in older children. The sharp angle of the spinous process and the vertebral arch in the thoracic region reduce the acoustic window, and the ultrasound beam from a linear probe cannot penetrate the acute angle window, especially in a short-axis view [8]. The ultrasound beam from the 3–5 MHz convex probe deeply penetrates the spinal column compared to that of a high-frequency linear probe. Thus, a longitudinal paramedian view by convex probe should be preferable to identify the thoracic epidural space in older children. Although the CT estimation and the needle depth in the present and previous studies [8] had high correlation, the 95% confidence interval was wider in CT data than that of ultrasound data. The larger the body size of patients, the larger a range of error would be for distance from skin to the epidural space as measured by CT or needle depth compared to that value obtained by ultrasound imaging.

We should point out a limitation of this study. First, the number of patients in this study was small and we did not perform power analysis. Enrollment of a sufficient number of patients may provide additional evidence such as body mass-related correlation with the utility of ultrasound

Table 1 Patient characteristics

	Control group	US group
n (male:female)	10 (5:5)	10 (7:3)
Age (years)	9 ± 4	9 ± 4
Body height (cm)	128 ± 24	133 ± 26
Body weight (kg)	30 ± 20	32 ± 17
Epidural puncture site (T5–T6/T6–T7)	6/4	6/4

Mean ± SD

US ultrasound

Table 2 Data for epidural puncture

	Control group	US group	*P*
Time for epidural block (s)	165 (130–206)	100 (77–116)	0.001
Ultrasound prescan time (s)	NA	133 (115–154)	–
Number of epidural puncture attempts	2 (1–3)	1 (1–2)	0.14
Needle depth to epidural space (mm)	33 (21–44)	35 (28–43)	0.44
US estimation of skin–dura distance (mm)	NA	32 (25–38)	–
CT estimation of skin–dura distance (mm)	27 (21–41)	28 (22–34)	0.36
Difficulty score	4 (3–4)	2 (1–2)	<0.001

Median values (95% confidence interval)

US ultrasound, *CT* computed tomography, *NA* not applicable imaging. Second, this study was not performed in a blind manner, and difficulty in the score or anxiety of anesthesiologists was not evaluated precisely. Although statistical differences were shown, these results could have involved bias of the operator. In addition, the difficulty score involved subjective judgment. Third, although catheterization in the epidural space was judged by ventral movement of the dura, there is no guarantee that the epidural catheter was identified in every case. A high-resolution ultrasound system or highly visible catheter could facilitate direct identification in ultrasound imaging [1]. The spread of local anesthetics or bubble-based fluid is also helpful to confirm catheter location [9].

We conclude that the longitudinal paramedian ultrasound imaging can visualize middle thoracic epidural space and catheterization in children. This technique would reduce the time for epidural catheterization and the difficulty of anesthesiologists during the procedure.

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