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Determination of the tracheal diameter with ultrasound and its relationship with the tube calculation formula in children aged 1 to 12 years.

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Abstract

Introduction: The formulas used to determine the number of endotracheal tubes (ETT) are inaccurate, so using new methods such as Ultrasound (US) seems promising. The objective of the present study was to determine the tracheal diameter in the US in children aged 1-12 years and to establish its relationship with the formulas.

Methods: This observational, descriptive, and cross-sectional study was carried out between January 2020 and December 2021 in 129 patients aged 1 to 12 years who underwent scheduled and emergency surgery. The sample was based on: a confidence level of 95%, a precision of 5%, a variance of 0.2, inclusion criteria were met, sociodemographic and clinical variables were analyzed, and as a result variable the correlation between the tracheal diameter was determined by the US with determined by formulas, the data were analyzed by descriptive statistics, using the mean, standard error, CI, standard deviation, Pearson's correlation, and Pearson's r coefficient.

Results: The following variables prevailed: age 3, 11, and 12 years (12.9%), male sex (69.8%), ASA I (76.7%), normal nutritional status (76.7%); it was shown that in the following groups there was no linear increase in tracheal diameter by the US concerning their age: 3 years old, 5.54 mm, with CI between 5.17-5.92 mm, six years old, 6.58 mm, with a CI between 5.67-7.49 mm and ten years old. 7.94 mm, with a CI between 7.39-8.50 mm It was correlated with the formulas, and a Pearson's r coefficient of 80.2% was obtained.

Conclusions: It is possible to predict the size of an ETT based on ultrasonographic measurements prior to intubation in children aged 1 to 12 years.

Keywords:

MESH: Apgar Score; Cardiopulmonary Resuscitation; Asphyxia neonatorum; Live Birth; Infant, Newborn; Adaptation.

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Introduction

Providing safe anesthesia to pediatric patients is challenging [1]; correct endotracheal intubation is a priority for maintaining the airway and ventilation in different surgical procedures. Due to the vulnerability of the anatomical structures involved, choosing an appropriately sized endotracheal tube (ETT) is essential to avoid complications [2].

Formulas based on physical indices are frequently used to determine ETT size in clinical practice but have not always been adequate [2].

With the availability and knowledge of modern ultrasound (US) equipment, it is expected that the rate of complications will be lower, and better results will be obtained [1]. Recent studies show that the US could be a more reliable technique to evaluate the transverse diameter of the trachea and thus better predict the size of the ETT adjusted to the patient's anatomy. However, more studies on the population are necessary. To evaluate its clinical validity and correlate it with conventional calculation techniques [3].

For the selection of ETTs, we must consider several aspects, such as the anatomical differences that children have compared to adults and the complications that an inadequately sized ETT could cause in our patients; for example, selecting a small ETT causes leaks and increases the risk of aspiration, with a larger ETT traumatism that could lead to ulcerations, local ischemia, and pathological scarring with supraglottic stenosis [4].

Most anesthesiologists calculate using formulas based on age, such as Cole, Khine, Motoyama, and the comparison with the bit of finger. Nevertheless, these are becoming increasingly obsolete every day. Age-dependent formulas are the fastest method; Cole's formula, for example, has a correct prediction rate of 47-77%. Height-based formulas such as the Broselow tape do not estimate individual variations in internal organ growth. Imaging methods, such as computed tomography and magnetic resonance imaging, are impractical apart from expensive. On the other hand, US is a method that allows easy, fast and precise visualization of the supraglottic, glottic and subglottic regions [5].

Shibasaki et al. showed that the agreement between tracheal diameter determination by the US with the selected tube was high, giving a 98% correct determination for cuffed tracheal tubes and 96% for uncuffed tracheal tubes, thus concluding that the US is a valuable method for selecting the appropriate endotracheal tube size compared to age-based formulas in pediatric patients [6].

Similarly, in 2012, Gupta et al. conducted a prospective clinical study in India to evaluate the subglottic region in the US and determine the appropriate ETT. This fact was compared with age-based formulas, and according to Bland's analysis (Altman), the concordance rate between clinically optimal ETT and ultrasound-guided ETT was 98% (P < 0.001). USG was found to be a more accurate tool [7].

An important consideration is the one postulated in a review, indicating that the minimum transverse subglottic diameter must be equal to the external diameter of a correctly placed ETT; it must be taken into account that the outer diameter of the ETT depends on the type of tube and manufacturer. The number of lines indicates the internal diameter, so 4.5 or 5 mm boxes of a particular brand will correspond to external diameters of 6 and 6.7 mm, respectively, but of another brand, they can be different; on the other hand, the formulas take into account the circumference internal diameter of the tube, leading us to select smaller ETTs by not considering the external diameter [8].

Thus, the following research question arose: What is the tracheal diameter by ultrasound in children aged 1-12 years, and what is its relationship with the formulas for calculating the diameter of the tube? We proposed an observational study to answer this question.

Population and methods

Type of study

The present study is observational - descriptive-cross-sectional.

Stage

The study was carried out in the surgical center of the "José Carrasco Arteaga" hospitals of the Ecuadorian Social Security Institute and the Vicente Corral Moscoso Hospital, located in Cuenca.

Universe and Sample

The sample was taken from patients aged 1 to 12 years, ASA I-II-III, who attended the HJCA and HVCM between January 1, 2020, and August 30, 2021, who underwent scheduled surgery or emergency under general anesthesia. The sample calculation was probabilistic, with a 95% confidence level of 1.96 (Z2), a variance of 0.04, and a precision of 5%. The following formula was applied to calculate the sample from an unknown universe: n= $Za^2 \times s^2/e^2$, where Z is the confidence level: 0.95%: 1.96, and S^2 is the variance: 0.2. The source for the calculation of the conflict was taken from a study carried out in India on the evaluation of the subglottic region by the US for the estimation of the size of the appropriate ETT, where a variance of the tracheal diameter of 0.2 was estimated); e^2 corresponds to the margin of error: 5%. A total of 129 patients were evaluated. The patients were chosen according to the scheduled surgeries and the order of arrival of emergency surgical reports.

Participants

Patients aged 1 to 12 years of both sexes, ASA I - II-III, undergoing elective and emergency surgeries who received general anesthesia with endotracheal intubation, were included. Patients named as anticipated difficult airway or not, cervical trauma, patients with a full stomach before surgery, lack of informed consent, informed assent from 10 years of age, respiratory or neck pathology (history of prolonged intubation, congenital pathology) were excluded. Affecting the airway, passive smokers, and asthmatics).

Variables

Age, sex, ASA, nutritional status, tracheal diameter by ultrasound, and endotracheal tube estimation formulas were studied.

Procedures

A structured, validated form was used.

Intubation technique and ultrasound measurement

Patients are usually admitted to the operating room, premedicated with midazolam to manage anxiety, and ASA standard 2 for monitoring was met. Induction was started with adequate preoxygenation with 100% FIO_2 in a closed circuit or Jackson Rees at 4 liters x min for 3 minutes. In patients without vascular access, induction was achieved with 8% sevoflurane until an adequate anesthetic plane or CAM 95 was achieved; when vascular access was achieved, 0.3-1.2 mg/kg rocuronium bromide was administered. If the patient had vascular access, propofol (dose: 2-3 mg/kg) or midazolam (dose: 0.05-0.2 mg/kg), remifentanil (dose: 0.05-1.3 mcg/kg/min), or fentanyl (dose: 0.05-1.3 mg/kg) were used. dose: 1-2 mcg/kg/dose) and rocuronium bromide 0.3-1.2 mg/kg. The operator in charge of the measurement remained on the patient's right side, and the ultrasound machine was placed on the left. The water-soluble lubricating gel was applied to achieve an adequate interface in the middle and upper parts of the patient's neck; all the necessary measures were used to optimize the image according to the operator's opinion using sectorial gain, total, depth, focus, and manipulation of the transducer. Ergonomically, the horns of the hyoid bone were visualized, if possible, characterized by presenting a phenomenon of posterior acoustic shadow on each side of the midline; in younger children, the incomplete ossification of this bone can make the visualization have cartilage characteristics, the result in mm comprised the transverse diameter of the cricoid, tubes with a pneumotropic were used, so it was 0.5 mm smaller than this result, in cases where the external diameter was intermediate between the range comprised of external diameter, the number was chosen immediately lower. The relationship of the measurement of the tracheal diameter with the US versus the conventional formulas was made after the stabilization of the patient. The ultrasound machine in each institution is located in a specific place, so before the patient enters the operating room, they are transferred to the corresponding operating room to avoid delays. This procedure did not compromise the patient's well-being, nor did it imply a delay in surgery. In cases where the external diameter was intermediate between the range included in the external diameter, the immediately lower number was chosen. The relationship of the measurement of the tracheal diameter with the US versus the conventional formulas was made after the stabilization of the patient. The ultrasound machine in each institution is located in a specific place, so before the patient enters the operating room, they are transferred to the corresponding operating room to avoid delays. This procedure did not compromise the patient's well-being, nor did it imply a delay in surgery. In cases where the external diameter was intermediate between the range included in the external diameter, the immediately lower number was chosen. The relationship of the measurement of the tracheal diameter with the US versus the conventional formulas was made after the stabilization of the patient. The ultrasound machine in each institution is located in a specific place, so before the patient enters the operating room, they are transferred to the corresponding operating room to avoid delays. This procedure did not compromise the patient's well-being, nor did it imply a delay in surgery. The ultrasound machine in each institution is located in a specific place, so before the patient enters the operating room, they are transferred to the corresponding operating room to avoid delays. This procedure did not compromise the patient's well-being, nor did it imply a delay in surgery. The ultrasound machine in each institution is located in a specific place, so before the patient enters the operating room, they are transferred to the corresponding operating room to avoid delays. This procedure did not compromise the patient's well-being, nor did it imply a delay in surgery.

Tabulation and analysis plan

The information was processed through the statistical program SPSS version 15 (Chicago, SPSS Inc.). The presentation of the report was made in the form of distributions according to descriptive statistics; the demographic and clinical characteristics of the study population were described, for age, sex, nutritional status, ASA, the number of cases, and the percentages were used. That is the average. The tracheal diameter was determined by the US using the mean and standard deviation, and the determination of the correlation of the measurements obtained by the US with the formulas was carried out using Pearson's correlation and Pearson's r coefficient, the mean, the standard error, the confidence interval, and standard deviation.

Results

A total of 129 patients entered the study.

General characteristics of the study sample

The most frequent age was between 3 and 11-12 years (12.9 %). A total of 69.8 % were male patients, the majority of patients were ASA I (76.7 %), and the most frequent nutritional status was normal (70.5 %).

Table 1. Demographic and clinical characteristics of the study population.

		N°	%
Age in years	1 year	15	10.7
	2 years	9	6.4
	3 years	18	12.9
	4 years	14	10.0
	5 years	9	6.4
	6 years	5	3.6
	7 years	10	7.1
	Eight years	12	8.6
	9 years	14	10.0
	10 years	5	3.6
	11-12 years	18	12.9
Sex	Male	90	69.8
	Female	39	30.2
ASA	ASA I	99	76.7
	ASA II	23	17.8
	ASA III	7	5.4
Nutritional condition	Malnutrition	4	3.1
	Underweight	4	3.1
	Normal	91	70.5
	Overweight	17	13.2
	Obesity	13	10.1

Tracheal diameter

The tracheal diameter was determined by ultrasound, and it was shown that in the following groups, there was no increase concerning their age: 3 years old 5.54 mm, with CI between 5.17-5.92 mm, six years old 6.58 mm, with a CI between 5.67-7.49 mm and at ten years 7.94 mm, with a CI between 7.39-8.50 mm. It is important to emphasize that the external diameter (OD) calculated by the US is more significant than the internal diameter (ID) obtained by the formulas. However, this cannot focus on choosing a larger tube size since the tube number indicates the inner diameter, so in 4.5 or 5 mm tubes of a particular brand, the external diameter is 6 and 6.7 mm, respectively, and the OD of the tubes varies with the brands.

Relationship of the measurements obtained by ultrasound with the formulas for calculating the diameter of the tube (Cole, Khine, Penlington)

A linear and parallel rise can be seen between the different formulas related to age; however, when correlating with the measurement of the tracheal diameter by the US, there is no linear progression about their age, with marked rises at ages 2, 5, and 9 years, which is why we did not consider in this study as one of the objectives to relate the tracheal diameter with variables such as nutritional status, ASA and gender. When analyzing these results, it is essential to justify this fact by analyzing the impact of these variables on the growth of the tracheal diameter.

Correlation analysis (Cole, Khine, Penlington).

In all cases, with a probability of error of 0.000, a Pearson r correlation coefficient of 80.2% was obtained between the tracheal diameter obtained by the US and those obtained using the formulas, indicating a very high correlation.

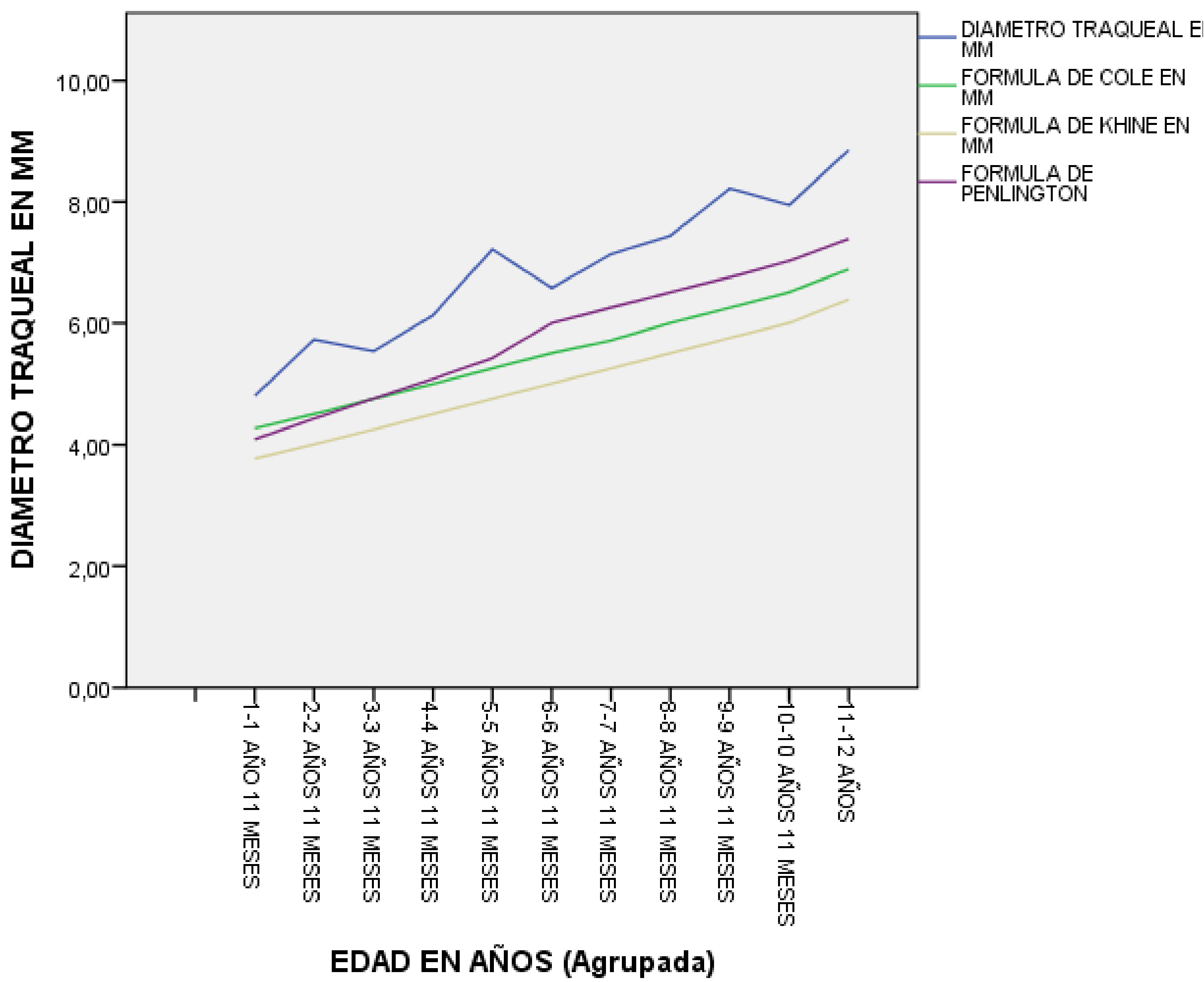

Figure 1. Comparative graph of tracheal diameter.

Table 2. Tracheal diameter by ultrasound.

Age		Tracheal diameter Ultrasound mmm	Coles´s formula mm	Kaine´s formula mm	Formula-4 mm
1 Year	Average	4,8067	4,2693	3.7693	4,0907
	CI 95%	4.31-5.30	4.25-4.29	3.75-3.79	4.04-4.15
	SE	.25136	.00959	.00959	.02831
	SD	.97352	.03712	.03712	.10964
2 Years	Average	5.7322	4,5078	4,0067	4.4300
	CI 95%	5.15-6.31	4.50-4.51	4.00-4.01	4.42-4.44
	SE	.29704	.00324	.00333	.00667
	SD	.89113	.00972	.01000	.02000
3 Years	Average	5,5411	4.7567	4.2511	4.7606
	CI 95%	5.17-5.92	4.75-4.76	4.24-4.26	4.75-4.77
	SE	.19186	.00214	.00517	.00318
	SD	.81401	.00907	.02193	.01349
4 Years	Average	6.1336	5.0014	4.5064	5.0843
	CI 95%	5.65-6.61	5.00-5.00	4.50-4.52	5.08-5.09
	SE	.24468	.00097	.00498	.00202
	SD	.91551	.00363	.01865	.00756
5 Years	Average	7.2189	5.2578	4.7578	5.4267
	CI 95%	6.57-7.87	5.25-5.26	4.75-4.76	5.42-5.43
	SE	.33278	.00222	.00222	.00408
	SD	.99835	.00667	.00667	.01225
6 Years	Average	6.5800	5.5100	5.0100	6.0060
	CI 95%	5.67-7.49	5.50-5.52	5.00-5.02	6.00-6.01
	SE	.46519	.00447	.00447	.00400
	SD	1.04019	.01000	.01000	.00894
7 Years	Average	7.1410	5.7190	5.2550	6.2600
	CI 95%	6.24-8.05	5.65-5.79	5.25-5.26	6.25-6.27
	SE	.46176	.03551	.00224	.00494
	SD	1.46021	.11229	.00707	.01563
8 Years	Average	7.4417	6.0075	5,5083	6,5083
	CI 95%	6.94-7.94	6.00-6.01	5.50-5.51	6.50-6.51
	SE	.25495	.00279	.00271	.00271
	SD	.88318	.00965	.00937	.00937
9 Years	Average	8,2193	6.2593	5.7593	6.7593
	CI 95%	7.67-8.77	6.25-6.26	5.75-5.76	6.75-6.76
	SE	.28191	.00245	.00245	.00245
	SD	1.05479	.00917	.00917	.00917
10 Years	Average	7.9480	6.5120	6,0080	7.0300
	CI 95%	7.39-8.50	6.50-6.52	6.00-6.02	6.99-7.07
	SE	.28216	.00490	.00490	.02049
	SD	.63093	.01095	.01095	.04583
11-12 Years	Average	8.8539	6.8911	6.3911	7.3911
	CI 95%	8.53-9.18	6.83-6.95	6.33-6.45	7.33-7.45
	SE	.16637	.02955	.02955	.02955
	SD	.70584	.12536	.12536	.12536
Total	Average	6.8377	5,4933	4.9957	5,7402
	SE	.14125	.07685	.07691	.09934
	SD	1.60432	.87289	.87353	1.12831

SD: Standar deviation. SE: standar error

Table 3. Pearson's correlation coefficient of tracheal diameter.

Tracheal diameter (mm)		Tracheal diameter		
		Coles´s formula mm	Khine´s formula mm	Penlington formula mm
Ultrasound mm	Pearson correlation	.802**	0.806**	0.801**
	Next (2-sided)	<0.0001	<0.0001	<0.0001
	N	129	129	129

Discussion

The availability of the US and the increasing familiarity of the anesthesiologist have paved the way for pediatric airway evaluation.

Regarding the demographic characteristics, it was determined that the most frequent age was between 3, 11, and 12 years with 12.9 %, the male sex predominated with 69.8 %, the majority of patients were ASA I with 76.7 %, and the most frequent nutritional status was normal with 70.5 %. Data differ from studies such as Singh S et al. who conducted a cross-sectional observational study in Saudi Arabia in 2019 on ETT size prediction in children by measuring subglottic diameter with the US versus traditional formulas included in the study of 100 patients aged 12 and 60 months, of both sexes, ASA I and II, undergoing various elective surgeries under general anesthesia that required STI, where a mean age of 26.88 months was determined [9]. This research has a more significant number of patients (129) in a more extensive age range, grouping each child by age for a more precise analysis of the results.

Regarding ETT calculation, formulas based on age and height are routinely used, the results are often incorrect, and patients often have to be reintubated [10]. Recent studies found that measuring the narrowest transverse subglottic diameter can guide proper tube sizing, improving the success rate in airway diameter prediction to approximately 90 % [11].

In the present study, when determining the tracheal diameter by the US in children aged 1 to 12 years, a nonlinear increase was observed according to their age in the following groups: 3, 6, and 10 years. Similarly, in graph 1, there were increases and decreases in the ages of 2, 5, and 9 years, raising the hypothesis that this variability could be due to ASA, sex, and nutritional status.

Regarding the ASA, in several studies, it was determined that the calculation of the TOT through empirical formulas was underestimated in sick children, especially with some heart disease, since these cannot reflect the growth of internal organs in particular patients [12]. Azarfarin et al., in a study using an age-based formula, found that children undergoing cardiac surgery required a larger TTE compared to those of similar age coming for noncardiac surgery, in addition to the fact that measurements in sick young children may need a more significant learning curve and may incur errors [13]. It should also be taken into account that children's growth is evaluated considering weight and height. Their increase correlated with age; different races cause the population to present phenotypic differences worldwide. The graphs of weight percentiles for the period and height-for-age are used to monitor growth; children in the <5 % weight and height-for-age range (with pathologically short stature) may have a smaller tracheal diameter relative to their age; this was stated by Daugherty et al. [5] when determining that the predictions based on height were not accurate, the same as defined in another retrospective study in which 5175 records of patients with short stature were analyzed. It was concluded that the prediction of tube size based on height is as short stature as the estimate based on age, both in patients with pathological and nonpathological short length [14], thus showing that formulas such as Cole, Khine, and Motoyama can be misleading in this population.

That is why it was imperative to justify this fact by analyzing the impact these variables have on the growth of the tracheal diameter. When performing the analysis, the results indicated that there is no correlation since when dividing the sample into 12 age groups, the groups formed each year were too small to be able to show significant differences; however, this result does not rule out this fact either, recommending future research with a larger population in each age group that allows us to determine this correlation more reliably.

Finally, the correlation that exists between the tracheal diameter measured by the US and that calculated with conventional formulas was determined using Pearson's correlation and Pearson's r coefficient, where a Pearson's r of 80.2 % was evidenced, which indicates a very high correlation, with the advantage that the US was associated with a lower incidence of failed intubations in children under five years of age, as reported by Schramm et al. [15].

In another study, Gupta et al. compared the size of the USG-derived ETT and the age-based formula with the clinically used ETT. They found a high correlation between the clinically used ETT and the USG-predetermined ETT than that predicted by the age-based formula. These results contrast with ours; however, this study did not clarify whether cuffed or uncuffed ETT was used [1].

Similarly, Rafael et al. found that the determination of the size of the cuffed ETT by the US was a good predictor of the appropriate size of the ETT in pediatric patients in comparison with the formula based on age, in agreement with the pilot study, when evidencing a more significant correlation between clinically used ETT and US-determined ETT than between clinically used ETT and age-based formula-determined ETT [16]. That is why it is advisable to carry out more research studies on this topic to demonstrate the superiority of the US compared to physical indices, especially in special populations.

The impact of carrying out this type of study will be the reduction of complications associated with unnecessary TOT changes or negative consequences in ventilation and oxygenation related to the use of tubes of inadequate sizes, especially in our population, which includes autochthonous ethnic groups that they can break out of familiar patterns.

The limitation of the study could be that the measurement is operator-dependent. Nevertheless, we believe that this limitation can be overcome with the practice since, according to some authors, the learning curve for evaluating the airways in the US is very short and stabilizes in 15 to 20 exams [14].

Conclusions

The average values and the CI in the different age groups were obtained; we calculated the tracheal diameter. Its correlation with the conventional formulas has been determined, showing a Pearson's r of 80.2%, which offers a very high correlation. However, at certain ages, it was possible to show that the US is a more precise method and is more related to the individual characteristics of the patients. It highlights its noninvasiveness and availability as a reliable method of estimation of the subglottic diameter in children.

Abbreviations

ETT: endotracheal tube.
ASA: American Society of Anesthesia.

Supplementary information

Supplementary materials are not declared.

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The study participants are acknowledged and thanked.

Author contributions

María José Serrano Oleas: Conceptualization, Data Conservation, Fundraising, Research, Resources, Software, Writing - original draft.
Francisco Antonio Cevallos Sacoto: Curation of data, research, acquisition of funds, Supervision, Methodology.
All authors read and approved the final version of the manuscript.

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Availability of data and materials

The data sets generated and/or analyzed during the current study are not publicly available due to participant confidentiality but are available through the corresponding author upon reasonable academic request.

Statements

Ethics committee approval and consent to participate

The Research Bioethics Committee approved the research protocol for the Health area of the University of Cuenca-(COBIAS).

Publication consent

It does not apply to studies that do not publish MRI/CT/Rx images or physical examination photographs.

Conflicts of interest

The authors declare no conflicts of interest.

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