Pediatric Anesthesia 2008 **18**: 113–118 doi:10.1111/j.1460-9592.2007.02382.x

Evaluation of cuffed tracheal tube size predicted using the Khine formula in children

CAROLINE DURACHER MD, EMMANUELLE SCHMAUTZ MD, CLAIRE MARTINON MD, JUDITH FAIVRE MD, PIERRE CARLI MD AND GILLES ORLIAGUET MD PhD

Département d'Anesthésie Réanimation Chirurgicale et SAMU de Paris, Université Rene Descartes Paris, Paris Cedex, France

Summary

Background: The correct size of cuffed endotracheal tube (CET) limits the risk of postintubation tracheal damage. The aim of this study was to compare the size of the CET used in children with the size predicted by the Khine formula [age (years)/4 + 3].

Methods: After ethical committee approval, 204 children aged 1 day–15 years were included prospectively in the study. The choice of the size of the CET was made at the discretion of the attending anesthesiologist. The main criterion of judgment was the comparison of the leak before and after inflating the cuff at a pressure of 20 cm·H_2O. Demographic data, tracheal tube size used and that predicted by Khine's formulae and side-effects were recorded.

Results: Overall, 21% of the CET were in accordance with the size predicted by the Khine formula. In the remaining patients, 72% were oversized and 7% undersized. In 12 cases, the size of CET chosen initially was modified: for a larger size in eight children and for a smaller size in four others. Six children (2.9%) presented with minor postoperative complications.

Conclusions: Our data suggest that Khine's formula for predicting the appropriate tracheal tube size underestimates optimal size by 0.5 mm. We therefore recommend the use of the following formula: internal diameter of the CET = [age/4 + 3.5] in children >1 year of age which may be applied without increased risk of complications. The rate of tracheal reintubation as well as the detected leaks supports these recommendations.

Keywords: endotracheal tube size; air leak; cuffed trachea tube; pediatric anesthesia

Introduction

Historically, uncuffed endotracheal tubes (UET) have always been recommended in pediatric anesthesia. Anatomic considerations, such as narrow subglottic region of the trachea, and the fear of a postintubation subglottic stenosis were the main arguments for the use of UET (1). Recent studies of both equipment and practice have shown that the use of a cuffed tracheal tube (CET) did not increase the incidence of postoperative respiratory complications (2–8). In addition, several advantages of CET

Correspondence to: Pr Gilles Orliaguet, Département d'Anesthésie Réanimation Chirurgicale et SAMU de Paris, Université Paris Descartes, CHU Necker Enfants Malades, AP-HP, 149, rue de Sèvres, 75743 Paris Cedex 15, France (email: gilles.orliaguet@nck.ap-hop-paris.fr).

have been documented in different studies, such as a reduced requirement for tracheal tube replacement, a more precise monitoring of the respiratory mechanics and endtidal CO_2, a decreased pollution of the operating room and a decrease in the cost of anesthesia related with a reduction in the consumption of volatile agents (3,6). Following the study by Khine *et al.* (3), where the authors have shown that the use of an adapted size of CET was not associated with an increased risk of respiratory complication, many pediatric anesthesia departments have changed to CET (6–10). Different algorithms and formulae have been proposed to choose the best fitting size of the tracheal tube (3,11,12). Khine *et al.* used a formula for the CET derived from the Cole's formula used in the UET [(age/4) + 3]. This modified formula takes account of the fact that because of an already larger external diameter, related with the cuff, the CET chosen must have an internal diameter lower than the UET. However, no study has so far validated the application of this formula in pediatric anesthesia.

The primary endpoint of this prospective study was to compare the size of the tracheal tube used with the size predicted using the formula of Khine. A secondary endpoint was to determine the incidence of postintubation respiratory complications.

Patients and methods

Following local ethical committee approval, children of ASA physical status I–III, aged 1 day–15 years, scheduled for routine surgery under general anesthesia with tracheal intubation with expected mechanical ventilation lasting at least 45 min, were prospectively included over a 6-month period.

Children with prior tracheal sequelae, difficult airway, known history of airway or pulmonary disease, ASA physical status >III and those requiring prolonged postoperative mechanical ventilation were excluded. Children were divided into seven groups according to the size of the tracheal tube used (G3.0, G3.5, G4.0, G4.5, G5.0, G5.5, and G6.0).

The decision to use a CET, the choice of the size of the tracheal tube and the anesthetic management were made at the discretion of the attending anesthesiologist. The tracheal tube cuff-pressure (Pcuff) was systematically monitored using a pressure manometer (Mallinckrodt® pressure manometer; Mallinckrodt, Athlone, Ireland), and the Pcuff was continuously maintained, throughout the duration of mechanical ventilation, between 20 and 25 cm·H_2O (13), according to routine practice in our department.

Routine monitoring was applied and general anesthesia was established as follows. Induction of anesthesia was performed using volatile anesthetics (sevoflurane) or i.v. hypnotic agent and a gas mixture including 50% N_2O. Tracheal intubation was performed, without muscle relaxant for most patients, using a CET size ranging from 3.5 to 6.0 (Hi-lo, Low pressure–High volume; Mallinckrodt, Athlone, Ireland). The lungs were mechanically ventilated using a closed circle system. Mechanical ventilation was performed with a tidal volume of 8–10 ml·kg^{-1}, an age-adapted respiratory rate, a maximal peak airway pressure of 20 cm·H_2O and an inspiratory to expiratory time ratio of 1 : 2 or 1 : 1.5. At the end of the surgical procedure, the tracheal tube was removed in the operating room and all patients were transferred in the PACU for postoperative follow up.

Air leak measurement

Air leak was calculated before (Pcuff 0) and after tracheal tube cuff inflation (Pcuff 20), using the following formula: [(tidal volume – expiratory volume)/tidal volume]. When air leak was >25% of tidal volume, with a Pcuff of 20 cm·H_2O or more, the size of the tracheal tube was considered as inappropriate and the tube was changed (6). For the purpose of air leak measurement, the head and body positions were standardized. The leak pressure was determined as follows: the patient was supine with the head in a neutral position to limit effect on leak test (14).

Study measurements

The data collected for the purpose of the study included the patient's age, weight, and surgical procedure. For all patients, tracheal tube size was prospectively recorded and the size predicted by Khine's formula was calculated. Thereafter, the size of the tracheal tube used was compared with the size obtained using the formula.

The number of tracheal reintubations and traumatic intubation, defined as obvious damage to the tracheal mucosa were collected, as well as postextubation respiratory complications and/or the use of inhaled racemic epinephrine and/or of i.v. corticoids. Intubation was considered as traumatic only if the procedure was described as traumatic by the physician who performed the intubation. For example, multiple attempts at intubation were not necessarily considered as traumatic. Patients were observed postoperatively in the PACU for evidence of croup, cough, sore throat, dyspnea, dysphonia or postextubation stridor, which were considered as postextubation respiratory complications.

Statistical analysis

Data are expressed as median (IQR), and as numbers of cases (%). Statistical analysis used the Mann–Whitney *U*-test for nonparametric variables, and the Fisher exact test for nominal variables. Comparison of several medians was performed using an ANOVA and the Newman Keuls multiple–comparison test where appropriate. All *P*-values were two-tailed and a *P*-value < 0.05 was considered significant. Statistical analysis was performed using STAT VIEW (SAS Institute Inc., Cary, NC, USA).

Results

Two hundred and four children were included prospectively and then distributed into six groups according to the size of the tracheal tube. Demographic characteristic and surgical procedures are shown in Tables 1 and 2, respectively.

Table 1
Demographic characteristics of the study population

Group	n	*Age (years)*	*Body weight (kg)*
G3.0	20	0.1 (0.1–0.3)	3.3 (3.0–4.0)
G3.5	31	0.5 (0.3–0.7)	7.0 (5.1–8.0)
G4.0	37	0.8 (0.6–1.2)	9.0 (8.0–11.0)
G4.5	41	3.0 (2.0–4.6)	15.0 (13.0–15.8)
G5.0	21	7.0 (4.9–7.6)	21.0 (18.0–25.3)
G5.5	25	9.0 (8.0–12.1)	29.0 (26.8–31.3)
G6.0	29	11.0 (9.8–12.0)	34.0 (31.0–35.8)
Total	204	3.0 (0.6–8.0)	13.0 (8.0–27.5)

Data are expressed as median ± IQR.

Table 2
Distribution of patients according to the surgical procedure

Surgical procedures	n (%)
Orthopedics	36 (18)
Neurosurgery	73 (36)
Urology	16 (8)
General surgery	45 (22)
Others	34 (16)
Total	204

Results are expressed as numbers of cases (%).

Table 3
Number of tracheal reintubation required because of an ill-fitted tracheal tube (*n*)

Group	n (%)	*Size used < size predicted*	*Size used > size predicted*
G3.0	1 (0.5)	1	0
G3.5	2 (1.0)	1	1
G4.0	2 (1.0)	1	1
G4.5	5 (2.0)	0	5
G5.0	1 (0.5)	1	0
G5.5	0	0	0
G6.0	1 (0.5)	0	1
Total (%)	12 (6.0)	4 (2.0)	8 (4.0)

Results are expressed as numbers of cases (%).

Reintubation and traumatic intubation

Twelve children (5.8%) were reintubated because of ill-fitting tracheal tubes (Table 3). The CET used was changed to a smaller size (0.5 mm less in internal diameter) in four children (1.9%) when there was no air leak with a Pcuff of 20 cm·H_2O or in the case of a resistance during the passage of the tube into the trachea during laryngoscopy and before the cuff inflation. A larger tube (0.5 mm more in internal diameter) was placed in eight children, including five patients in the group G4.5, when air leak exceeded 25% of tidal volume after cuff inflation. No traumatic intubation was recorded. Esophageal intubation occurred in one patient and was immediately recognized and the child was correctly intubated into the trachea.

Evaluation of air leak

In the groups G3.0, G3.5, G4.0, G4.5, and G6.0, the air leak was significantly lower following the inflation of the cuff to 20 cm·H_2O. In the groups G5.0 and

Table 4
Comparison between tracheal tube's size used and predicted using the Khine formula

Size used (DI mm)	n	*Size predicted by Khine (IQR)*	*Size used − size predicted (IQR)*	*Size used > size predicted (%)*	*Size used < size predicted (%)*	*Size used = size predicted (%)*
3.0	20	3.0	0	0	0	20 (100)
3.5	31	3.1* (3.0–3.2)	0.37 (0.33–0.43)	29 (93)	0	2 (7)
4.0	37	3.2* (3.1–3.3)	0.79 (0.67–0.85)	37 (100)	0	0
4.5	41	3.8* (3.5–4.2)	0.69 (0.34–1.01)	38 (93)	1 (2)	2 (5)
5.0	21	4.7* (4.2–4.9)	0.25 (0.09–0.71)	15 (72)	3 (14)	3 (14)
5.5	25	5.3 (5.0–6.0)	0.25 (−0.50 to 0.50)	13 (52)	9 (36)	3 (12)
6.0	29	5.7* (5.4–6.2)	0.25 (0.01–0.56)	16 (55)	2 (7)	11 (38)
Total	204	3.7 (3.1–5.0)	0.42 (0.01–0.75)	148 (72)	15 (7)	41 (21)

Results are expressed in median ± IQR and number of cases (percentage).
*$P < 0.05$.

Table 5
Detail of the respiratory complications according to the size of the tracheal tube in the six patients with postoperative complications

Patient	*Age (years)*	*Current size of the tracheal tube*	*Size predicted by Khine*	*Size predicted by your formula*	*Type of complications*
1	0.42	3.5	3.5	3.5	Dysphonia
2	1.25	4.0	3.5	4.0	Hoarse cough
3	0.50	4.5	3.5	4.0	Laryngeal dyspnea
4	3.50	4.5	4.0	4.0	Dysphonia
5	7.00	5.0	5.0	5.0	Dysphonia
6	5.50	5.5	4.5	5.0	Hoarse cough

In three cases (patients 3, 4, and 6) the size of the tracheal tube used was larger than the size predicted by our formula.

G5.5, no child demonstrated an air leak ≥25% following the cuff inflation to 20 cm·H_2O. There was no significant difference in air leak between the different size-groups. Among the 204 children, an air leak was noted in 18% of the cases immediately after intubation and before cuff inflation, and persisted in 7% of the patients following the Pcuff adjustment at 20 cm·H_2O. Before cuff inflation, 67 children (33%) had air leak ≥25%. After cuff inflation, only 19 children (9%) presented with persistent air leak ≥25%. There was no significant difference in maximal peak airway pressure between the different groups.

Size of tracheal tubes used and predicted

The size of the tracheal tube, used by the attending anesthesiologist, was in agreement with the Khine formula only in patients of group G3.0. Overall, 21% of tracheal tubes used were in accordance with the size predicted by the formula. Seven percent were of a size lower than that predicted by Khine and 72% were higher. The median difference between the used and the predicted size was 0.42 (0.01–0.75 mm) in internal diameter (Table 4).

Postoperative respiratory complications

Respiratory complications were reported in six patients (2.9%) during the postoperative course in the PACU. Half of them required a treatment using racemic epinephrine and/or corticoids. These complications were dysphonia, hoarse cough, and a laryngeal dyspnea. Three patients had a tracheal tube of larger size than that predicted by Khine as well as by our formula (Table 5). No postoperative reintubation was recorded and we did not observe any case of subglottic stenosis after tracheal intubation. On discharge from the PACU, all clinical signs and symptoms had disappeared. No long-term complication was reported.

Discussion

The main result of this study is that the size of the tracheal tube predicted by the Khine formula underestimated the size of cuffed tracheal tubes in two out of three children. This underestimation corresponded with a choice of a CET which was a half size too small (0.5 mm in internal diameter).

However, the study also showed that the use of a larger size of CET was not associated with an increased risk of postintubation respiratory complications. The observed rates of tracheal reintubation as well as the presence of air leaks also confirmed these hypotheses.

Few studies have attempted to predict correct size of CET. Different algorithms, sometimes complex, or formulae have been described for guiding the choice of the size of a tracheal tube (3,11,12). The study by Khine *et al.* was the only one suggesting a formula for CET selection. This formula, based on the experience of their team and on the necessity of using a size lower than that of an UET, was derived from the formula of Cole and Khine's recommendation for children <2 years of age.

A minimal air leak is accepted in most of the series and usually between 5% and 10% of tidal volume. In our study, the residual air leak after cuff inflation was 7%. The presence of an air leak does not fully prevent the occurrence of postoperative respiratory complications in children (15). This technique cannot totally eliminate the pressure that the tracheal cuff can exert on the tracheal mucosal membrane. The diameters of the tracheal tube and trachea are different, and compressions of the tube are preferentially applied at the level of the cricoid cartilage on the posterior part of the trachea. Only continuous monitoring of the tracheal Pcuff seems to be able to reduce, but not totally avoid, laryngeal and tracheal damage (16,17). The reduction of the air leak observed in our study can contribute to an improved reliability of endtidal gas monitoring, to optimized measurements of respiratory mechanics and also to a reduced contamination of the operating room with inhaled gases, as previously suggested (3).

The rate of reintubation in our study (5.8%) was not associated with an increased risk of airway trauma. In the study by Khine *et al.* (3), 54/237 children included in the UET group were reintubated, corresponding to 23% of the study population, while the rate of reintubation was 1.2% in the CET group. The difference in reintubation rate observed between our study and Khine's CET study could be explained by a more precise definition of criteria for reintubation in our study.

The rate of postintubation complications (2.9%) reported in our study is similar to the results obtained by other teams. Indeed, the incidence of laryngeal and tracheal complications varied from 1% to 6% with UET according to the studies and following short-duration tracheal intubation (2–9). This rate does not appear to be modified by the use of a CET. Several risk factors for damage of the tracheal mucosal membrane have been identified including traumatic intubation, prolonged duration of intubation, severe arterial hypotension during the procedure, but the main factor constantly found is the use of an oversized tracheal tube (18).

All these aspects regarding the choice of an adequately sized tracheal tube and monitoring of Pcuff are especially important in young children. Koka *et al.* (18), in a study of 7875 children, showed that the incidence of postintubation complications was more important in children aged from 1 to 4 years and that half of these complications were related to the use of a tracheal tube of excessive size (18).

In our study, the pressure of the cuff was continuously maintained between 20 and 25 cm·H_2O. In contrast, in several studies performed in adult patients, the Pcuff was kept <30 cm·H_2O (19–21). In children, in spite of the absence of data in the pediatric literature, the critical Pcuff should certainly be situated between 20 and 25 cm·H_2O, because of a physiologically decreased blood pressure as compared with adult patients (22).

The results of a recently published study conducted in a pediatric intensive care unit are in agreement with our results (3). In 597 children, of whom 210 had CET, the tracheal tube size was chosen using the modified Cole formula for UETs and one half-size less for cuffed tubes.

Overall, the results of our study together with those of other studies previously published, suggest the use of the following formula: internal diameter of the CET = (age/4 + 3.5), for application in pediatric anesthesia and in the pediatric intensive care unit.

Limitations of the study

Our study is a descriptive study performed in a single institution and only a larger prospective study would be able to validate the results, especially with regard to the new proposed formula for predicting the adequate size of a CET. In addition, the assessment of respiratory complications was only performed during the in-hospital stay. Study of longer-term complications, which would be useful, was not performed. However, no long-term complications were reported by the ENT department of our hospital. On the other hand, the clinical evaluation of postintubation complications remains subjective, while objective methods would allow a better evaluation of the laryngotracheal damage potentially induced by the cuff. Different techniques could be used, including: laryngotracheal fibroscopy, MRI, physiological measurement with thoracic-abdominal asynchrony study (16). Meanwhile, it is unlikely that significant respiratory complications occurred during the hospital stay without marked clinical signs and symptoms.

We have shown that the size predicted using the Khine formula underestimated the size of the cuffed tracheal tube used in children. However, the choice of an half-size higher tracheal tube, compared with the size predicted by Khine, was not associated with an increased risk of short-term postextubation respiratory complications. The choice of a correctly sized CET is one of the main factors reducing the risk of postoperative complication, while respect for other rules of the correct use of CET (appropriate size, low pressure–high volume cuff and monitoring of the Pcuff) remains important (23). Only the application of these rules will allow a wider use of CET in pediatric anesthesia, to benefit from their numerous advantages: reduction of the number of reintubations, better control of air leak, improved ventilatory monitoring and possible reduction of the pollution of operative rooms.

References

1 Eckenhoff JE. Some anatomic considerations of the infant larynx influencing endotracheal anesthesia. *Anesthesiology* 1951; **12:** 401–410.
2 Deakers TW, Reynolds G, Stretton M *et al.* Cuffed endotracheal tubes in pediatric intensive care. *J Pediatr* 1994; **125:** 57–62.
3 Khine HH, Corddry DH, Kettrick RG *et al.* Comparison of cuffed and uncuffed endotracheal tubes in young children during general anesthesia. *Anesthesiology* 1997; **86:** 627–631.
4 Newth CJ, Rachman B, Patel N *et al.* The use of cuffed versus uncuffed endotracheal tubes in pediatric intensive care. *J Pediatr* 2004; **144:** 333–337.
5 Weiss M, Gerber AC. Cuffed tracheal tubes in children – things have changed. *Pediatr Anesth* 2006; **16:** 1005–1007.
6 Murat I. Cuffed tubes in children: a 3-year experience in a single institution. *Paediatr Anaesth* 2001; **11:** 748–749.
7 Meakin GH. Low-flow anaesthesia in infants and children. *Br J Anaesth* 1999; **83:** 50–57.
8 Fine GF, Borland LM. The future of the cuffed endotracheal tube. *Pediatr Anesth* 2004; **14:** 38–42.
9 Meyer P, Orliaguet G, Blanot S *et al.* Complications of emergency tracheal intubation in severely head-injured children. *Paediatr Anaesth* 2000; **10:** 253–260.
10 Orliaguet GA, Renaud E, Lejay M *et al.* Postal survey of cuffed or uncuffed tracheal tubes used for paediatric tracheal intubation. *Paediatr Anaesth* 2001; **11:** 277–281.
11 Eck JB, De Sauverzac G, Phillips-Bute BG *et al.* Prediction of tracheal tube size in children using multiple variables. *Paediatr Anaesth* 2002; **12:** 495–498.
12 Cole F. Pediatric formulas for the anesthesiologist. *AMA J Dis Child* 1957; **94:** 672–673.
13 Felten ML, Schmautz E, Delaporte-Cerceau S *et al.* Endotracheal tube cuff pressure is unpredictable in children. *Anesth Analg* 2003; **97:** 1612–1616.
14 Schwartz RE, Stayer SA, Pasquariello CA. Tracheal tube leak test – is there inter-observer agreement? *Can J Anaesth* 1993; **40:** 1049–1052.
15 Khalil SN, Mankarious R, Campos C *et al.* Absence or presence of a leak around tracheal tube may not affect postoperative croup in children. *Paediatr Anaesth* 1998; **8:** 393–396.
16 Combes X, Schauvliege F, Peyrouset O *et al.* Intracuff pressure and tracheal morbidity: influence of filling with saline during nitrous oxide anesthesia. *Anesthesiology* 2001; **95:** 1120–1124.
17 Tu HN, Saidi N, Leiutaud T *et al.* Nitrous oxide increases endotracheal cuff pressure and the incidence of tracheal lesions in anesthetized patients. *Anesth Analg* 1999; **89:** 187–190.
18 Koka BV, Jeon IS, Andre JM *et al.* Postintubation croup in children. *Anesth Analg* 1977; **56:** 501–505.
19 Nguyen TH, Saidi N, Lieutaud T *et al.* Nitrous oxide increases endotracheal cuff pressure and the incidence of tracheal lesions in anesthetized patients. *Anesth Analg* 1999; **89:** 187–190.
20 Nordin U. The trachea and cuff-induce tracheal injury. An experimental study on causative factors and prevention. *Acta Otolaryngol* 1977; **345:** 1–71.
21 Stenqvist O, Bagge U, Nilsson K. The tracheal mucosa microvasculature and microcirculation. Intravital microscopic observations in rabbits and a histologic study in man. *Acta Otolaryngol* 1979; **87:** 123–128.
22 Veyckemans F. New develops in the management of the pediatric airway: cuffed or uncuffed tracheal tubes, laryngeal mask airway, cuffed oropharyngeal airway, tracheostomy and one-lung ventilation device. *Curr Opin Anaesthesiol* 1999; **12:** 315–320.
23 James I. Cuffed tubes in children. *Paediatr Anaesth* 2001; **11:** 259–263.

Accepted 29 July 2007