Pediatric Anesthesia

Pediatric Anesthesia ISSN 1155-5645

ORIGINAL ARTICLE

Do pediatric patients undergoing cardiac surgeries require larger-size cuffed endotracheal tubes? A prospective study

Rasoul Azarfarin[1], Mahin Seyedhejazi[2], Samad E. J. Golzari[3,4], Eissa Bilehjani[2], Kamyar Ghabili[5] & Azin Alizadehasl[1]

1 Cardiovascular Research Center, Tabriz University of Medical Sciences, Tabriz, Iran
2 Department of Anesthesiology, Tabriz University of Medical Sciences, Tabriz, Iran
3 Medical Philosophy and History Research Center, Tabriz University of Medical Sciences, Tabriz, Iran
4 Students' Research Committee, Tabriz University of Medical Sciences, Tabriz, Iran
5 Physical Medicine and Rehabilitation Research Center, Tabriz University of Medical Sciences, Tabriz, Iran

Keywords
endotracheal tubes; cuffed; cardiac surgery; children

Correspondence
Samad Golzari, Medical Philosophy and History Research Center, Tabriz University of Medical Sciences, Daneshgah St.,Tabriz 515665931, Iran
Email: dr.golzari@hotmail.com

Section Editor: Greg Hammer

Accepted 1 December 2012

doi:10.1111/pan.12112

Summary

Background: There is a controversy over using either smaller- or larger-size endotracheal tubes (ETT) in children undergoing cardiac surgery, and some anesthesiologists prefer to use ETT sizes different from the formula-based sizes. The aim of the present study was to compare proper-size cuffed ETT in children undergoing cardiac vs noncardiac surgeries.

Methods: In an observational prospective study, 80 children planned to undergo noncardiac elective surgeries (NCS group) and 80 children scheduled for cardiac surgeries (CS group) were recruited. For intubation, initial cuffed ETT size was calculated based on the following formula: Tube size (mm ID) = age (year)/4 + 3.5. The estimated ETT size for each age group and the size of final utilized tubes for each age range were recorded.

Results: Patients of tube sizes 4.5, 5, and 5.5 in the CS group were of lower age, weight, height, and body surface area compared with the patients of the same tube sizes in the NCS group ($P < 0.05$). The compatibility of the predicted vs actual required tube sizes was more in the NCS group compared to the CS group (72.5% vs 56.2%; $P = 0.02$). Additionally, the cases with underestimated tube sizes were significantly more in the CS group compared with the NCS group (38.8% vs 18.8%, $P = 0.01$).

Conclusion: Children undergoing cardiac surgeries in relation to their age and body size do require larger-size ETTs compared with the children scheduled for noncardiac surgeries.

Introduction

Since the advent of cuffed endotracheal tubes (ETT), their placement in children younger than ten years old has been challenged and a varied range of ages has been recommended for cuffed tubes (1). The logic behind this preference stems from the fear of the complications that could occur following the placement of cuffed ETT including laryngeal damage followed by overinflated cuffs (2). Although this is mostly important in situations where intubation is required for long duration, it seems to be of less importance in operations with limited duration provided that the proper cuff placement is achieved in the mid-trachea (3). The trend, however, is about to change as many anesthesiologists have challenged the idea of preferring uncuffed to cuffed ETT (4–6); further studies comparing cuffed vs uncuffed ETTs are suggestive of equal rates of complications such as subglottic stenosis (7). In recent years, the privilege of having high-volume low-pressure cuffed ETTs has led us to use them in daily practice unconcernedly.

Selection of a proper-sized ETT is of utmost importance as tubes with smaller sizes could result in insufficient ventilation, high airway pressure, gas leak to the operating room, increased risk of aspiration, and inappropriate endtidal CO_2 monitoring (8–10). On the

other hand, larger-sized tubes could be associated with upper airway damage such as pressure-induced mucosal ischemia and related subglottic stenosis (11,12). The most frequently used age-based formulas for estimation of the appropriate ETT size have been derived from the previous studies (4,13,14). These formulas, however, are useful if the physical status of children correlates to the standards. Children with chronic medical conditions, for example, cardiac diseases requiring cardiac surgery, are mostly believed to be nutritionally compromised and of different physical and airway characteristics. There is a controversy over using either smaller or larger tube size in children undergoing cardiac surgery, and some anesthesiologists prefer to use ETT sizes different from the formula-based sizes (15–17). To the best of our knowledge, no comparison between the appropriate sizes of cuffed ETT required in children undergoing cardiac and noncardiac surgeries has been hitherto reported in the literature. Therefore, the aim of the present study was to compare proper-size cuffed ETT in children undergoing cardiac vs noncardiac surgeries.

Methods

The study was approved by the local ethics committee, and written informed parental consent was obtained for each subject. In an observational prospective study, we studied 80 children, American Society of Anesthesiologists (ASA) physical status I-III, aged 2–12 years old who were planned to undergo noncardiac elective surgeries (NCS group). The types of the surgery performed in the noncardiac group included inguinal and abdominal hernia, and adenotonsillectomy. Additionally, 80 children aged 2–12 years old with ASA class II-III who were scheduled for cardiac surgeries were recruited (CS group). Exclusion criteria consisted of patients with Mallampati class of 3 or 4, history of laryngeal surgery or any operation affecting their airway, diagnosed or suspicious abnormal airway, need to unusual tube size according to their history of previous operations and anesthesia, and present upper respiratory tract infection.

In NCS group, the premedications used for anesthesia included midazolam 20 $\mu g \cdot kg^{-1}$ and fentanyl 1–2 $\mu g \cdot kg^{-1}$; anesthesia was induced using propofol 2–2.5 $mg \cdot kg^{-1}$, lidocaine 1 $mg \cdot kg^{-1}$, and cisatracurium 0.1–0.2 $mg \cdot kg^{-1}$, and maintained by isoflurane 1–1.5%. In the CS group, premedication was performed using midazolam 20 $\mu g \cdot kg^{-1}$; anesthesia was induced using midazolam 0.05–0.15 $mg \cdot kg^{-1}$, fentanyl 2–5 $\mu g \cdot kg^{-1}$, and cisatracurium 0.1–0.2 $mg \cdot kg^{-1}$, and maintained by infusion of midazolam 1 $\mu g \cdot kg^{-1} \cdot min^{-1}$, fentanyl 0.5–1 $\mu g \cdot kg^{-1} \cdot min^{-1}$, cisatracurium 1–2 $\mu g \cdot kg^{-1} \cdot min^{-1}$, and isoflurane 0.5–1%. For intubation, cuffed ETTs (SUPA Medical Devices, Tehran, Iran) were used by a same anesthesiologist in each study group. Initial tube size was calculated based on the following formula: Tube size (mm ID) = age (year)/4 + 3.5 (14). Later, cuff pressure was measured using Cuff Pressure Gauge (VBM Medizintechnik GmbH, Sulz, Germany), and consequently, the cuff pressure was set at 25 ± 2 cmH_2O. Existence of any probable air leakage from around the cuff was diagnosed by auscultation over the larynx while gradual filling of the cuff. The ETT was exchanged with a smaller size tube if there was air leakage auscultated at peak inspiratory pressure (PIP) > 30 cmH_2O and with a larger-size tube if the air leakage occurred at the PIP < 20 cmH_2O. Correct tube placement was confirmed using capnography and auscultation. At the end of the surgery, all noncardiac patients were extubated and transferred to the recovery unit, whereas all cardiac patients were transferred to ICU remaining intubated. They were extubated after waking up and maintaining the required criteria for being extubated under the supervision of an ICU specialist. None of the cases in the noncardiac group required ICU admission.

The estimated ETT size for each age group and the size of final utilized tubes for each age range were recorded by a second anesthesiologist while the intubating anesthesiologist was not informed about these sizes. As it was not practical to provide some sizes of ETT, the closest sizes to the estimated values were selected. For estimated sizes of X-X.24, a smaller size (X); for estimated sizes of X.25-X.49, a bigger size (X.5); for estimated sizes of X.5-X.74, a smaller size (X.5); and for estimated sizes of X.75-X.99, a bigger size (X + 1) were selected. For instance, for sizes 3–3.24, size 3; for sizes 3.25–3.49, size 3.5; for sizes 3.5–3.74, size 3.5; and for sizes 3.75–3.99, size 4 were selected.

To achieve a power of 80% while considering the selection of 0.3- and 0.6-mm larger sizes in the studies of Shiroyama *et al.* (16,18) and $\alpha = 0.05$ and $\beta = 0.2$, the sample size was calculated as eighty patients for each group. To determine the sample size, online software was used (please see: http://www.stat.ubc.ca/~rollin/stats/ssize/). Data were presented as mean ± standard deviation (SD). Quantitative data were analyzed using independent samples *t*-test. The comparison of the qualitative data was performed using Fisher's exact test or chi-square test depending on the condition. Pearson's correlation test was used to study the correlation between ETT size with age, height, weight, body mass index (BMI), and body surface area (BSA) of the patients in each study group. Based on the previous studies on linear regression analysis models (19), a formula for cardiac group was designed in which age and initial formula (age (year)/4 + 3.5) were considered as

independent and dependent factors, respectively. Statistical analysis was performed with SPSS for Windows version 18.0 (SPSS Inc, Chicago, IL, USA). A P value ≤ 0.05 was considered statistically significant.

Results

Data from 160 children were analyzed: 80 in the CS group and 80 in the NCS group. There were no differences in gender, BMI, and the mean tube size between the groups (Table 1, $P > 0.05$). The patients in the CS group were of lower age, weight, height, and BSA compared with the NCS group (Table 1, $P = 0.001$). There was no significant difference regarding age, gender, height, weight, BMI, and BSA between CS and NCS patients in whom tube sizes 4, 6, 6.5, and 7 were used ($P > 0.05$, Table 2). Patients of tube sizes 4.5, 5, and 5.5 in the CS group were of lower age, weight, height, and BSA compared with the patients of the same tube sizes in the NCS group (Table 2, $P < 0.05$).

Table 1 General variables of both cardiac and noncardiac groups (mean ± SD)

	CS group (n = 80)	NCS group (n = 80)	P value
Gender (M/F)	33 : 47	40 : 40	0.34
Age (year)	6.31 ± 3.0	7.80 ± 2.4	0.001*
Height (cm)	110.64 ± 21.1	124.26 ± 14.4	0.001*
Weight (kg)	19.45 ± 8.1	24.57 ± 8.5	0.001*
BMI	15.47 ± 3.2	15.51 ± 2.9	0.88
BSA (m^2)	0.77 ± 0.22	0.91 ± 0.20	0.001*
Tube size (ID mm)	5.40 ± 0.64	5.57 ± 0.62	0.09

CS, cardiac surgery; NCS, noncardiac surgery; BMI, body mass index; BSA, body surface area; ID, internal diameter.
*Statistically significant ($P < 0.05$).

In both the CS and NCS groups, age, height, weight, and BSA were positively correlated with the tube size ($P = 0.001$, Table 3). In the NCS group, BMI was positively correlated with the tube size ($r = 0.26$, $P = 0.01$, Table 3); however, there was no correlation between BMI and tube size in the CS group ($r = 0.06$, $P = 0.55$, Table 3).

In the present study, 38.8% of the children in the CS group required tubes with larger sizes to be replaced and the age-based formula underestimated the required tube size ($r = 0.75$, Figure 1, $P = 0.01$). Four patients (5%) in the CS group required tubes with smaller sizes to be replaced, and the age-based formula overestimated the required tube size ($r = 0.75$, Figure 1, $P = 0.01$). Tube sizes predicted using age-based formula were in accordance with actual required tube sizes in 56.2% of the CS patients ($r = 0.75$, Figure 1, $P = 0.01$).

Fifteen patients (18.8%) in the NCS group required tubes with larger sizes to be replaced, and the age-based formula underestimated the required tube size ($r = 0.79$, Figure 2, $P = 0.01$). Seven patients (8.7%) in the NCS group required tubes with smaller sizes to be replaced, and the age-based formula overestimated the required tube size ($r = 0.79$, Figure 2, $P = 0.01$). Tube sizes predicted using age-based formula were similar to actual required sizes in 72.5% of the NCS patients ($r = 0.79$, Figure 2, $P = 0.01$). The compatibility of the predicted vs actual required tube sizes was more in the NCS group compared to the CS group (72.5% vs 56.2%; $P = 0.025$). Additionally, the cases with underestimated tube sizes were significantly more in the CS group compared with the NCS group (38.8% vs 18.8%, $P = 0.01$).

Further statistical studies were performed on the linear correlation coefficient between actual tube size and age in the cardiac group resulting in a linear formula for the patients in the cardiac group: Tube size = 0.16* (age) + 4.39.

Table 2 Age and anthropometric variables in different tube size subgroups of CS and NCS groups (mean ± SD)

Tube Size	Age (year)		Height (cm)		Weight (kg)		BMI ($kg \cdot m^{-2}$)		BSA (m^2)	
(ID mm)	CS group	NCS group	CS group	NCS group	CS group	NCS group	CS group	NCS group	CS group	NCS group
4.0	2a	3a	70–76b	93a	8.0–8.3b	13.0a	16.3–14.4b	15.0a	0.39–4.2b	0.5–8b
4.5	3.0 ± 0.9	4.8 ± 1.0*	83 ± 14	110 ± 2*	13.0 ± 3.6	18.1 ± 4.7*	19.3 ± 5.4	15.0 ± 3.4	0.54 ± 0.12	0.74 ± 1.00*
5.0	4.8 ± 1.5	5.7 ± 1.2*	103 ± 12	111 ± 9*	15.1 ± 3.2	18.4 ± 5.6*	14.1 ± 1.6	14.6 ± 3.1	0.66 ± 0.10	0.75 ± 0.13*
5.5	6.4 ± 2.0	7.8 ± 1.7*	111 ± 13	124 ± 9*	19.7 ± 5.8	23.5 ± 5.3*	15.7 ± 2.6	15.2 ± 2.9	0.78 ± 0.15	0.89 ± 0.12*
6.0	9.0 ± 2.5	9.0 ± 1.5	128 ± 13	129 ± 7	25.7 ± 8.2	27.4 ± 4.4	15.3 ± 2.7	16.4 ± 2.7	0.95 ± 0.19	0.99 ± 0.09
6.5	9.5 ± 3.5	10.9 ± 1.3	133 ± 20	141 ± 10	26.7 ± 3.2	34.2 ± 10.0	14.7 ± 1.4	16.7 ± 3.0	0.99 ± 0.22	1.2 ± 0.21
7.0	11a	11–12b	154a	138–163b	45a	35–55b	18.9a	16.3–19.4b	1.39a	1.07–1.50b

CS, cardiac surgery; NCS, noncardiac surgery; BMI, body mass index; BSA, body surface area; ID, internal diameter.
*Statistically significant ($P < 0.05$).
[a]Includes one patient.
[b]Includes two patients.

Table 3 The correlation between variables and tube size in CS and NCS groups

	CS group (n = 80)		NCS group (n = 80)	
	r	P value	r	P value
Age (year)	0.75	0.001*	0.79	0.001*
Height (cm)	0.77	0.001*	0.80	0.001*
Weight (kg)	0.70	0.001*	0.71	0.001*
BMI (kg·m^{-2})	0.06	0.55	0.26	0.01*
BSA (m^2)	0.75	0.001*	0.76	0.001*

CS, cardiac surgery; NCS, noncardiac surgery; BMI, body mass index; BSA, body surface area.
*Statistically significant ($P < 0.05$).

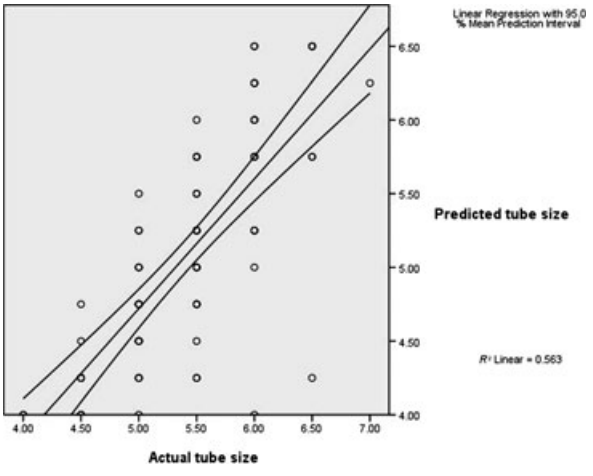

Figure 1 The correlation between predicted and actual required tube sizes in the CS group.

Discussion

The findings of the present study revealed no statistically significant difference between two studied groups regarding the mean tube size. However, age, weight, height, and BSA in children of the CS group were significantly in lower values compared with the NCS group. Furthermore, comparing the predicted (using Motoyama's formula) and actual tube sizes revealed that the compatibility between the predicted and actual sizes was more in the NCS group (72.5%) compared with the cardiac group (56.2%). Additionally, the cases with underestimated tube sizes were significantly more in the CS group compared with the NCS group (38.8% vs 18.8%, $P = 0.01$). Therefore, it seems that the patients undergoing cardiac surgeries in relation to their age and body size require bigger-size ETT compared with the children of normal cardiac status. Infants with congenital heart disease are usually small, underweight, and have a reduced energy intake. Serum IGF-1 and IGFBP-3

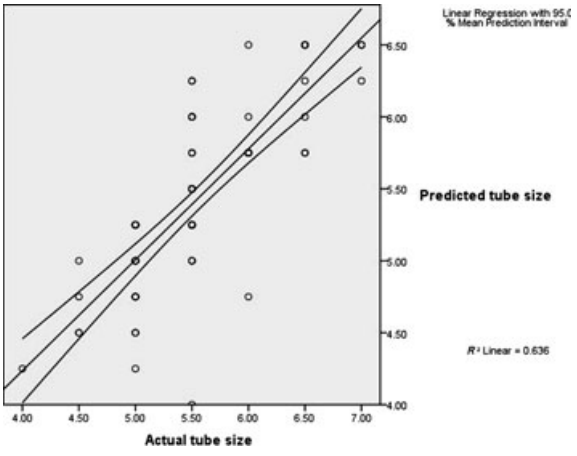

Figure 2 The correlation between predicted and actual required tube sizes in the NCS group.

concentrations are significantly reduced. Decreased IGF-1 and IGFBP-3 levels can be observed in nutritional deficiency; similar findings in congenital heart disease suggest that undernutrition leads to the poor growth of these infants (20). Unequal growth of the different parts of their body might contribute to the different size of larynx compared to their body in children with congenital cardiac disease. To the best of our knowledge, the present study is the first investigation orchestrated to compare the appropriate sizes of cuffed ETT required in children undergoing cardiac and noncardiac surgeries. The proposed formula derived from our study could be used specifically in the patients undergoing cardiac surgeries and is different from the previously proposed formulae regarding it being age-based and designed for cuffed ETTs.

Bunchungmongkol and Pipanmekaporn (15) suggested that the age-predicted ETT size matched the actual size exactly in almost 62% of the children undergoing cardiac surgery, which is similar to the corresponding finding in our study (~56%). While the age-based formula underestimated the actual size in 17%, it overestimated the actual ETT size in 22% (15). Bunchungmongkol and Pipanmekaporn (15) concluded that the age-based prediction of the ETT size, that is, Morgan–Steward formula, can be applied for most children with underlying heart disease. In a retrospective study on children with congenital heart diseases, Shiroyama *et al*. reported that the uncuffed ETT sizes were larger than those estimated by Cole's formula in one-third of patients (13,16). In spite of difference in types of ETTs (uncuffed vs cuffed) used in two studies, this finding parallels the results obtained from our study. In a similar retrospective study conducted by Chumpathong *et al*., (17) it was revealed that the tube size predicted by age-based formula could be more applied to NCS

patients. Likewise, compatibility of the predicted vs actual required tube sizes was more in the NCS group of the present study. The ETT with larger internal diameter than the predicted size was more often used in CS patients than NCS patients (17). Consequently, they concluded that children with cardiac diseases tend to require one size larger ETT than the children with noncardiac diseases (17). Nonetheless, different anesthesiologists intubated the patients in their study resulting in probable selection bias. Altogether, these studies suggest that different ETT sizes are required in CS patients compared with NCS patients. However, their retrospective nature and use of uncuffed ETT make these investigations different from the present study.

Most available formulae are derived from the data obtained from children with normal growth pattern. Children with cardiac diseases, however, often have delayed growth and development. Predicting appropriate ETT size based on the formula for normal population may not appropriately estimate proper ETT size in this population. Additionally, anthropometric factors such as height and weight could influence airway size. Several studies reported the influence of height and weight on the appropriate ETT size in children (21,22). On the other hand, published data on the existing formulae have been based on populations with normal growth pattern, and children with different body structures and growth patterns would require different guidelines (4,13,14,23).

In conclusion, children undergoing cardiac surgeries in relation to their age and body size do require larger-size ETTs compared with the noncardiac surgeries. Based on the findings of the present study, a new formula for the selection of a proper cuffed ETT specifically devised for children undergoing cardiac surgeries is proposed. However, further prospective studies are required to confirm the compatibility and generality of this formula.

Acknowledgments

This study was financially supported by a grant from the Research Vice Chancellor office of Tabriz University of Medical Sciences, Tabriz, Iran. This paper is based on Samad EJ Golzari's specialty dissertation (89/3-4/3) submitted to the Faculty of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran.

Conflict of interest

No conflicts of interest declared.

References

1 Uejima T. Cuffed endotracheal tubes in pediatric patients. *Anesth Analg* 1989; **68**: 423.
2 Aker J. An emerging clinical paradigm: the cuffed pediatric endotracheal tube. *AANA J* 2008; **76**: 293–300.
3 James I. Cuffed tubes in children. *Paediatr Anaesth* 2001; **11**: 259–263.
4 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.
5 Fine GF, Fertal K, Motoyama EK. The effectiveness of controlled ventilation using uncuffed versus cuffed endotracheal tubes in children. *Anesthesiology* 2000; **93**: A-1251.
6 Fine GF, Borland LM. The future of the cuffed endotracheal tube. *Pediatr Anesth* 2004; **14**: 38–42.
7 Deakers TW, Reynolds G, Stretton M *et al.* Cuffed endotracheal tubes in pediatric intensive care. *J Pediatr* 1994; **125**: 57–62.
8 Browning DH, Graves SA. Incidence of aspiration with endotracheal tubes in children. *J Pediatr* 1983; **102**: 582–584.
9 Oshodi A, Dysart K, Cook A *et al.* Airway injury resulting from repeated endotracheal intubation: possible prevention strategies. *Pediatr Crit Care Med* 2011; **12**: e34–e39.
10 Roy WL. Intraoperative aspiration in a paediatric patient. *Can Anaesth Soc J* 1985; **32**: 639–641.
11 Sherman JM, Nelson H. Decreased incidence of subglottic stenosis using an "appropriate-sized" endotracheal tube in neonates. *Pediatr Pulmonol* 1989; **6**: 183–185.
12 Dillier CM, Trachsel D, Baulig W *et al.* Laryngeal damage due to an unexpectedly large and inappropriately designed cuffed pediatric tracheal tube in a 13-month-old child. *Can J Anaesth* 2004; **51**: 72–75.
13 Cole F. Pediatric formulas for the anesthesiologist. *AMA J Dis Child* 1957; **94**: 672–673.
14 Motoyama EK. Endotracheal intubation. In: Motoyama EK, Davis PJ, eds Smith's Anesthesia for Infants and Children. St Louis, CV Mosby 1990; 269–275.
15 Bunchungmongkol N, Pipanmekaporn T. Prediction of endotracheal tube size in children with failure to thrive, who underwent cardiac surgery. *Chiang Mai Med J* 2010; **49**: 49–52.
16 Shiroyama K, Izumi H, Kubo T. Estimation of size of the uncuffed endotracheal tube for pediatric cardiac anesthesia–Cole's formula cannot estimate the appropriate tube size. *Masui* 2001; **50**: 284–286.
17 Chumpathong S, Sukavanicharat P, Butmangkun W, *et al.* Effectiveness of endotracheal-tube size by age-based formula for Thai pediatric cardiac patients: a retrospective study. *Asian Biomed* 2010; **4**: 765–771.
18 Shiroyama K, Izumi H, Kubo T *et al.* A formula based on body length for determining the size of an uncuffed endotracheal tube for pediatric cardiac anesthesia. *Hiroshima J Med Sci* 2001; **50**: 97–99.
19 Lau N, Playfor S, Rashid A *et al.* New formulae for predicting tracheal tube length. *Pediatr Anesth* 2006; **16**: 1238–1243.
20 Barton JS, Hindmarsh PC, Preece MA. Serum insulin-like growth factor 1 in congenital heart disease. *Arch Dis Child* 1996; **75**: 162–163.
21 Hofer CK, Ganter M Tucci M, *et al.* How reliable is length-based determination of body weight and tracheal tube size in the paediatric age group? The Broselow tape reconsidered. *Br J Anaesth* 2002; **88**: 283–285.
22 Eipe N, Barrowman N, Writer H *et al.* A weight-based formula for tracheal tube size in children. *Pediatr Anesth* 2009; **19**: 343–348.
23 Morgan GA, Steward DJ. A pre-formed paediatric orotracheal tube designed based on anatomical measurements. *Can Anaesth Soc J* 1982; **29**: 9–11.