

Determination of Endotracheal Tube Size in a Perinatal Population

An Anatomical and Experimental Study

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Background: This study aimed at correlating anatomical dimensions of the larynx and trachea to age and weight in a prenatal population. Endotracheal tube size determination was then proposed according to these considerations.

Methods: Anatomical measurements were obtained during 150 fetal and infant postmortem examinations. The optimal endotracheal tube size was determined by three methods: clinically, by a pressure method using calibrated inextensible balloons, and anatomically by comparing the laryngotracheal perimeter to the tube perimeters. Based on these results, recommended tube sizes were calculated.

Results: In premature babies before 37 weeks gestation, the optimal tube size according to pressure estimation was significantly greater than that determined by anatomical measurement alone. This difference was no longer valid after 40 weeks gestation.

Conclusions: This study identified the elasticity of laryngeal structures in premature babies, allowing intubation with tube sizes greater than predicted by anatomical measurements with an increasing injury risk located in the posterior part of the glottic plane. This elasticity disappears near 40 weeks gestation, and the injury risk then predominates in the subglottic region. These results lead the authors to recommend that the size of the endotracheal tube used in the perinatal population should be based on anatomical and experimental data to limit the injury risks.

ADVANCES in neonatal medicine have contributed to the survival of extremely preterm infants. Because of their respiratory immaturity, long-term tracheal intubation is often necessary. Practical determination of endotracheal tube size in the premature population is classically based on clinical reports¹⁻³ and industrial recommendations. Tube size determination varies among sources; medical recommendations^{4,5} are generally higher than clinical ones. Comparisons are difficult because the authors do not consider the same age or weight groups.

Our study design on intubation was based on the different types of lesions reported in the literature^{1,6-15} and experimental studies dealing with the development

of postintubation lesions.¹⁶⁻²² These studies demonstrated that injury occurs at two levels: the posterior part of the glottic plane,⁷⁻¹² with a risk of vocal process necrosis or cricoarytenoid ankylosis, and the subglottic level,^{7,8,10-13,15} with a risk of cricoid necrosis and subglottic stenosis.

These lesions resulted from two distinct etiologies: injury lesion of the mucosa and ischemic lesions caused by a pressure excess on laryngeal structures. Ischemic lesions occur frequently in the subglottic lumen, where the mucosa is compressed between the endotracheal tube and the cricoid cartilage. When the pressure on the mucosa is greater than the capillary pressure, ischemic lesions develop in adjacent structures.^{16,17,19,20} Inflammation resulting from this phenomenon can lead to development of fibrous tissue.¹¹

Multiple causes are implicated in the genesis of these lesions,^{1,3,6,7,9,11,14,15,23-26} but most authors agree that the main determinant of the injury is an excessive tube size.

Postintubation subglottic stenosis rarely occurs in premature babies, with a rate estimated from 0 to 4%,^{1-3,6,7,23,24} whereas posterior glottic lesions seem to be more frequent in this age group.⁷⁻¹²

The aim of this study was to determine the anatomical dimensions and characteristics of the larynx and trachea according to age and weight in the prenatal population, and to elaborate criteria for the endotracheal tube size based on these measurements.

Materials and Methods

The larynx and trachea from 150 postmortem examinations of fetuses and infants were prospectively collected, between January 1999 and February 2002. Legal and ethical considerations were consistent with our institution's rules.

Inclusion criteria required that the fetuses and infants were free of malformative syndromes affecting the laryngotracheal structures and had never been intubated. All anatomical structures, including the larynx, the trachea, and the thyroid gland, that were free of malformation on macroscopic examination were included.

The study was performed on anatomical pieces during postmortem examination. The pieces were studied within a delay of 6 h after death. No fixative agent or conservative agent was used.

All biometrical, clinical, and pathologic data were col-

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lected during autopsy. For each fetus, gestational age (GA) was determined based on biometric data.

Each larynx was intubated to estimate clinically the largest tube size (clinical ID) that could be introduced without glottic friction or cricoid deformation. Portex Blue Line® endotracheal tubes (SIMS Portex, Hythe, United Kingdom) with ID size ranging from 2.5 to 4.0 and Vygon® endotracheal tube (Vygon, Ecoen, France) ID size 2.0 were used. The largest endotracheal tube that could be introduced without deforming the cricoid ring was considered to be the largest size tube that would not result in injury to the upper airway. In the case where an endotracheal tube ID size 2.0 could not be introduced without cricoid deformation, the patient was considered to have a “high injury risk” intubation.

In a second stage, each larynx was intubated successively with different calibrated inextensible balloons of increasing size. Balloons were made with thermoformed polyvinyl chloride fixed on an 18-gauge catheter. Balloon diameters corresponded, when inflated with air at 20 cm H₂O, to the OD of an endotracheal tube. The balloon was connected to a low-pressure manometer (Mallincrodt, Hazelwood, MO) (fig. 1), and inflated with 20 cm H₂O pressure. It was positioned through the laryngotracheal structures with the proximal extremity placed 1 cm over the glottis and with the distal one sticking out under the fifth tracheal ring.

Pressure changes were evaluated during the intubation. The optimal tube size estimated by this method (pressure ID) corresponded to the largest one that could pass through the laryngotracheal structures without increasing the balloon pressure or with a pressure normalization time that was less than 15 min.

Intubation was considered to have a high injury risk if the pressure in the smallest balloon remained increased for at least 15 min.

Finally, each larynx was dissected for anatomical estimation. The larynx was separated from the trachea by section along the inferior edge of the cricoid cartilage. A precision digital caliper was used to measure the anteroposterior and lateral diameters of the cricoid lumen, introducing the caliper by the inferior face of the cricoid lumen, and the tracheal lumen. The anteroposterior and lateral diameters of the cricoid lumen were measured using a precision digital caliper (Mitutoyo, Roissy, France; precision = 0.02 mm). The caliper was introduced into the cricoid ring through the caudal end of the lumen. Measurements were obtained without deformation of the anatomical structures (fig. 2). The interarytenoid distance (IAD) was obtained by introducing the caliper between the vocal processes of the arytenoids and opening the glottic plane until the maximal passive abduction movement of the arytenoid cartilage without friction was achieved.

By these measurements, two different tube size estimations were calculated:

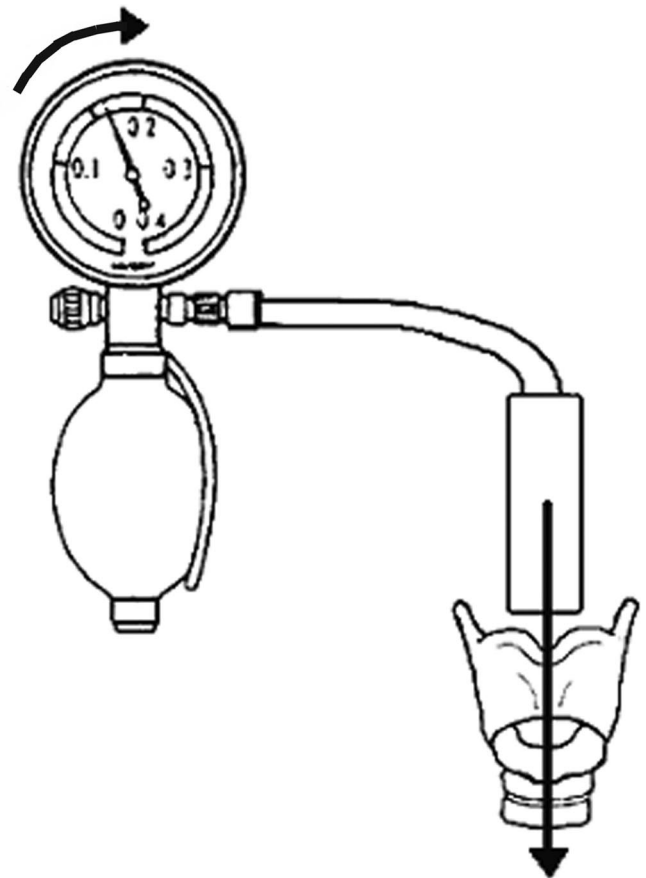


Fig. 1. Principle of pressure test. The calibrated balloons, with diameters corresponding to the OD of the Vygon® (Vygon, Ecoen, France) endotracheal tube 2.0 and Portex Blue Line® (SIMS Portex, Hythe, United Kingdom) endotracheal tube from 2.5 to 4.0 mm, were inflated with 20 cm H₂O pressure and were passed through the laryngotracheal specimen. The variation of pressure during the intubation was observed on the low-pressure manometer. The tube size retained (pressure ID) corresponded to the largest diameter passing through the larynx without inducing pressure increase or with a pressure normalization shorter than 15 min.

- The mean subglottic and tracheal perimeters were calculated for each specimen, considering the lumen as an ellipse ($P = 2\pi\sqrt{(a^2 + b^2)/2}$). These perimeters were compared with the endotracheal tube perimeters calculated based on the external diameter of each tube size. The optimal tube size based on the laryngotracheal perimeter (SG ID) corresponded to the tube whose external perimeter was less than or equal to the subglottic or tracheal perimeter. The intubation was considered to have a high injury risk when the laryngotracheal perimeter was less than the external perimeter of the smallest endotracheal tube.
- The maximal tube size that could be passed through the glottic plane was determined by the maximal OD that was less than or equal to the IAD (IAD ID).

Intubation was considered to have a high injury risk when the IAD was less than the OD of the smallest endotracheal tube.

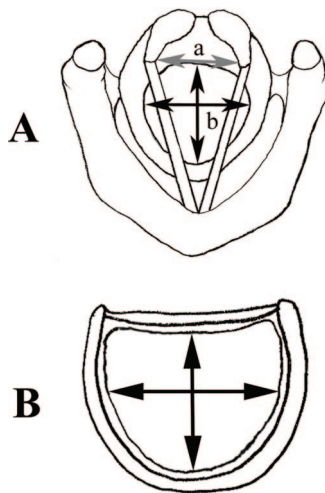


Fig. 2. Anatomical measurements. Measurements were obtained using a digital caliper on fresh anatomical specimens. The diameters were measured with the endoluminal mucosa in the larynx (A) (a = interarytenoid distance; b = subglottic antero-posterior and lateral diameters) and in the trachea (B) (antero-posterior and lateral diameters).

The population was divided into five groups according to GA (A: \leq 28 weeks GA; B: 29–32 weeks GA; C: 33–36 weeks GA; D: 37 weeks GA to term; and E: term to 3 months) to analyze the data statistically.

Statistical analysis was performed using StatView 6.0 software (SAS Institute, Cary NC). A descriptive analysis of the population was realized. Continuous variables were compared between groups stratified for age and sex. A nonparametric Wilcoxon test was used for the comparison of variables in each group. The comparison of variables between groups was performed using a Mann-Whitney test. A nonparametric correlation test (Spearman) was performed between the intubation data (clinical ID, pressure ID, SG ID, and IAD ID) and clinical data (theoretical GA, corrected GA, weight, and height) collected for each patient. Differences were considered statistically significant at $P < 0.05$.

Based on these results, the recommended OD was calculated in each larynx, corresponding to the external perimeter of the tube size determined by pressure estimation less than or equal to the maximal IAD. The

corresponding ID according to different trademarks was reported.

Results

The larynxes and tracheas from 122 fetuses aged 25–41 weeks GA and 28 infants from newborn to 3 months of age were included (table 1). The causes of death in the fetus population were termination of pregnancy for neurologic malformations (43 cases), cardiac malformations (31 cases), urogenital malformations (12 cases), polymalformative syndromes (11 cases), intra-uterine death (17 cases), and stillbirth (8 cases). The cause of death in the infant population was sudden death syndrome (24 cases) and evolution of nonreanimated neurologic disease (4 cases). No infant was intubated. In 9 cases, a laryngeal mask was used during resuscitation.

Anatomical measurements were characterized by a quasi-linear evolution until birth and followed by an inflection after the birth (fig. 3).

The narrowest part of the airway was the cricoid area in the general population and in each age group (Wilcoxon, $P < 0.001$). Interindividual variations of measurements were important.

There was no statistical difference between males and females for subglottic and tracheal measurements. The interarytenoid distance in females was significantly less than that in the population (Mann-Whitney, $P < 0.001$). This difference was statistically significant only in age group E (Mann-Whitney, $P < 0.01$).

The results of the intubation study are illustrated in table 2.

Intubation based on clinical estimation was always possible.

Intubation based on pressure estimation was considered with a high injury risk in only 2 cases; both were included in group A (7.4%).

Intubation based on laryngotracheal estimation was considered to have a high injury risk in 46 cases: 25 cases in group A (92.5%), 16 cases in group B (43.2%), and 5 cases in group C (20.8%).

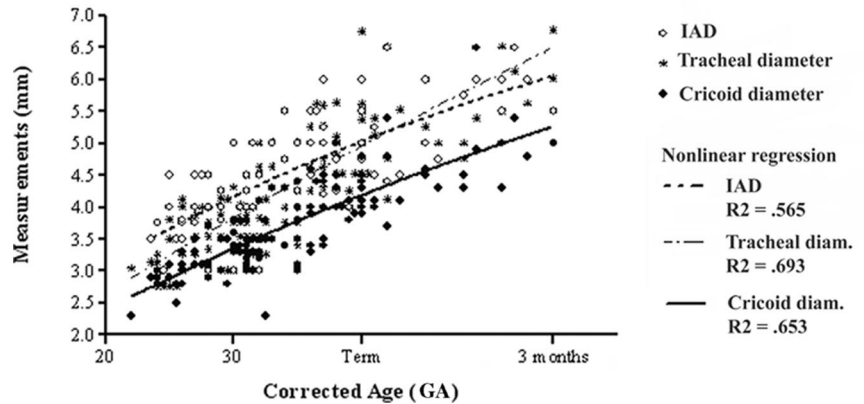
The value of the optimal ID varied according to the method of measurement. In premature babies before 37

Table 1. Demographic Data

Age Group	A	B	C	D	E
Gestational age or age	\leq 28 weeks GA	29–32 weeks GA	33–36 weeks GA	37 weeks GA to term	Term to 3 months
Mean weight, g	904 (468–1,370)	1,435 (1,190–1,770)	2,223 (1,730–2,820)	3,136 (2,500–4,010)	4,878 (3,750–6,520)
Mean height, cm	32.7 (28–38)	40.4 (37–42.5)	45.3 (39–47)	50.9 (47–53)	58 (52–69)
Male	12	20	13	20	13
Female	15	17	11	20	9
Total	27	37	24	40	22

The population included in the study was divided into five groups according to the corrected gestational age (GA) for preterm infant and corrected age for babies. The corrected age was based on biometric measurements obtained during autopsy. The table illustrates the mean weight and height with the minimal and maximal value for each age group and the repartition of the patients by sex.

Fig. 3. Anatomical measurements. The figure illustrates the results of anatomical measurements by age. The narrowest part of the laryngotracheal lumen was the cricoid diameter. These results showed an important interindividual variability. GA = gestational age; IAD = ID determined according to interarytenoid distance.



weeks GA, pressure modification occurred more frequently. The mean difference between pressure estimation of ID and laryngotracheal estimation of ID (pressure ID – SG ID) (fig. 4) was statistically significant in groups A, B, and C (Wilcoxon, $P < 0.001$). This observation disappeared progressively after 37 weeks GA (group D) and was no longer valid after term (group E) (Wilcoxon).

The mean difference between pressure ID and IAD ID (pressure ID – IAD ID) (fig. 5) is statistically significant only in groups C–E (Wilcoxon, $P < 0.001$). In 8 of 24 cases in group A, 2 of 24 cases in group C, and 6 of 40 cases in group D, the IAD ID was inferior to the pressure ID.

The clinical ID was always significantly greater than the pressure ID (Wilcoxon, $P = 0.02$).

There was no statistical difference for the different ID estimations between males and females in all age groups.

The correlations between ID obtained by the different methods of measurement and clinical parameters were always statistically significant (Spearman test, $P < 0.0001$). The highest correlation coefficients were obtained with corrected GA and birth weight (respectively, clinical ID $r = 0.841$, $r = 0.834$; SG ID $r = 0.825$, $r = 0.808$; IAD ID $r = 0.704$, $r = 0.663$; pressure ID $r = 0.770$, $r = 0.773$).

Recommended ODs by weight evaluated by the results of this study are illustrated in fig. 6.

Discussion

For the purposes of conducting the current study, we obtained fresh autopsy specimens to ensure that the airway dimensions were close to the dimensions in live patients. The use of fresh specimens allows preservation of physicochemical characteristics of the cartilaginous structures necessary to obtain an evaluation similar to physiologic conditions, especially for pressure evaluation. In embedded specimens, because of tissue shrinkage, measurements are modified²⁷ or impossible to realize (e.g., IADs which correspond to the abduction passive movement of the cricoarytenoid join).

The major finding of this study concerns premature babies at less than 37 weeks gestation. In this age group, we observed that IDs based on anatomical measurements were systematically lower those obtained with other methods (pressure, clinical, and IAD estimations). In all age groups, we observed correlations between ID and both corrected GA and weight.

Few studies have been published on the anatomical measurements of the airway in either pediatric populations^{13,27–32} or premature populations.

The dimensions of the cricoid lumen in preterm infants in the current study were less than those published previously in the same age group^{30–32} but greater than those published by Tucker *et al.*¹³ The dimensions of the cricoid lumen in term neonates in the current study are consistent with those published in some stud-

Table 2. Repartition of the Population According to Internal Diameters Obtained by Four Different Methods

Age Group	A: ≤ 28 weeks GA (n = 27)				B: 29–32 weeks GA (n = 37)				C: 33–36 weeks GA (n = 24)				D: 37 weeks GA to term (n = 40)				E: Term to 3 months (n = 22)						
	ID	HIR	2.0	2.5	3.0	HIR	2.0	2.5	3.0	HIR	2.0	2.5	3.0	3.5	2.0	2.5	3.0	3.5	4.0	2.5	3.0	3.5	4.0
Clin	—	9	18	—	—	2	28	7	—	—	5	18	1	—	—	28	12	—	—	7	11	4	—
Press	2	12	13	—	—	2	30	5	—	—	15	9	—	—	1	36	3	—	—	17	5	—	—
SG	25	2	—	—	16	14	7	—	5	5	6	8	—	2	18	18	2	—	2	11	9	—	—
IAD	3	6	15	3	—	2	25	10	—	2	8	3	11	—	7	6	24	3	1	2	6	13	—

The population was divided into five age groups (A–E).

Clin = clinical estimation of ID; GA = gestational age; HIR = high injury risk; IAD = ID determined according to interarytenoid distance; ID = endotracheal tube internal diameter, in millimeters; Press = pressure estimation of ID; SG = ID determined according to laryngotracheal perimeter.

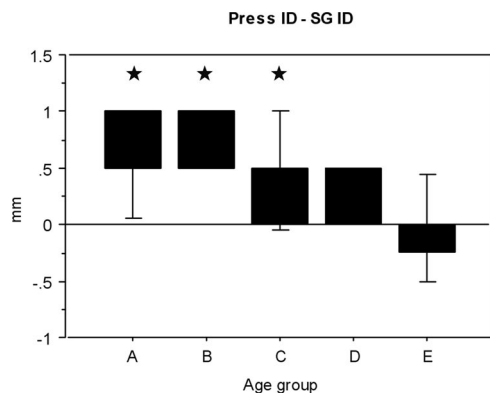


Fig. 4. Mean difference between pressure estimation of ID and laryngotracheal estimation of ID (pressure ID – SG ID). Stars indicate statistical significance in the considered age group (Wilcoxon test, $P < 0.01$).

ies^{27,28,33–35} but less than those published in others.^{30,32} Observed differences between our data and the literature may be attributed to the interindividual variability due to small sample sizes in other studies as well as methodologic differences in measurement. In the current study, the narrowest diameter of the cricoid rings was based on measurements obtained from the entire cricoid cartilage. Differences between the results of the current study and others may be attributed in part to the latter studies measuring luminal diameters at predetermined planes in the cricoid ring. Serial section studies may be influenced by the level of the section and the orientation of the section plane.

Ultrasound measurements of tracheal diameter³⁶ in fetuses reported a smaller diameter than our results. An experimental study³⁷ demonstrated that tracheal measurements obtained by ultrasound are smaller than anatomical measurements. For newborns and babies, the tracheal lumen observed in our study is similar to those observed by Pracy³³ and less than those observed by Fearon and Whalen.²⁹

At least two relations have been reported for the diameter of the cricoid lumen and age. On the one hand,

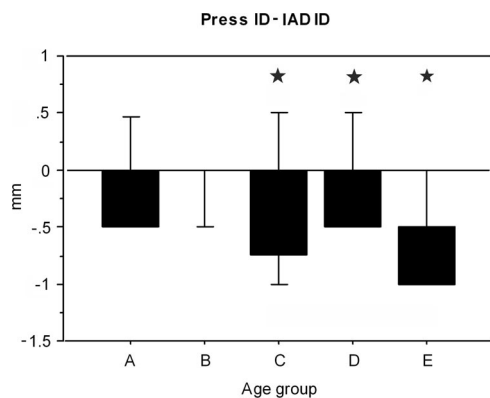


Fig. 5. Mean difference between pressure ID and ID determined according to interarytenoid distance (pressure ID – IAD ID). Stars indicate statistical significance in the considered age group (Wilcoxon test, $P < 0.01$).

Weight (g)	500	800	1500	3000	5000
Recommended OD (mm)	3	3.5	4	4.5	5
Corresponding ID					
Mallinckrodt contour™ (Athlone, Ireland)	2.0	2.5	3.0	3.5	
Portex Blue line™ (SIMS, Hythe, UK)	HIR	2.5	3.0	3.5	
Rüsch Safety clear™ (Kernen, Germany)	HIR	2.5	3.0	3.5	
VYGON™ (Ecouen, France)	HIR	2.0	2.5	3.0	

Fig. 6. Recommended ODs according to weight and corresponding ID. The figure illustrates the recommended OD based on the results of the pressure study and on an OD inferior or equal to the ID determined according to interarytenoid distance. These IDs were calculated based on OD of each kind of tube specified by the fabricants. ID is expressed in millimeters. HIR = high injury risk due to a pressure excess on the cricoid or on the vocal processes of the arytenoids.

Fishman and Pashley³¹ described a hyperbolic relation between cricoid ring diameter and GA. On the other hand, Schild,³² along with our evidence, supports a quasi-linear relation.

The absence of difference between males and females was also observed by some authors^{27,30,34} for laryngeal and tracheal lumens, but no observation was reported regarding the IAD.

Some studies have reported that the anteroposterior dimension of the glottis exceeds the same dimension at the level of the subglottis and tracheal lumen.^{32,33} This does not constitute a limiting factor in intubation. Only IAD was considered as a potential limiting factor at the level of the glottis; the OD of the tube should be less than or equal to the maximal IAD determined for each larynx. In our study, IAD was significantly less in females older than 40 weeks GA. Even if no significant difference was found for IAD ID estimation, the use of a smaller size tube in this population should probably be considered.

The pressure study was based on the capillary pressure estimated between 20 and 30 mmHg^{16,17,19} in adults with a pressure of the venous end of a capillary of approximately 12 mmHg¹⁷ and on the study of Nordin *et al.*,¹⁶ which demonstrated ischemic lesions as a result of excessive pressure after 15 min. The normal pressure within the tracheal mucosa in preterm infants has not been reported. Nonetheless, many clinicians accept a maximum inflation pressure of 20 cm H₂O (13 mmHg) to minimize tracheal mucosal injury. The observations of Nordin *et al.* justified criteria used in our study for a pressure normalization shorter than 15 min in case of pressure increase. The role played by the laryngeal sur-

rounding tissues, dissected for the study, is difficult to evaluate in pressure variations. The absence of circumferential muscular structures and presence of large adipose connective tissue should not significantly affect pressure variations.

This pressure study concerned the whole laryngotracheal lumen and did not define the level of the obstacle in case of pressure increase. The anatomical study confirms that the thinner level of the lumen corresponds to the subglottic area. Moreover, the pressure test was performed directly in the larynx and did not consider the potential pressure induced by the inclination of the tube by the upper structures (nasal fossa, oropharynx) and the position of the head.^{8,9}

The analysis of the intubation study shows a significant difference between the anatomical estimation of ID and the pressure estimation of ID in the premature population with a higher number of patients considered to have a high injury risk according to anatomical estimation compared with pressure estimation. These results suggest that premature laryngeal structures possess an elasticity allowing the passage of a tube with a higher size than that predicted by anatomical measurements. This observation could explain the better tolerance of intubation in premature infants than in newborns as suggested by Hawkins.⁶ In this case, although the cricoid is anatomically the narrowest part of the airway, its elasticity allows the passage of a higher diameter endotracheal tube, and the limiting factor becomes the interarytenoid distance.

Therefore, the risk of injury is most likely evident in the posterior glottis as demonstrated in clinical reports.⁷⁻¹²

This elasticity disappears around 37 weeks GA, and the limiting parameter becomes the cricoid area with a risk of induced subglottic stenosis.

Clinical estimation of ID was greater than the ID evaluated by pressure estimation, suggesting that clinical estimation does not seem to be a valid criterion to determine tube size. The clinical parameter reported in the literature that best correlated with tube size was GA^{23,38-40} or birth weight.^{1,2,26} In our study, the highest correlation was observed with corrected GA and weight. The correction of the GA based on biometric parameters seems unrealistic in clinical practice. Guidelines based on birth weight seem more relevant.

Based on these results, a recommended OD table could be proposed to limit a potential injury risk due to intubation. The relation between OD and ID is different according to different trademarks because of different tube thicknesses. For similar ODs, the difference of IDs should reach 1 mm. This is an important point for tube choice for ventilation assistance because respiratory resistance is correlated with the internal endotracheal tube size.

Recommended OD guidelines proposed in this study

are intended to provide a safe intubation and to limit laryngeal injury. This does not always correspond to efficient ventilation, principally when high-pressure ventilation is required.

Conclusion

This study demonstrated that laryngeal structures possess a certain degree of elasticity in the premature that permits a tracheal intubation with a tube size that is greater than that predicted by the anatomical measurement. In the premature population, injury risks predominate in the posterior part of the glottis. This elasticity disappears around 37 weeks GA, and injury risk then predominates in the subglottis.

Endotracheal tube size in neonates should be based on anatomical and experimental data to limit these injury risks.

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