The accuracy of ultrasound to predict endotracheal tube size for pediatric patients with congenital scoliosis

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Research article

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Abstract

Background: Ultrasonography has been used for prediction the endotracheal tube(ETT) size through measuring the cricoid cartilage diameter. The aim of this study was to determine the accuracy of ultrasound to predict ETT size for pediatric patients with congenital scoliosis.

Methods:Fifty pediatric patients underwent scoliosis surgery were included in the study. According to the position of scoliosis, patients were divided into three groups: Group C (cervical lateral bending); Group T (thoracic scoliosis); and Group L (lumbar scoliosis). For all participants, the transverse diameter of the cricoid cartilage was measured with ultrasonography and the initial ETT size was chosen according to the measurements, then the leak test was used to determine the best-fit ETT size. In each group, the ETT size measured by ultrasound and the best-fit ETT size were compared using Bland-Altman analysis and linear regression analysis.

Results: There was a strong correlation between the best-fit ETT size and the ETT size predicted by ultrasound in Group T ($r=0.93$, $p<0.001$) and Group L($r=0.95$, $p<0.001$) and a moderate correlation in Group C($r=0.83$, $p<0.001$). Bland-Altman analysis show that the ETT size was over estimated by ultrasound in pediatric patients with cervical lateral bending.

Conclusion: Ultrasound is a reliable tool to predict ETT size for pediatric patients with thoracic scoliosis and lumbar scoliosis. However, compared to what was predicted by ultrasonography, pediatric patients with cervical lateral bending need a smaller sized ETT.

Background

Selection of optimal endotracheal tube (ETT) size is critical in pediatric anesthesia. A larger-than-optimal-sized ETT can damage the airway[1]. In contrast, a small-sized ETT increases the risk of aspiration and insufficient ventilation[2,3]. Various methods have been used to estimate the required size of ETT, such those using age formulas, height formulas, and finger size. However, because of the individual differences, these calculation methods have a large deviation, especially in children[4,5]. Recent studies have used ultrasonography to predict the optimal ETT size by measuring the cricoid cartilage diameter, and the success rate can reach above 90%[6,7,8].

Scoliosis is the most common 3-dimensional deformation abnormality of the spine. The rotation of the centrum can produce displacement or rotation of the mainstem bronchi, especially in cervical lateral bending and thoracic scoliosis[9,10]. Therefore, we conducted this study to compare the accuracy of ultrasound to predict endotracheal tube size for pediatric patients with cervical lateral bending, thoracic scoliosis and lumbar scoliosiss.

Methods

The study protocol was approved by the institutional review board of HongHui Hospital. The trial was registered with the Chinese Clinical Trial Registry (ChiCTR: 1900023408). Informed written consent was obtained from the parents of all children.

Fifty pediatric patients underwent scoliosis surgery at Hong Hui Hospital, Xi'an Jiaotong University from February 2019 through December 2019 were enrolled in the study. The inclusion criteria included being aged 5-12 years and having an American Society of Anesthesiologists (ASA) physical status I-II. The exclusion criteria included neck trauma, throat disorders and anticipated difficult airway. According to the position of scoliosis, patients were divided into three groups: Group C (cervical lateral bending); Group T (thoracic scoliosis); and Group L (lumbar scoliosis) (Figure 1).

After transfer into the operating room, non-invasive blood pressure, electrocardiogram, pulse oximeter oxygen saturation, end-tidal carbon dioxide concentration and bispectral index were continuously monitored. The children were administered propofol 1.5 mg kg-1IV for mild sedation and positioned in horizontal recumbency with slight extension of the head. Ultrasonography was performed using a linear 7–15-MHz linear probe. The probe was positioned on the anterior side of the neck and scanned to localize the true vocal folds; the probe was then moved caudally to visualize the cricoid arch. The cricoid cartilage appears as a round hypoechoic structure with hyperechoic edges; the air-column in the cricoid cartilage appears hyperechoic. The transverse air-column diameter was considered for estimating the cricoid cartilage diameter (Figure 2). According to the measurements of the cricoid cartilage diameter by ultrasonography, the corresponding ETT size was selected(Table 1). The ultrasonography was performed by two trained anesthesiologists.

Anaesthesia was induced by fentanyl 4 μg kg^{-1}, propofol 2 mg kg^{-1} and atracurium 0.4 mg kg^{-1}. After 3 minutes, tracheal intubation was performed. The leak test was used to determine the best-fit ETT size(Table 2). The ETT size predicted by ultrasonography and the best-fit ETT size were recorded in each participant. All the tracheal intubation was done by the same investigator

Anaesthesia was maintained with remifentanil (0.16 μg kg^{-1} min^{-1}) and sevoflurane (1.5%). At the end of all surgical procedures, sevoflurane and remifentanil infusion was stopped. The trachea was extubated when the children got their breath back. After extubation, the children were transferred to the PACU.

The data were analysed using SPSS® for windows (v. 18, SPSS, Inc., Chicago, IL). The demographic characteristics were compared using chi-squared test or ANOVA. Linear regression was performed and a Bland-Altman plot was generated to analyze the agreement between the ETT size predicted by ultrasonography and the best-fit ETT size. $P < 0.05$ was considered statistically significant.

Results

Fifty pediatric patients with congenital scoliosis were included in this study. No significant differences were found for age, sex, hight and weight in three group (Table 3).

There was a strong correlation between the best-fit ETT size and the ETT size predicted by ultrasound in Group T (n=26, r=0.93, p< 0.001, Figure 3b) and Group L (n=11, r=0.95, p< 0.001, Figure 3c) and moderate correlation in Group C (n=13, r=0.83, p< 0.001, Figure 3a).

Bland–Altman analysis showed that there was no obvious bias between the ETT size predicted by ultrasonography and the best-fit ETT size in Group T (bias=0.02 mm, precision=0.12 mm, limit of agreement= −0.42 to 0.46 mm, Figure 4b) and in Group L (bias=0.09 mm, precision=0.17 mm, limit of agreement= −0.31 to 0.49 mm,Figure 4c), but the ETT size was over estimated by ultrasound in Group C (bias=0.73 mm, precision=0.42 mm, limit of agreement= 0.08 to 1.38 mm, Figure 4a).

Discussion

The cricoid cartilage, as the narrowest part of the larynx in children, plays an important role in the selection of optimal ETT size for intubation[11, 12]. However, recently, Dalal et al[13] found that the vocal cord and subvocal cord area was the narrowest portion in pediatric airways. We found that the vocal cord is narrower than the cricoid cartilage in ultrasound images. Compared with the vocal cords, the cricoid is a complete and relatively rigid cartilaginous ring, and also the most frequently damaged structure during endotracheal intubation[14]. Therefore, theoretically, the cricoid cartilage is the limiting factor during intubation, and can be a predictive factor in the selection of optimal ETT size for intubation.

The leading edge of the cricoid cartilage and the air-column in the airways were identified on ultrasound images[15]. The former is a round, hypoechoic structure with hyperechoic edges, whereas the latter is hyperechoic with a hypoechoic mucosal edge. The transverse air-column diameter can be measured by ultrasonography (Fig. 2). The transverse diameter of the cricoid cartilage is represented by the transverse air-column diameter at the cricoid cartilage level[16]. In our study, the cricoid cartilage diameters were estimated from the measurements of the transverse air-column diameter. According to the measurements of the cricoid cartilage diameter by ultrasonography, the corresponding ETT size was selected.

Leak test was a classic experimental method and has been applied to determine the bestfit ETT size for many years. Therefore, in our study, bestfit ETT size was chosen according to the leak test. In leak test, the allowed leak pressure often was 15-30cm H_2O for cuffed ETT[17,18,19]. Scoliosis can affect pulmonary function, and lung function abnormalities are mainly of the restrictive type[20]. During the procedure, the children were positioned in prone recumbency, and the operation can bring pressure to bear on the chest. All these aspects can cause the elevated of the airway pressure.Therefor, we chose a higher leak pressure 25 cm H_2 O to determine the bestfit ETT size.

The study results show a strong correlation and high agreement between the ETT size predicted by ultrasonography and the bestfit ETT size in pediatric patients with thoracic scoliosi ($r = 0.93$, $p < 0.001$) and lumbar scoliosis($r = 0.95$, $p < 0.001$). The Bland–Altman analysis showed that there was no obvious bias between the ETT size predicted by ultrasonography and the bestfit ETT size in pediatric patients with thoracic scoliosis (bias = 0.02 mm) and lumbar scoliosis (bias = 0.09 mm). Our finding was consistent with that reported by Rahul Pillai[6]. In their study, the correlation was 0.98, $p < 0.001$, and the bias was 0.041 mm. Therefore, it is feasible to to predict ETT size through measuring thetransverse diameter of cricoid cartilage by ultrasonography in pediatric patients with thoracic scolios and lumbar scoliosis.

However, in pediatric patients with cervical lateral bending, Bland–Altman analysis showed that the ETT size was over estimated by ultrasound (bias = 0.73 mm).

MRI is considered the gold-standard method for evaluating the larynx. High-quality images of the cricoid cartilage can be acquired by MRI and the cricoid cartilage diameter can be accurately measured[21]. Therefor, in order to ascertain the cause of this result, we reviewed the MRI of the patients with cervical lateral bending. We found that the cricoid cartilage of the pediatric patients with cervical lateral bending was rotary(Fig. 5). Previous research shown that the rotation of the centrum can produce displacement or rotation of the mainstem bronchi[9, 10]. Thefore, we speculate that the rotation of the cricoid cartilage results from the deviation or rotation of the cervical vertebra.

Under normal circumstances, the cricoid cartilage is elliptical, and the transverse diameter is smaller than the anteroposterior diameter[22]. When measuring the transverse diameter of the cricoid cartilage by ultrasound, the probe was positioned on the anterior side of the neck, and the transverse air-column diameter measured by ultrasound was considered for estimating the cricoid cartilage diameter. The rotation of the cricoid cartilage can make the air-column measured by ultrasound broader, resulting in the measurement of cricoid cartilage diameter was larger, and the ETT size was over estimated(Fig. 6). In our study, we found that the ETT size predicted by ultrasonography was larger than the bestfit ETT size in pediatric patients with cervical lateral bending. Therefore, compared to what was predicted by ultrasonography, pediatric patients with cervical lateral bending need a smaller sized ETT.

Study Limitations

The present study has some limitations. First, the sample size was not equally distributed among groups. Thoracic scoliosis has the highest proportion of children with scoliosis. Second, we did not include children with kyphosis, throat disorder and anticipated difficult airway. These children require additional airway assessment. Third, we did not investigate the incidence of respiratory complications such as post-extubation stridor and laryngospasm. All these aspects need further investigation.

Conclusion

Ultrasound is a reliable tool to predict ETT size for pediatric patients with thoracic scoliosis and lumbar scoliosis. Howere, compared to what was predicted by ultrasonography, pediatric patients with cervical lateral bending need a smaller sized ETT.

Abbreviations

ETT: endotracheal tube; ASA: American Society of Anesthesiologists; PACU: postanesthesia care unit; MRI: magnetic resonance imaging

Declarations

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors’contributions

Jianhong Hao and Zhenguo Luo designed the project; Jianhong Hao, Jie Zhang and Buhuai Dong performed the experiments and data collection; Jianhong Hao prepared the figures and drafted the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study protocol was approved by the institutional review board of HongHui Hospital. The trial was registered with the Chinese Clinical Trial Registry (ChiCTR: 1900023408).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1 Outer and inner diameters of cuffed endotracheal tubes of the used brand*.

CCD (mm)	>3.3	3.4-4.0	4.1-5.3	5.4-6.0	6.1-6.7	6.8-7.3	7.4-8.0	8.1-8.7	8.8-9.3	9.4-10.0	<10.1
OD (mm)	3.3	4.0	5.3	6.0	6.7	7.3	8.0	8.7	9.3	10.0	10.7
ID (mm)	2.0	2.5	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5

*Xinxiang Tuoren Medical Equipment Co., Ltd, Henan, China.

CCD: Cricoid cartilage diameter; OD: outer diameter; ID: inner diameter

Table 2 The leak test

The ETT was replaced with a tube whose internal diameter was 0.5 mm smaller.	a. In the presence of resistance to passage of the tube into the trachea; b. In the absence of an audible leak at airway pressure of >25 cm H_2O.
The ETT was changed to a tube one size larger.	a. A leak was audible at airway pressures of <10 cm H_2O; b. A seal could not be achieved with a cuff pressure of >25 cm H_2O; c. A peak airway pressure of <25 cm H_2O was observed during ventilation.

Table 3 Demographic characteristics.

Group	C (n=13)	T(n=26)	L (n=11)
Age(years)	7.5(1.6)	9.0(2.0)	8.5(1.8)
Sex(male/female)	5/8	12/14	4/7
Hight(cm)	125.2(10.8)	130.4(15.7)	130.8(14.0)
Weight(kg)	23.2(6.5)	27.8(10.4)	19.5(14.1)

Data are mean (SD) or ratio. C: Cervical lateral bending; T: Thoracic scoliosis; L: Lumbar scoliosis.

Figures

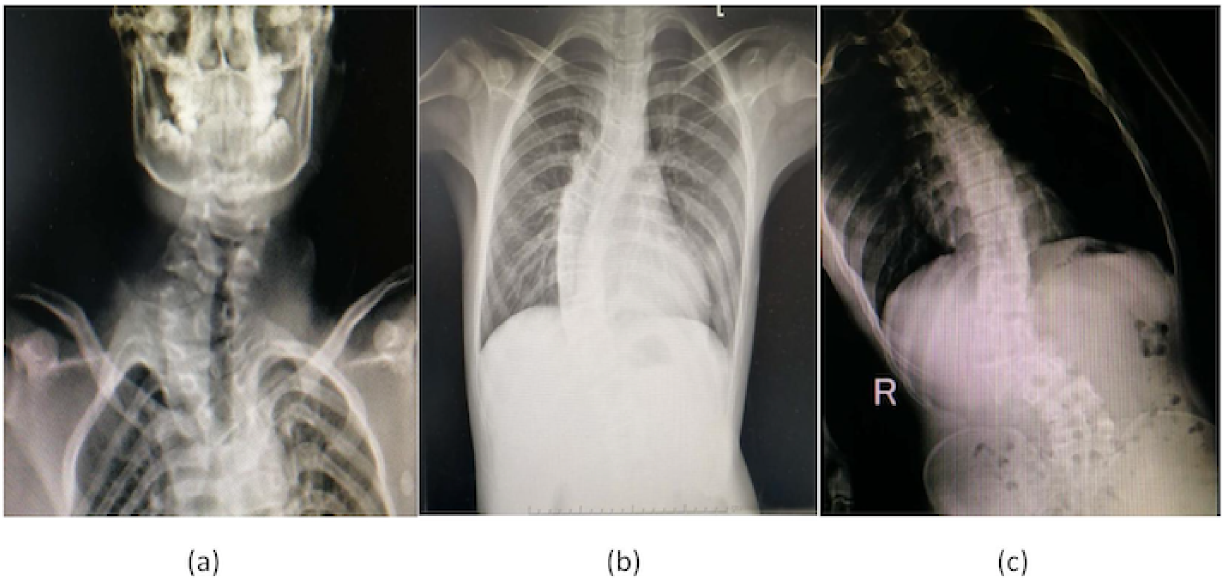

Figure 1 The CT images of the pediatric patients with congenital scoliosis. Cervical lateral bending (a); thoracic scoliosis (b); lumbar scoliosiss (c).

Figure 1

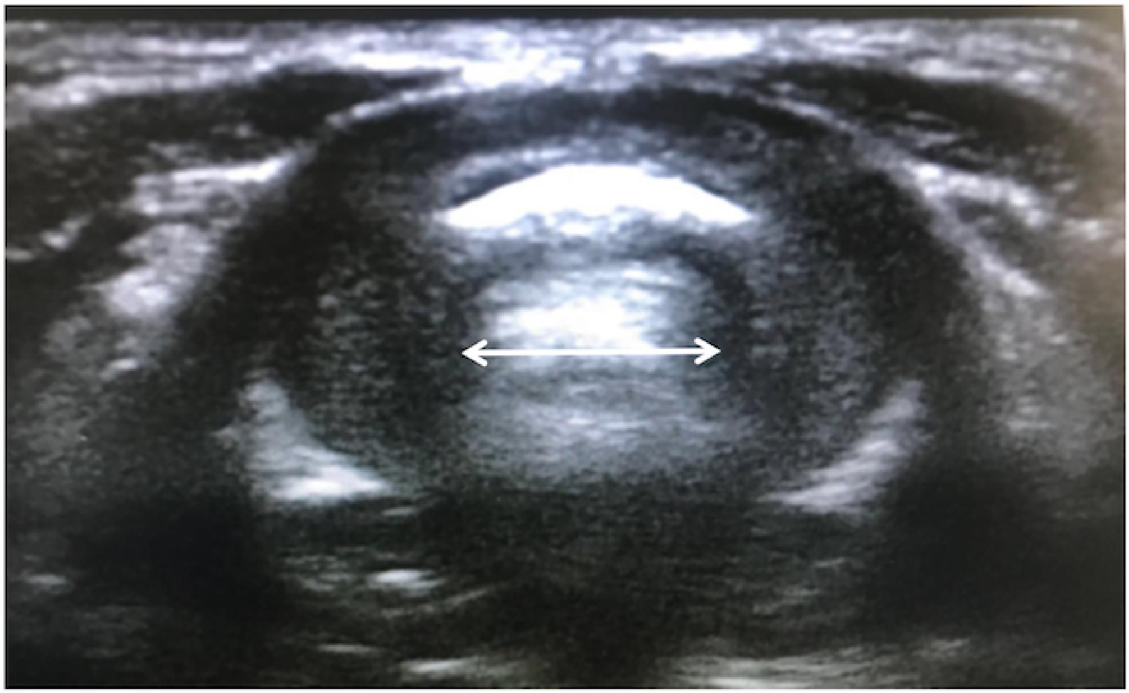

Figure 2 The anatomy of the airway at the level of the cricoid cartilage in the ultrasound image. The cricoid cartilage is a round hypoechoic structure with hyperechoic edges. The air-column appeared hyperechoic and created a posterior acoustic shadow. The mucosa–air interface created a hypoechoic edge. Solid arrow represents the transverse diameter of the air-column at the level of cricoid cartilage.

Figure 2

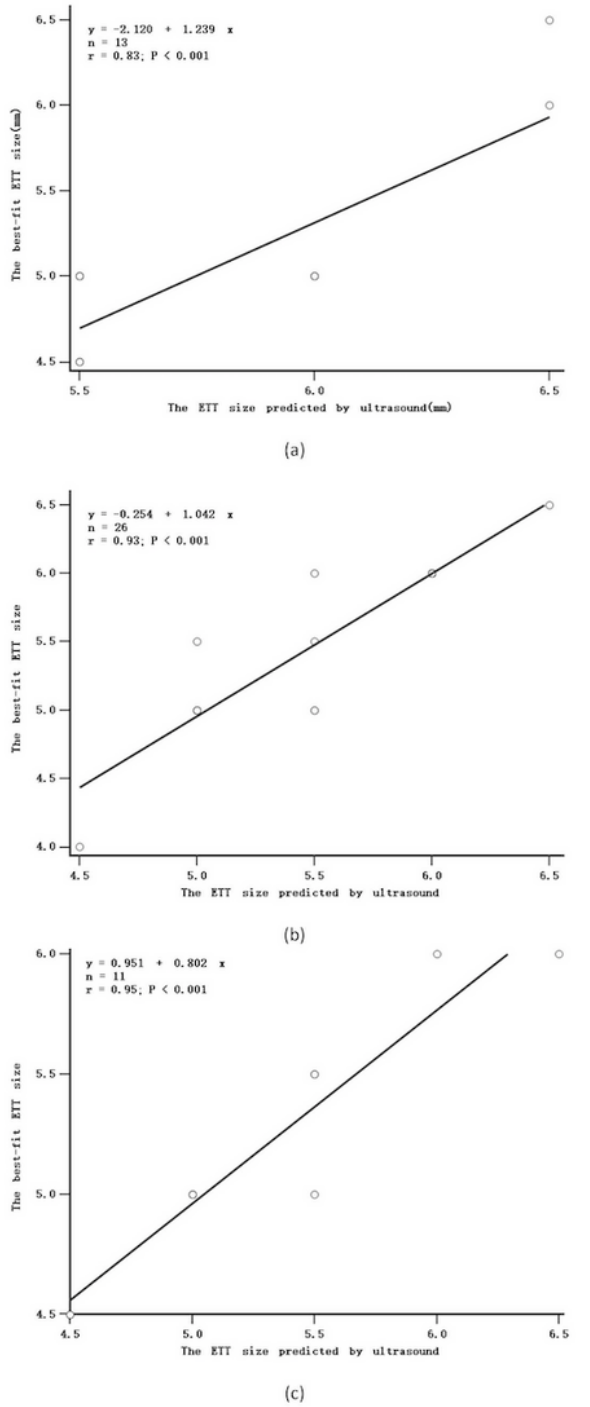

Figure 3 The scatter plot of the best-fit ETT size and the ETT size predicted by ultrasound in Group C (a), Group T(b) and Group L(c).

Figure 3

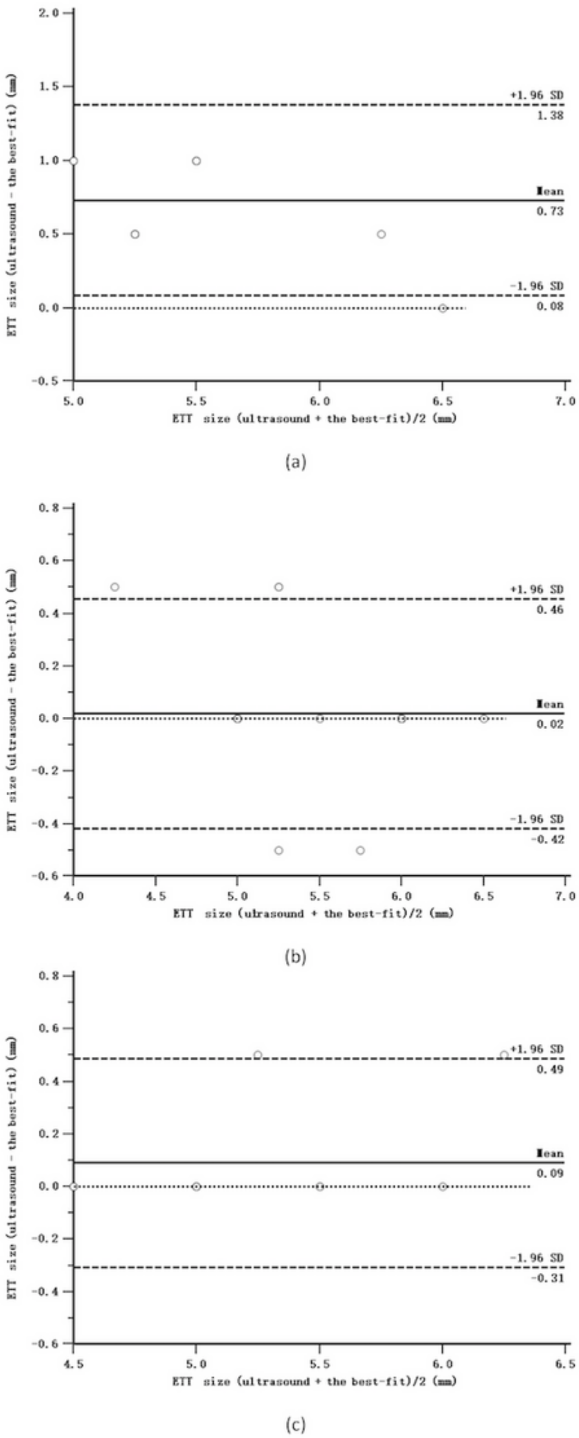

Figure 4 Bland-Altman graph of the best-fit ETT size and the ETT size predicted by ultrasound in Group C (a), Group T(b) and Group L(c).

Figure 4

Figure 5 The anatomy of the neck of the pediatric patients with cervical lateral bending in MRI. The red circle represents the cricoid cartilage.

Figure 5

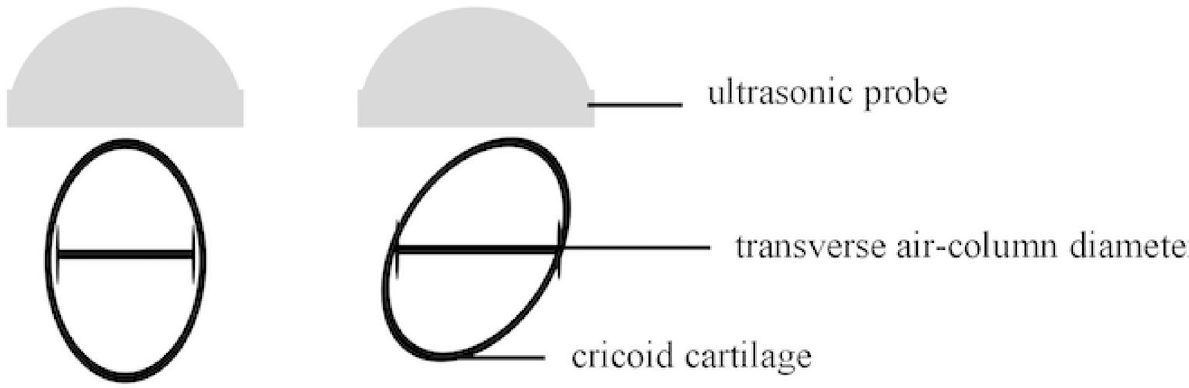

Figure 6 The schematic diagram of the measurements of the cricoid cartilage diameter by ultrasonography in pediatric patients with cervical lateral bending

Figure 6