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ORIGINAL RESEARCH

Estimation of the depth of the thoracic epidural space in children using magnetic resonance imaging

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Background: The estimation of the distance from the skin to the thoracic epidural space or skin to epidural depth (SED) may increase the success rate and decrease the incidence of complications during placement of a thoracic epidural catheter. Magnetic resonance imaging (MRI) is the most comprehensive imaging modality of the spine, allowing for the accurate determination of tissue spaces and distances. The present study uses MRI-derived measurements to measure the SED and define the ratio between the straight and inclined SEDs at two thoracic levels (T_{6-7} and T_{9-10}) in children.

Methods: The T_2-weighed sagittal MRI images of 109 children, ranging in age from 1 month to 8 years, undergoing radiological evaluation unrelated to spine pathology were assessed. The SEDs (inclined and straight) were determined, and a comparison between the SEDs at two thoracic levels (T_{6-7} and T_{9-10}) was made. Univariate and multivariate linear regression models were used to assess the relationship of the inclined thoracic T_{6-7} and T_{9-10} SED measurements with age, height, and weight.

Results: Body weight demonstrated a stronger association with the SED than did the age or height with R^2 values of 0.6 for T_{6-7} and 0.5 for T_{9-10}. The formulae describing the relationship between the weight and the inclined SED were T_{6-7} inclined (mm) = $7 + 0.9 \times$ kg and T_{9-10} inclined (mm) = $7 + 0.8 \times$ kg.

Conclusion: The depth of the pediatric thoracic epidural space shows a stronger correlation with weight than with age or height. Based on the MRI data, the predictive weight-based formulas can serve as guide to clinicians for placement of thoracic epidural catheters.

Keywords: thoracic epidural space, magnetic resonance imaging, measurement techniques

Introduction

Epidural anesthesia/analgesia in children has increased in popularity over the past 20 years, with a very low rate of complications following direct thoracic placement.[1–3] In addition to providing effective analgesia following major thoracic and upper abdominal procedures, it may offer compelling physiologic advantages over systemic opioid analgesia in infants and children, including a reduced need for postoperative ventilatory support, improved analgesia without the risk of opioid-induced respiratory depression, and improved control of the surgical stress response.[4–10]

Direct placement of a thoracic epidural catheter in the pediatric-aged patient may be technically challenging due to compliant soft tissues/ligaments as well as shallow and variable distances from the skin to the epidural space. The prediction of the actual depth of the thoracic epidural space or the skin to epidural depth (SED) may increase the success rate and improve the safety of epidural procedures.[11,12] The SED varies

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depending on the vertebral level, patient characteristics, including age and weight, and the angle of needle entry for puncture.[13] The SED in children has been derived mainly from direct needle measurements after entry into the epidural space, computed tomography (CT) imaging, magnetic resonance imaging (MRI), and ultrasonography.[13–15]

MRI is highly sensitive for identifying injuries to the posterior longitudinal ligament and interspinous soft tissues when compared to CT imaging and remains the method of choice for assessing spinal cord lesions and ligamentous injury.[16–18] Since MRI is the most comprehensive imaging modality of the paraspinal and intraspinal soft tissues and ligaments, the measurements derived may be more accurate and thereby provide a useful tool to derive the SED. The primary objective of the current study was to derive a formula from MRI-based data for predicting the SED in infants and children. The secondary aim was to evaluate potential differences in the SED at various thoracic levels and to determine how changes in the needle approach (straight versus inclined) may affect these measurements.

Methods

A database search of the electronic medical records identified MRI examinations of the lumbar and thoracic spine performed in children up to 8 years of age. The institutional review board (IRB) of King Fahad Medical City approved the study. Informed consent was waived by the IRB on the basis that it was a retrospective study where the collection of radiological data was based on deidentified patients by the archive department only. Exclusion criteria included any diagnosis or condition that the investigators felt would cause abnormal spinal anatomy or interfere with the measurements obtained during MRI. Patients with scoliosis, tethered cord, spina bifida, myelomeningocele, tumors of the spinal cord or vertebral bodies, spinal metastatic disease, and those outside the 10th–90th percentile of weight-for-age based on World Health Organization growth standards were excluded from the study. Patients with poor image quality were also excluded.

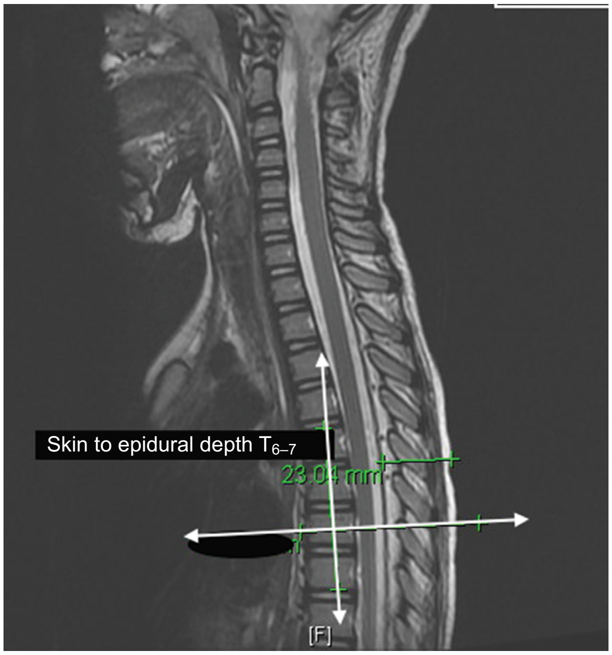

Figure 1 Magnetic resonance image of the thoracic spine and vertebral bodies showing technique for the measurement of the perpendicular skin to epidural distance at the $T_{6–7}$ interspace.
Note: The measurement was taken perpendicular to the long axis of the vertebral body (dark lines).

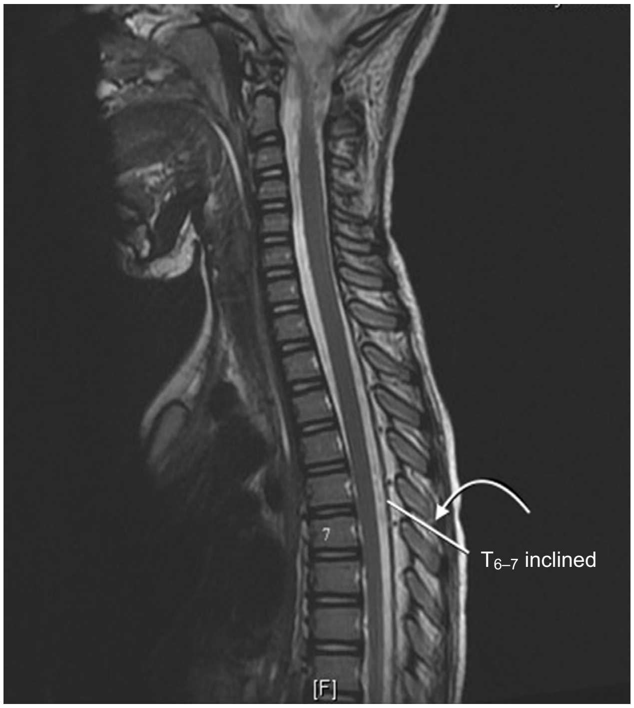

Figure 2 Magnetic resonance image of the thoracic spine and vertebral bodies showing technique for the measurement of the inclined skin to epidural depth at the $T_{6–7}$ interspace.
Note: The measurement (inclined) was taken between and parallel to the spinous processes.

Using an internal measurement device, sagittal T_2-weighted imaging of the thoracic spine was used to measure the SED (distance from the skin edge to the dural side of the ligamentum flavum) at the $T_{6–7}$ and $T_{9–10}$ interspaces. At each level, two measurements were taken. The first measurement was taken perpendicular to the long axis of the vertebral body. The second measurement (inclined) was taken between the spinous processes with the measurement parallel to the spinous processes (Figures 1 and 2). Measurements were taken by two of the authors (AN and AH) independent of each other and verified by a coauthor. The measurement used was the mean distance of both observers (MR). All authors subsequently reviewed any discrepancy between the measurements. All investigators were blinded to the age of the patients until measurements were analyzed.

Statistical analysis

All analyses were performed using SPSS. Group comparisons were performed using independent samples *t*-tests after verifying approximate normality and equality of group variances. Univariate and multivariate linear regression models were used to assess the relationship of the inclined thoracic T_{6-7} and T_{9-10} SED measurements with the age, height, and weight. $P < 0.05$ was considered statistically significant. Coefficient of determination (R^2) was calculated to study the predictive ability of age, height, and weight on the inclined thoracic T_{6-7} and T_{9-10} SED measurements. Confidence intervals were calculated for all the age groups. Two-sided P-values <0.05 were considered statistically significant. The ratios between inclined and straight SEDs at the two levels were analyzed.

Results

A total of 109 MRI scans of the spine in children, ranging in age from 1 month to 8 years undergoing radiological evaluation unrelated to spine pathology, were included in the study cohort. Of these 109 patients, 68 (62%) were boys with a mean age of 46.1 ± 16.1 months and 41 (37%) were girls with a mean age of 63 ± 21.6 months. The mean values and confidence intervals of inclined and straight SEDs (T_{6-7} and T_{9-10}) for all the age groups are listed in Table 1. No difference in the SEDs was noted based on gender (Table 2).

Using univariate analysis (Table 3), all the variables studied (age, height, and weight) showed a significant positive relationship with the SEDs at T_{6-7} and at T_{9-10} (inclined). Weight showed the strongest association with the inclined SED (T_{6-7} and T_{9-10}) with R^2 values of 0.6 for inclined measurements at T_{6-7} and 0.5 for inclined measurements at T_{9-10} (Figures 3 and 4). In the multivariate regression analysis (Table 4), weight was the only variable that predicted the inclined SED (T_{6-7} and T_{9-10}) independently with $P < 0.05$ and $R^2 = 0.5$. Age and weight did not contribute to a further reduction in the variance of the inclined SED at T_{6-7} or T_{9-10} (Figures 3 and 4). The data demonstrated a well-defined relationship between the weight and the inclined SED at T_{6-7} and T_{9-10}. Based on these data, the following formulas were developed:

$$T_{6-7} \text{ inclined (mm)} = 7 + 0.9 \times \text{kg}$$

$$T_{9-10} \text{ inclined (mm)} = 7 + 0.8 \times \text{kg}$$

Table 1 Distribution of SED measurements by age

Age (years)	Level	Mean ± SD (mm)	95% Confidence interval	
			Lower (mm)	Upper (mm)
0–1 (n = 4)	T_{6-7} straight	13.9 ± 3.2	8.9	17.3
	T_{6-7} inclined	15.6 ± 2.9	11.1	20.2
	T_{9-10} straight	13.7 ± 2.8	9.6	17.9
	T_{9-10} inclined	15.1 ± 2.7	10.9	19.3
1–2 (n = 5)	T_{6-7} straight	16.7 ± 1.9	10.9	22.5
	T_{6-7} inclined	19.5 ± 2.1	13.4	25.5
	T_{9-10} straight	15.8 ± 1.5	9.9	21.6
	T_{9-10} inclined	18.5 ± 1.8	11.3	25.7
2–3 (n = 13)	T_{6-7} straight	16.9 ± 1.9	10.9	22.5
	T_{6-7} inclined	18.5 ± 2.1	13.4	25.6
	T_{9-10} straight	16.3 ± 1.5	15.5	17.2
	T_{9-10} inclined	18.2 ± 1.8	17.1	19.2
3–4 (n = 27)	T_{6-7} straight	18.1 ± 3.5	16.7	19.5
	T_{6-7} inclined	20.5 ± 3.9	18.9	21.9
	T_{9-10} straight	17.1 ± 2.9	15.9	18.2
	T_{9-10} inclined	19.3 ± 3.3	17.9	20.6
4–5 (n = 21)	T_{6-7} straight	19.3 ± 3.1	17.9	20.7
	T_{6-7} inclined	22.1 ± 4.1	20.3	23.9
	T_{9-10} straight	18.4 ± 2.9	17.1	19.8
	T_{9-10} inclined	20.7 ± 3.5	19.1	22.2
5–6 (n = 29)	T_{6-7} straight	20.1 ± 5.1	18.9	22.8
	T_{6-7} inclined	24.1 ± 5.9	21.9	26.3
	T_{9-10} straight	20.7 ± 5	18.8	22.6
	T_{9-10} inclined	22.7 ± 5.7	20.1	24.9
6–7 (n = 10)	T_{6-7} straight	21.5 ± 5.5	17.7	25.4
	T_{6-7} inclined	27.5 ± 10.3	20.2	34.9
	T_{9-10} straight	22.4 ± 7.1	17.4	27.5
	T_{9-10} inclined	25.5 ± 9.2	18.9	32.1
7–8 (n = 6)	T_{6-7} straight	22.8 ± 5	18.7	27
	T_{6-7} inclined	28.3 ± 8.9	20.8	35.8
	T_{9-10} straight	23.6 ± 6.5	18.2	28.9
	T_{9-10} inclined	26.7 ± 7.6	20.4	32.9

Abbreviations: SED, skin to epidural depth; SD, standard deviation.

Table 2 Comparison of the SED between genders

Level of measurement and incline	Gender	Mean ± SD (mm)	95% Confidence interval		*P*-value
			Lower (mm)	Upper (mm)	
T_{6-7} straight	Boys	18.1 ± 3.4	17.3	18.9	0.00
	Girls	20.9 ± 5.3	19.1	22.5	0.00
T_{6-7} inclined	Boys	20.5 ± 3.9	19.6	21.4	0.00
	Girls	24.5 ± 7.3	22.1	26.7	0.00
T_{9-10} straight	Boys	19.5 ± 3.6	18.7	20.5	0.00
	Girls	20.8 ± 5.3	18.9	22.6	0.00
T_{9-10} inclined	Boys	19.6 ± 3.6	18.7	20.1	0.00
	Girls	22.9 ± 6.8	20.8	25.9	0.00

Abbreviations: SED, skin to epidural depth; SD, standard deviation.

Table 3 Univariate regression effects of inclined measurements of SED

Level	Parameter	SE (mm/month)	*P*-value	R^2
T_{6-7} inclined	Age	0.03	0.000	0.3
	Height	0.06	0.000	0.3
	Weight	0.16	0.000	0.6
T_{9-10} inclined	Age	0.23	0.000	0.3
	Height	0.04	0.000	0.2
	Weight	0.09	0.000	0.6

Abbreviations: SED, skin to epidural depth; SE, standard error.

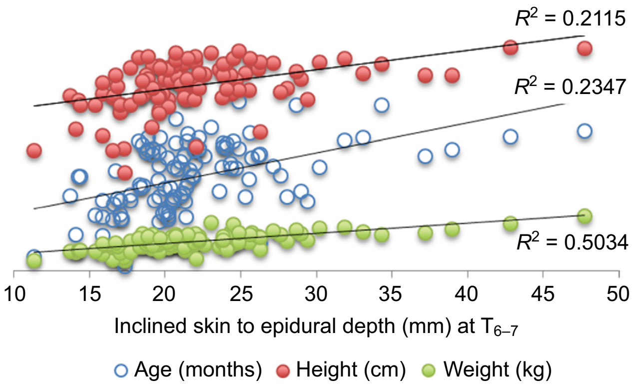

Figure 3 Linear correlation of age, height, and weight with straight skin to epidural depth at T_{6-7}.

Over the various ages, T_{6-7} straight varied from 8.9 to 35.9 mm and T_{9-10} straight varied from 10.3 to 28.9 mm; T_{6-7} inclined varied from 11.4 to 47.7 mm and T_{9-10} inclined varied from 10.9 to 41 mm (Figure 5). The incline to straight ratios at T_{6-7} and T_{9-10}swere 1.1 ± 0.1 (0.9–15) and 1.1 ± 0.09 (1.0–1.4), respectively.

Discussion

Information regarding the depth from the skin to the thoracic epidural depth may be a useful adjunct to the clinician and may help minimize complications during placement of neuraxial catheters. Although clinical experience has demonstrated the safety of the direct placement of an epidural catheter at the thoracic level, complications may occur including inadvertent entry into the intrathecal space and rarely neurologic damage.[19] Deep insertion of a needle beyond the distance to the epidural space may theoretically lead to inadvertent trauma to the spinal cord, nerve roots, or entry into the intrathecal space. These issues may be further compounded when supervising trainees as there is no direct tactile sensation available as the soft tissue and ligaments are entered. Knowing the distance to the epidural space so that excessive needle entry is avoided may prevent such issues.

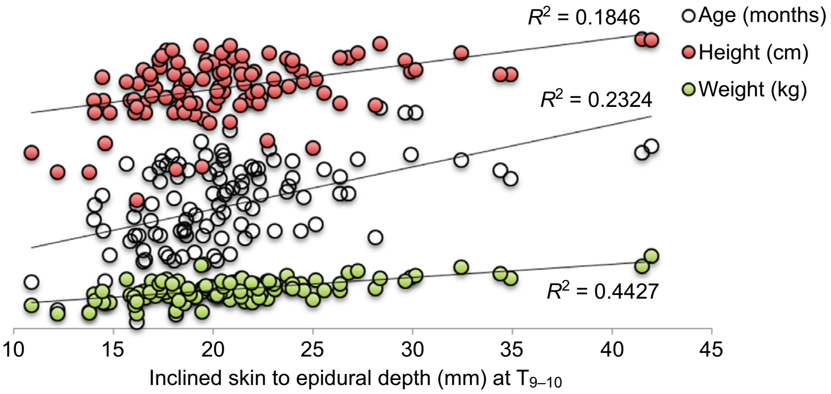

Figure 4 Linear correlation of age, height, and weight with inclined skin to epidural depth at T_{9-10}.

Table 4 Multivariate regression effects on T_{6-7} inclined and T_{9-10} inclined SEDs

Level	Parameter	Coefficient	SE	*t*	*P*-value	95% Confidence interval	
						Lower	Upper
T_{6-7} inclined	Age	0.056	0.033	0.505	0.615	−0.048	0.081
	Height	−0.389	0.056	−3.034	0.003	−0.283	−0.059
	Weight	0.985	0.153	8.335	0.000	1.0	1.579
T_{9-10} inclined	Age	0.136	0.032	1.148	0.254	−0.027	0.100
	Height	−0.415	0.055	−3.042	0.003	−0.277	−0.058
	Weight	0.903	0.150	7.18	0.000	0.778	1.372

Abbreviations: SEDs, skin to epidural depth; SE, standard error.

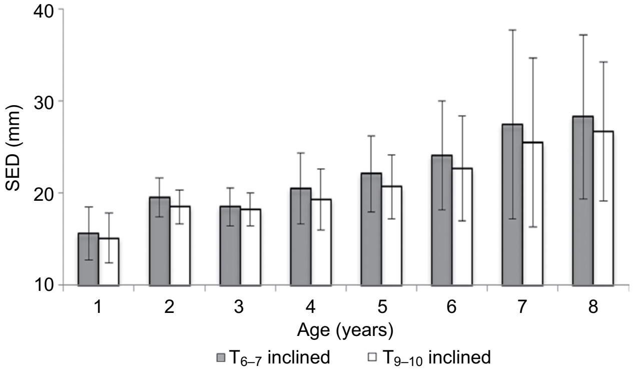

Figure 5 Comparison of the skin-to-epidural distance (SED) at T_{6-7} and T_{9-10} (inclined).

The present study using MRI is the first effort at defining the SED in children at two specific thoracic levels (T_{6-7} and T_{9-10}) and deriving a relationship between the straight and the inclined SEDs at these levels. The data demonstrate that although there was a relationship between SED with age, height, and weight, the correlation was greatest with weight. Formulae for the calculation of the SED at the thoracic level in children have been previously suggested.[20] Masir et al reported a linear relation between the SED and the weight in a clinical study of 61 children. The formula devised by Masir et al[20] (SED = 1.95 + [0.045 × kg]) does not appear to be applicable to small children as the fixed constant of 1.95 cm (19.5 mm) used in their calculation is greater than the mean SED in the younger children (≤4 years of age) in our study. The formula that we devised has a smaller fixed constant of 0.7 cm (7 mm) that is applicable to children of all ages. The discrepancy between the two formulae can be explained by the differences in the cohorts of the two studies with the mean age of our study being 51.4 months with a weight of 16.3 kg compared to 61.6 months with 19.7 kg in the study of Masir et al. The smaller SED at lower thoracic intervertebral spaces observed in their study is similar to our findings; however, the wide interindividual variability observed by Masir et al was not seen in our study.

To our knowledge, this is the first study using MRI to evaluate the SED at the thoracic level in the pediatric population. Franklin et al[15] used MRI to evaluate the SED in 70 children aged <6 years at the lumbar level and derived a formula for estimation of the SED. Their weight-based formula for lumbar SED (SED [mm] = 9.00 + 0.62 × kg) is comparable to our predictive formula for thoracic SED ([T_{6-7} inclined] = 7.00 + 0.9 × kg). The fixed constant in our predictive formula closely resembles that of the Franklin et al's formula.

One of the challenges confronted when attempting to measure the SED is that the distance will be affected by the needle angle with an increased SED noted as the angle decreases to <90° to the skin. Although straight distances may be applicable when ultrasound is used to guide epidural catheter placement especially at the lumbar interspaces, a more acute angle is commonly used at the thoracic level. Kil et al[21] reported a significant correlation between ultrasound-guided prepuncture measurements and the actual SED for lumbar epidural catheter placement. However, as the usual entry line into the thoracic epidural space is more inclined than the lumbar approach, a direct correlation would not be expected with ultrasound-guided measurements. In the current study using MRI, a constant ratio of 1.1 was observed between inclined and straight SEDs at each level. This ratio may be helpful in calculating the inclined depth from the ultrasound-measured perpendicular depth.

One drawback of the current study is the limited study cohort size. Subsequent clinical validation with future trials to add additional patients will be of value in predicting the accuracy of the formulas derived from this study. One of the major limitations of the current study is that all of the patients were studied in the supine position while epidural catheter placement is performed in either the sitting or lateral decubitus position. To date, there are limited data regarding changes in the SED with changes in positioning. In a study of 10 young, healthy female volunteers, the SED did not change when measured using MRI in the flexed and neutral positions.[22]

Conclusion

The main advantage of the present study is that the measurements are based on MRI measurements, which is accepted as the most accurate imaging technology available. While meticulous attention to placement technique, provider experience, and proper equipment for thoracic epidural catheter placement is mandatory, the proposed arithmetic calculation may aid anesthesiologists by providing an estimation of the SED. This information may facilitate accurate needle placement and decrease the risk of complications. The data derived from the current study need subsequent clinical validation with a clinical study comparing the calculated versus the actual SED.

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Author contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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