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# **A Bronchoscopic, Computer-assisted Examination of the Changes in Dimension of the Infant Tracheal Lumen with Changes in Head Position**

## **Implications for Emergency Airway Management**

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**Background:** Resuscitation guidelines caution against extreme extension or flexion of an infant's head because tracheal obstruction may occur. No data support this recommendation. The authors therefore examined the dimensions of the

tracheal lumen in neutral, extended, and flexed head positions in infants undergoing general endotracheal anesthesia for elective surgery.

**Methods:** Eighteen healthy full-term infants were studied. A flexible fiberoptic bronchoscope was passed through a previously inserted endotracheal tube and positioned above the cricoid cartilage. Video recordings were taken in each of three head positions. Recordings were analyzed by an investigator blinded to head position. A computer-digitized technique was used to measure anterior-posterior and lateral dimensions and cross-sectional area. Data were analyzed using paired *t* tests and sign tests.

**Results:** No significant differences in mean tracheal dimensions with changes in head position were found. No infant had complete tracheal obstruction. Infants were equally as likely to have a small increase as they were to have a small decrease in tracheal dimension with changes in head position.

**Conclusions:** Despite the belief that infants and neonates have obstruction at the level of the trachea with extreme positions of the head, the authors were unable to demonstrate this phenomenon. (Key words: Airway obstruction; computer graphics; infant resuscitation; infant ventilation; medical imaging.)

GUIDELINES from the American Heart Association (AHA)<sup>1</sup> and the American Academy of Pediatrics<sup>2</sup> caution against extreme extension or flexion of an infant's head during resuscitation because stretching of the highly compliant trachea may result in airway obstruction. No scientific data support this recommendation. Therefore, we examined, in a prospective, blinded, controlled study, the dimensions of the tracheal lumen in the neutral, flexed, and extended head positions in infants undergoing general endotracheal anesthesia for elective surgery.

## **Materials and Methods**

After approval by the Institutional Review Board of the Children's Memorial Hospital, written informed

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consent was obtained from the parents of 18 full-term infants younger than 4 months old scheduled to undergo elective surgery requiring placement of an oral endotracheal tube. Current weight, height, age, and gestational age at birth were recorded. All infants were American Society of Anesthesiologists physical status 1 or 2, with no history of airway anomalies, chronic airway disease, acute respiratory illness, or previous intubation.

All infants received halothane and 60% nitrous oxide in oxygen by mask to induce anesthesia. After induction, an intravenous catheter was placed, and a nondepolarizing muscle relaxant was administered. After muscle relaxation was judged to be adequate, infants' tracheas were intubated using a 3.0- or 3.5-mm ID oral endotracheal tube (Mallinckrodt Medical, St. Louis, MO). Endotracheal tubes were modified by cutting off the tip to eliminate the Murphy eye and to decrease the bevel angle, thus allowing better visualization of the trachea for video recording. A swivel adapter with diaphragm was then placed on the endotracheal tube. The endotracheal tube was held in place by an assistant while one of the investigators placed a flexible ultrathin fiberoptic laryngoscope (2.2 mm in diameter; Olympus LFP, Lake Success, NY) through the adapter until the trachea was visualized. The endotracheal tube tip was placed just below the vocal cords, above the cricoid cartilage, to eliminate the possibility of stenting open the trachea during head manipulation. Video recordings of the trachea were obtained in each infant with the head in neutral position, maximum possible extension, and maximum possible flexion (chin to chest). There was no positive pressure on the airway during recordings. The time required for each recording was <10 s, and patients were ventilated between each measurement. Order of head position was determined using a random number table. The angles of extension and flexion were determined by placing each infant's head in the neutral position. A protractor was used to draw a vertical line on the face and to measure the position change of this line relative to the neutral position with flexion and extension of the head. An investigator not responsible for endoscopy moved the head and measured the angles of flexion and extension. All infants were monitored with pulse oximetry, end-expired carbon dioxide and anesthetic agent analyzer, electrocardiography, and noninvasive blood pressure.

Video recordings were analyzed using a computer-assisted technique by an investigator (MED) blinded to head position. Measurements were made from digital

images captured from the video recordings on an Indigo-2 Extreme work station equipped with Galileo video capture hardware (Silicon Graphics, Mountain View, CA; fig. 1A). Linear and area measurements of the airway lumen were taken using software developed for the project.<sup>3</sup> This image morphometry software was developed in the C++ language using the OpenGL graphics development tool kit. Three independent measurements (anterior-posterior dimension, lateral dimension, and cross-sectional area) were made in each head position for each infant, a total of nine measurements per patient.

The captured images were processed to outline the airway lumen (fig. 1B). Higher contrast images were segmented using an automatic edge detection algorithm. A few images lacked sufficient contrast for complete automatic edge detection and had to be finished manually. By relying primarily on an automatic edge detection algorithm and by using consistent illumination from the endoscopy source during recording, a uniform site of area measurement between head positions was ensured. Anterior-posterior dimensions of the lumen were measured manually using the posterior trachea as a landmark; lateral dimensions were measured using the largest diameter perpendicular to the anterior-posterior axis.

A planar calibration factor was measured from a digital image of a glass micrometer using the same fiberoptic laryngoscope and imaging system used during endoscopy and video recording (fig. 1C). The micrometer was ruled with 0.1-mm markings. A constant distance (4 mm) from the end of the bronchoscope to the image plane was maintained. An overall system resolution value of 0.2 mm was determined from the calibration image. The calibration scale factor for the bronchoscope was implemented in the morphometry program. The potential error in the imaging and morphometry systems was estimated to be 8–10%.<sup>3</sup>

To calculate area, the computer-generated lumen edge was flood filled, and the number of pixels present in this digitized area was determined by the morphometry software. Using the number of pixels per 0.1 mm<sup>2</sup> determined from the calibration image and the number of pixels contained in the outlined tracheal lumen edge, an area measurement was calculated (fig. 1D).

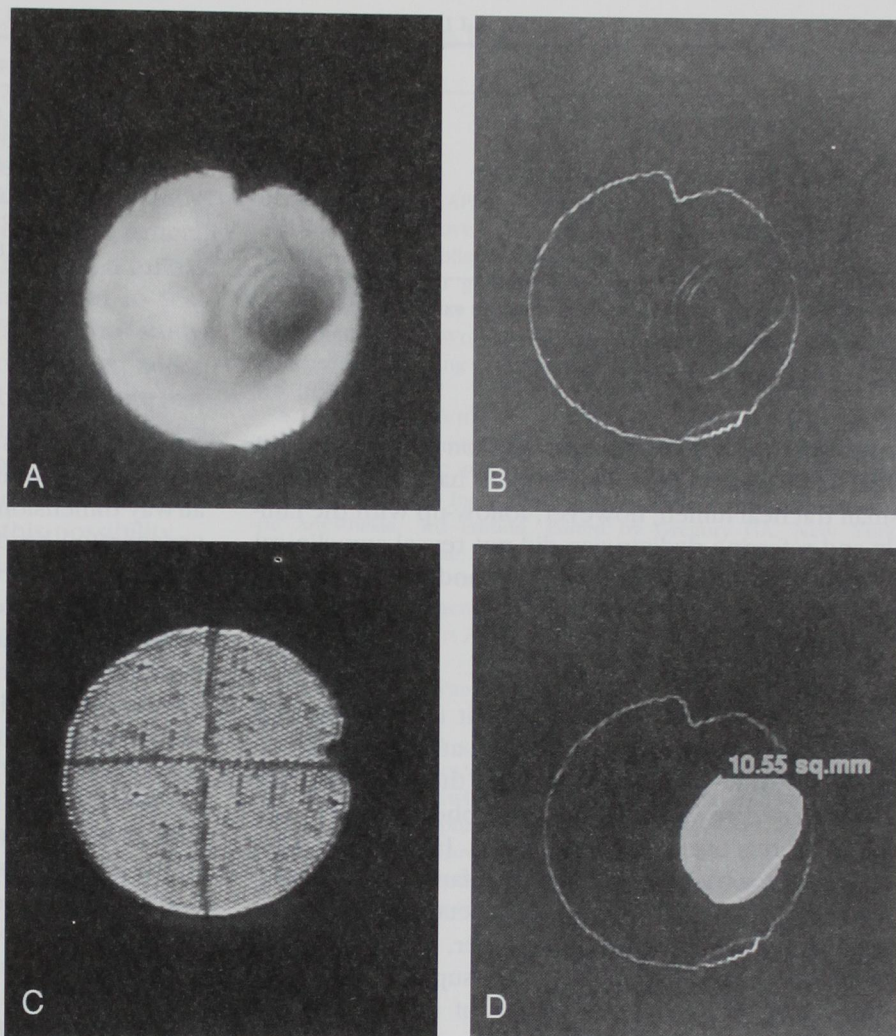
#### *Statistical Analysis*

Three measurements were made of each digitally captured image and averaged for the final value. The reliability of the measurements was evaluated using the in-



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Fig. 1. (A) Digital image of a tracheal lumen captured from the video recording. (B) Digital image after automatic edge detection. (C) Planar calibration image used to determine the number of pixels per 0.1 mm<sup>2</sup>. (D) Digital image after flood filling the lumen edge; the number of pixels were counted to determine cross sectional area.



traclass correlation coefficient from a random selection of the cohort (all measurements for four patients). With each patient serving as his or her own control, we compared the dimensions of the trachea in each position using paired *t* tests and either the increase or decrease in dimension from the neutral position using the sign test.

## Results

Patient demographics are presented in table 1. Mean tracheal dimensions with changes in head position are presented in table 2. Using each patient as his or her own control, no patient had significant changes in tracheal dimension with changes in head position. There

was no significant difference in the number of patients who had an increase in dimension *versus* those who had a decrease in dimension (Table 3).

The range of angle of maximum possible flexion from the neutral position was 20–35°. The range of angle of maximum possible extension from the neutral position was 10–30°. The reliability of the measurements was

Table 1. Patient Demographics

	Mean $\pm$ SD	Range
Age (days)	58 $\pm$ 37	1–119
Weight (kg)	5.2 $\pm$ 1.2	3.5–7.3
Height (cm)	58.7 $\pm$ 5.3	50–67
Gestational age at birth (wk)	39 $\pm$ 1.2	37–41



**Table 2. Infant Tracheal Lumen Areas and Dimensions for Neutral, Maximum Flexed, and Maximum Extended Head Positions\***

	Neutral	Flexion	Extension
Cross-sectional area (mm <sup>2</sup> )†	12.9 ± 3.49 (5.87–20.8)	13.0 ± 2.94 (6.68–19.2)	13.0 ± 3.79 (5.01–20.8)
Anterior–posterior dimension (mm)†	3.85 ± 0.73 (2.18–4.79)	3.66 ± 0.60 (2.65–4.69)	3.82 ± 0.73 (2.81–5.48)
Lateral dimension (mm)†	4.15 ± 0.64 (2.93–5.36)	4.27 ± 0.61 (2.83–5.37)	4.25 ± 0.84 (2.22–5.57)

\*  $P = \text{NS}$  comparing neutral to flexion or neutral to extension.

† Mean ± standard deviation (range).

excellent, with intraclass correlation coefficients of 0.92–1.00. One patient appeared to have an unusually small tracheal lumen; however, follow-up with the family and referring pediatrician did not reveal any clinical evidence of a tracheal pathologic condition.

## Discussion

Despite the widely held belief that infants and neonates experience airway obstruction at the level of the trachea with flexion or extension of the head,<sup>1,2,4–7</sup> we were unable to demonstrate this phenomenon. The source of this observation is unclear. In the 1980 AHA guidelines for basic life support in infants and children, head position and the possible effects on airway patency were not discussed<sup>8</sup>; however, the 1986 AHA guidelines for pediatric basic life support state that “some believe that overextension of the head closes the trachea in small babies; there are no data that this is so . . .”<sup>2</sup> In the 1986 and 1992 AHA guidelines for neonatal advanced life support, another unreferenced statement suggests that “overextension or underextension may produce airway obstruction and should therefore be avoided.”<sup>2,6</sup> The site of this obstruction is not described.

**Table 3. Number of Patients with a Change in Area or Dimension from the Neutral Position\***

	Flexion (increase/decrease)	Extension (increase/decrease)
Cross-sectional area	9/9	9/9
Anterior–posterior dimension	7/11	9/9
Lateral dimension	10/8	13/5

\*  $P = \text{NS}$  using the sign test.

Our study was designed to examine the effects of maximum possible flexion or extension of the head on airway dimensions below the level of the glottis. These exaggerated head positions are outside the range used clinically but were chosen as an easily reproducible and uniform clinical end point. In addition, because these were the maximum possible positions of extension and flexion for each infant, this included all possible changes in the dimensions of the tracheal lumen that might occur with extreme changes in head position.

We specifically placed the endotracheal tube tip just below the vocal cords and thus within or above the cricoid cartilage (a complete and noncompressible anatomic ring) to prevent stenting open the airway by the endotracheal tube tip. For the same reason, we avoided positive pressure on the airway during video recordings. Because there was an endotracheal tube in place, this study could not evaluate changes in airway anatomy above the level of the glottis.

Although no classification exists for tracheal stenosis, clinical experience and guidelines for treatment suggest that obstruction needs to be >80% to become important clinically.<sup>9</sup> The mean percent changes in cross sectional area were 3.7% with flexion and 2.6% with extension. No infant had a >38% decrease in dimension of the tracheal lumen with changes in head position. In addition, no child had complete obstruction of the trachea, as was suggested might occur in the resuscitation guidelines. Some infants had a 58% increase in dimension with flexion or extension.

As shown in table 3, there was no predictable tendency for the tracheal lumen to either increase or decrease with changes in head position. Infants were equally as likely to have a small increase as they were to have a small decrease in tracheal dimension with maximum possible changes in head position.

Because our sample size was limited to 18 infants,



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however, there still may not be a zero incidence of the long-term risk of this phenomenon in the general population. A reasonable estimate of long-term risk when the numerator of a study is zero, and accepting a 95% confidence interval, is  $1-3/n$ , where  $n$  is the number of patients studied.<sup>10</sup> Therefore, in our study, the long-term risk of a zero incidence in the general population is limited to 83%. To limit the long-term risk of a zero incidence of tracheal compression to 95% would require a study group of 300 infants. In our study, all infants were healthy and had no known airway anomaly or pathologic condition. It is possible that there may be conditions such as tracheomalacia or tracheoesophageal fistula in which the trachea is more compliant and at risk for compression with extreme head positions. Further study is required to evaluate this possibility.

Airway obstruction does not appear to occur at the level of the trachea in healthy infants. If airway obstruction does occur with extreme positions of an infant's head, it must be at another site such as the hypopharynx. Obstruction to ventilation at this site may be overcome by adjustment of mask fit, continuous positive pressure ventilation, positive end-expiratory pressure, or use of an oropharyngeal airway. These maneuvers, rather than manipulation of the head, should be the focus of improving ventilation during resuscitation of infants.

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