

# Cricoid ring: Shape, size, and variability in infants and children

## ABSTRACT

**Background:** Knowledge regarding the shape, size, and variability of the cricoid ring is important to properly choose the correct endotracheal tube (ETT) in the pediatric patient. Studies have measured the size of the cricoid ring using methodologies such as mouldages, magnetic resonance imaging, and video-bronchoscopy. In the present study, computed tomography (CT) -based images were used to determine the shape, size, and configuration of the cricoid ring in the pediatric population taking into considerations growth and development.

**Methods:** This is a retrospective review using 130 CT images of children ranging in age from 1 month to 10 years undergoing radiological evaluation unrelated to airway symptomatology. The CT scans were obtained in spontaneously breathing patients during either natural sleep or procedural sedation. Anteroposterior (AP) and transverse (T) diameters were measured at the cricoid ring using these images.

**Results:** The cricoid ring is generally round in children older than 1 year with a T/AP ratio ranging between 0.98 and 1.01. However, in infants (1–12 months of age), the cricoid ring is elliptical with the AP dimension an average of 0.31 mm larger than the T dimension with a T/AP ratio of 0.95. A statistically significant difference between the T and AP dimensions was only observed in infancy ( $P < 0.05$ ).

**Conclusion:** The cricoid ring is round in children older than 1 year of age. In infants, the cricoid shape presents a more elliptical configuration because the T-axis is narrower than the AP dimension. CT is recognized as the most accurate technique to study cricoid ring configuration, and the present data may help clinicians determine the appropriate type, size, and shape of ETTs, particularly in infants.

**Key words:** Cricoid ring; endotracheal intubation; pediatric airway; pediatric anesthesiology

## Introduction

Historically, the cricoid ring has been considered the narrowest part of the pediatric airway.<sup>[1]</sup> Earlier investigations have described the cricoid ring as being round, while new evidence suggests that it may be more elliptical.<sup>[2-4]</sup> We have recently published data using computed tomography (CT)

imaging to provide further evidence that the pediatric airway is not conical in shape.<sup>[5]</sup> Information regarding the size and shape of the growing pediatric airway are of significance as the cricoid ring area (circumference) and shape remain the major factors that impact the size of the endotracheal

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tube (ETT) to be used in the pediatric population. This information is particularly relevant as the smaller size of the pediatric airway makes children more vulnerable to adverse effects related to improper ETT sizing.

Determination of the appropriate-sized ETT is an essential consideration during the provision of general anesthesia or any circumstance dictating endotracheal intubation in children. Age-based formulas have been used to estimate the optimal ETT size for more than half a century.<sup>[6]</sup> Other predictive formulas used to select the appropriate ETT size continue to use features such as weight and/or height. However, none of these formulas can accurately predict the proper size of ETTs in infants and children as they do not involve consideration of the configuration or shape of the cricoid ring. Improper sizing of the ETT may result in repeated or prolonged laryngoscopies with the need to exchange the ETT to find the appropriate size for each patient.

When using age-based formulas to select the ETT size, the need to exchange the ETT after the first attempt at endotracheal intubation is reported to be 30% in children younger than 2 years of age and 18% in patients  $\geq 2$  years of age.<sup>[7]</sup> If left in place, an ETT with an excessively large outer diameter may result in subglottic edema, laryngeal injury, and consequently, postextubation croup and respiratory difficulty, whereas an undersized ETT may result in difficulties maintaining proper intraoperative positive pressure ventilation, causing underestimation of end-tidal CO<sub>2</sub> and/or environmental pollution with anesthetic gasses.<sup>[7-9]</sup>

CT delineates the air-tissue interface better than other imaging modalities and is generally considered the gold standard for airway measurements.<sup>[10]</sup> It is an excellent method of displaying the cross-sectional anatomy of the trachea with more accurate measurements of the inner portions of the trachea than other imaging modalities.<sup>[11-13]</sup> The primary objectives of the current study were: (1) determine the dimensions of the cricoid (anteroposterior [AP] and transverse [T] diameters) in infants and children ranging in age from 1 month to 10 years using CT imaging, (2) evaluate variations in dimensions within age groups, and (3) assess the progression of these dimensions with age. The AP and T diameters were used to establish the shape of cricoid ring (elliptical or circular) in infants and children of various ages.

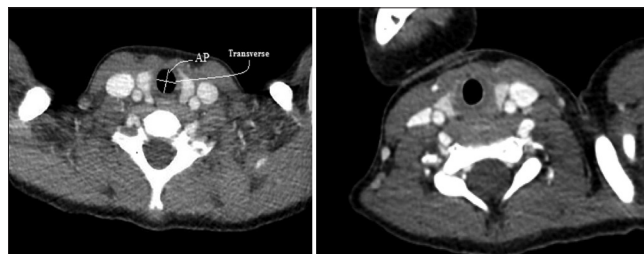
## Methods

This retrospective study was performed at King Fahad Medical City (Riyadh, Saudi Arabia). Institutional Review Board approval was obtained and the need for written, informed consent was waived. Two hundred and twenty CT scans of

children, ranging in age from 1 month to 10 years, undergoing radiological evaluation for medical or surgical conditions not affecting the airway were reviewed retrospectively. Exclusion criteria included any diagnosis or condition that would lead to abnormal laryngeal anatomy or interfere with the measurements. Patients were excluded from the study for any diagnosis or condition that would lead to abnormal laryngeal anatomy or interfere with the measurements including patients with a tracheostomy or ETT in place, tracheoesophageal fistula, pulmonary collapse or atelectasis, the presence of a mediastinal mass, diaphragmatic hernia, extrapulmonary intrathoracic mass, preterm infants, genetic or congenital syndromes, and primary lung diseases. All CT images were acquired using Philips™ and GE™ scanners. The image resolution was standardized for all CT images. Slice thickness of 2–2.5 mm and an in-plane resolution of submillimeter were used for measurements.

In all infants and children, the images were obtained either during natural sleep or sedation with spontaneous ventilation through a native airway in the supine position throughout the study period. No upper airway devices (oral or nasal airways) or supraglottic airways were used. Medications for sedation included either chloral hydrate or sevoflurane in oxygen delivered via a nasal cannula. Spontaneous ventilation was maintained throughout radiographic imaging. Supplemental oxygen was administered using a nasal cannula. The head of the patient was maintained in the neutral position at all times as per the protocol designed by the Department of Radiology.

The measurements were taken at the cricoid ring using the complete cricoid cartilage as the radiological identifier. The images were studied in both transverse, and sagittal planes and measurements were taken using images in the transverse planes. The AP and T dimensions were measured at the cricoid ring [Figure 1]. The standard soft tissue windows were used with window of 400 and level of 40 HU (400/40). Measurements were taken by two of the authors (T. W., M. R.) independent of each other and verified by a co-author (M. S.). Electronic calipers were used to obtain the measurements. All authors subsequently reviewed any discrepancy between



**Figure 1: Axial images of computed tomography scan showing measurement of and differences between transverse and anteroposterior diameters. AP: Anteroposterior**

the measurements. All investigators were blinded to the age of the patients until measurements were analyzed. The measurements recorded included the AP and T diameter of the airway at the cricoid levels. The AP and T measurements at the cricoid levels were used to determine the geometric shape of the airway.

**Statistical analysis**

AP, T, difference between the AP and T dimensions (calculated as T-AP), and cross-sectional area (CSA) were calculated for each predetermined age group (1 month to 10 years). The mean and 95% confidence intervals (CIs) for each of the cricoid measurements, including the difference between the AP and T dimensions were determined. To evaluate whether the AP and T dimensions were equal within each age group, two-sided paired *t*-tests were performed at a significance level of  $\alpha = 0.05$ . The effect of age (in months) on each of the measurements was examined using a univariate regression model. One-way analysis of variance was used to compare AP and T dimensions across age groups, with a Tukey correction for multiple comparisons.

**Results**

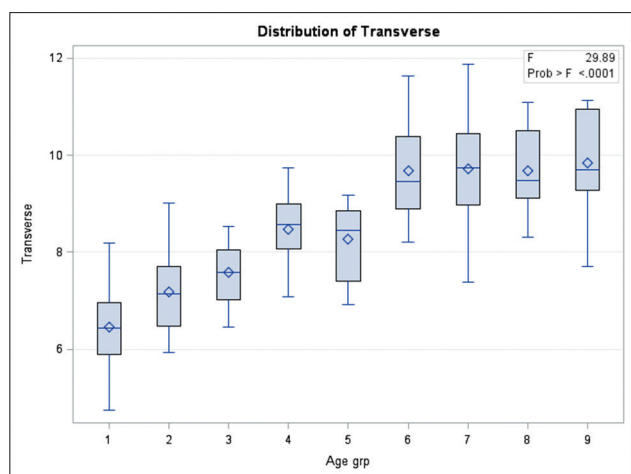
The study cohort included 220 patients, ranging in age from 1 month to 10 years. The CT scans of 130 patients were retained and reviewed (ninety patients were excluded from the study as appropriate measurements could not be obtained due to the lack of needed images). Of these 130 patients, 67 (51.5%) were boys with a mean age of  $48.1 \pm 33.1$  months and 63 (48.5%) were girls with a mean age of  $46.6 \pm 33.5$  months. There were no statistically significant gender differences in any of the cricoid measurements. The mean and 95% CIs for AP and T dimensions for each of the cricoid measurements across various age ranges are shown in Table 1 as well as Figures 2 and 3. In the 1–12 month age

group, the AP dimension was  $0.31 \pm 0.56$  mm greater than the T dimension ( $P = 0.04$ , after adjustment for multiple comparisons). For all other age groups, the difference between the T and AP dimensions was not statistically

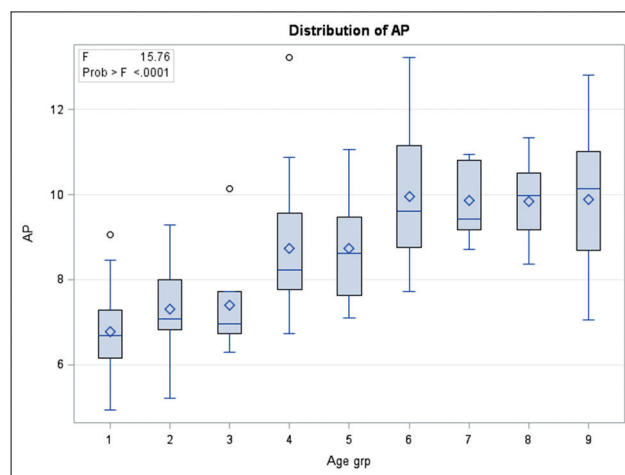
**Table 1: Descriptive statistics for cricoid measurements by age group**

Age group (months)	Variable	Mean±SD	95% CI from mean	
			Lower	Upper
1-12 (n=17)	T	6.46±0.91	6.00	6.93
	AP	6.77±1.07	6.22	7.32
	T-A	-0.31±0.56	-0.59	-0.02
12.5-24 (n=32)	T	7.17±0.77	6.90	7.45
	AP	7.31±0.86	7.00	7.62
	T-AP	-0.14±0.77	-0.42	0.14
25-36 (n=7)	T	7.59±0.69	6.94	8.23
	AP	7.41±1.29	6.22	8.60
	T-AP	0.18±1.32	-1.04	1.40
37-48 (n=18)	T	8.47±0.82	8.06	8.87
	AP	8.73±1.64	7.92	9.54
	T-AP	-0.26±1.21	-0.86	0.34
49-60 (n=7)	T	8.27±0.84	7.50	9.04
	AP	8.73±1.38	7.47	10.00
	T-AP	-0.46±1.83	-2.15	1.22
61-72 (n=16)	T	9.67±1.04	9.12	10.23
	AP	9.95±1.57	9.12	10.79
	T-AP	-0.28±1.05	-0.83	0.28
73-84 (n=9)	T	9.72±1.34	8.70	10.75
	AP	9.87±0.89	9.19	10.56
	T-AP	-0.15±1.05	-0.96	0.65
85-96 (n=9)	T	9.68±0.89	8.99	10.37
	AP	9.84±0.96	9.10	10.57
	T-AP	-0.16±1.23	-1.11	0.79
97-114 (n=15)	T	9.84±1.09	9.24	10.44
	AP	9.89±1.6	9.00	10.77
	T-AP	-0.05±0.89	-0.54	0.44

AP: Anteroposterior; T: Transverse; CI: Confidence interval; SD: Standard deviation



**Figure 2: Age-related distribution of transverse diameters**



**Figure 3: Age-related distribution of anteroposterior diameters. AP: Anteroposterior**

different than 0. Exact *P* values for the differences in dimensions are reported in Table 2.

The effect of age (in months) on cricoid CSA as well as the AP and T dimensions is shown in Table 3. For each measurement, age had a statistically significant effect on the cricoid size. Both the AP and T dimensions increased by approximately 0.037 mm for each month, whereas the CSA increased by approximately 0.116 mm<sup>2</sup> for each month. Only 3 of the patients in the entire cohort of 130 patients were noted to have an exactly equal AP and T diameter of the cricoid ring.

## Discussion

The shape of the cricoid ring remains a key component when considering endotracheal intubation as it is the primary unyielding structure in the pediatric airway. The area below vocal cords (subglottis) can be narrow, but it is generally a yielding structure because of the absence of cartilaginous or bony structures. The present study shows that the cricoid ring is essentially round in children older than 1 year of age. In children <1 year of age, the cricoid area is elliptical with the T-axis being less than the AP axis. The relevance of this observation is important as the specific contact points on the lateral walls of the airway, and consequently, the external pressure exerted upon the mucosa by a circular, uncuffed ETT in an elliptical airway may theoretically cause more damage and postextubation respiratory complications.<sup>[14]</sup>

Two recent studies using magnetic resonance imaging and video bronchoscopy have suggested that the cricoid lumen is

not circular but rather elliptical.<sup>[2,3]</sup> At the cricoid level, both studies reported the cross-section of the cricoid to be mildly elliptical with a smaller T diameter (T/AP ratio of 0.8–0.9 reported by Litman *et al.* and 0.95 by Dalal *et al.*).<sup>[2,3]</sup> In the present study, the T/AP ratio was 0.95 for patients <1 year of age and ranged between 0.98 and 1.01 for older children. The difference between the T and AP dimensions was significantly different only in children, 1–12 months of age, whereas it was similar in those >12 months of age. These data suggest a more circular cricoid ring in patients who are more than 1 year of age. In children <1 year of age, the AP diameter was an average of 0.31 mm larger than T diameter, suggesting a more elliptical shape.

ETTs have a perfectly circular outer shape. This likely has significant clinical implications when inserted in an elliptical structure. Even an appropriately sized uncuffed ETT based on age or weight can apply excessive pressure on the lateral areas of the cricoid (transverse axis) and cause laryngeal or tracheal mucosal damage.<sup>[15]</sup> This may occur despite what is considered an acceptable “leak” around the ETT [Figure 4]. In fact, a higher incidence of sore throat has been demonstrated when using uncuffed versus cuffed ETT.<sup>[16]</sup> Alternatively, if a cuffed ETT is placed into an elliptical airway, the cuff can then be inflated to seal the airway, thereby potentially minimizing the effects on the airway providing that the intracuff pressure is monitored and controlled.<sup>[15]</sup>

CT images and measurements can be affected by the position of the patient and the spatial orientation of the airway. To prevent this potential problem, the positioning of each patient was similar and according to the standards of the Radiology Department obtaining the imaging. Furthermore, as this was a retrospective study, we did not control for the phase of respiration during which the images were obtained. However,

**Table 2: Statistical analysis of the transverse to anteroposterior difference of the cricoid ring**

Age (years)	T-AP difference	<i>P</i>
1	-0.3082	0.0358
2	-0.1394	0.3118
3	0.1786	0.7321
4	-0.2628	0.3688
5	-0.4657	0.5243
6	-0.2763	0.3064
7	-0.1533	0.6712
8	-0.1567	0.7135
9	-0.0487	0.8342

The only group for whom the two-dimensions were statistically different was infants <1 year of age. T-AP: Transverse to anteroposterior

**Table 3: Univariate regression effects of age on cricoid measurements**

	Estimate <sup>a</sup>	SE	<i>t</i>	<i>P</i>
AP	0.0368	0.0034	10.9600	<0.0001
Transverse	0.0370	0.0025	14.8600	<0.0001

<sup>a</sup>Interpreted as the expected increase in cricoid measurement for each 1 year increase in age. AP: Anteroposterior; SE: Standard error



**Figure 4: Axial image with an uncuffed endotracheal in the trachea at the level of the cricoid. There is no space between the endotracheal tube and the inner mucosa of the cricoid ring**

the cricoid ring is a nonexpandable rigid structure that should not be affected by the phases of respiration. Furthermore, both images (AP and T) were obtained from the same image and therefore the phase of respiration would be the same.

## Conclusion

There was no difference in airway configuration or size based on gender in patients up to 10 years of age (the upper age limit of patients included in the current study). The cricoid ring was elliptical in infants <1 year of age and round in children >1 year of age. The elliptical shape of the airway provides an anatomical reason for the consideration of using a cuffed ETT in the pediatric population. The variation in T and AP dimensions noted within age groups supports the clinical findings that a significant percentage of uncuffed ETTs may not provide an appropriate fit when age-based formulas are used.<sup>[8,14]</sup> The dimensions of the cricoid ring obtained from the current study across the various age groups are a useful guide for the sizing of ETTs in the pediatric population especially when the external diameters of the ETTs are taken into consideration.

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## Conflicts of interest

There are no conflicts of interest.

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