

## *The clinical applications of body weight and endotracheal tube size prediction formulas in pediatric patients*

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### ABSTRACT

#### **The clinical applications of body weight and endotracheal tube size prediction formulas in pediatric patients**

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There are various formulas and algorithms for the prediction of body weight and appropriate ETT size, in pediatric patients. Body Weight estimation is of paramount importance in pediatrics, especially in emergencies. Predicting the appropriate size of the endotracheal tube saves time, money and reduces complications. The goal of this study was to evaluate the validity of two commonly used formulas for predicting the body weight and the size of the appropriate endotracheal tube, both based on age. 353 consecutive pediatric surgical patients aged 2 to 12 years, who required general anesthesia and oral endotracheal intubation were included in this study. Patients were stratified according to their age in two groups: group 2-5 (79 children, 2 to 5 years) and group 6-12 (274 children, 6 to 12 years). At the end of surgery an anesthesiologist, who was not involved in the perioperative treatment, recorded the demographic data and also the size and type of the endotracheal tube used. The prediction of Body Weight (BW) was made according to the following formula: 2-5 y.o.: Weight (kg) = (2 x age in years) + 8 and 6-12 y.o.: Weight (kg) = (3 x age in years) + 7. The formula for calculating the size (size= internal diameter=I.D.) of the endotracheal tube (ETT) was: I.D. for cuffed ETT (mm) = (age / 4) + 3.5 and I.D. for uncuffed ETT

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(mm) = (age / 4) + 4. For all statistical tests p value <0.05 was considered as statistically significant. In

all patients as sum and in both age groups, the predicted body weight was significantly ( $p < 0.05$ ) lower than the actual (measured) weight. In group 2-5y.o, 74.7% of patients received cuffed ETT. In group 6-12y.o. 100% of patients received cuffed ETT. In group 2-5 y.o, all patients showed a significantly ( $p < 0.05$ ) lower predicted internal diameter of the ETT, either cuffed or uncuffed, compared to ETT ultimately used. In group 6 -12y.o, there was no statistically significant difference between the predicted and the actually used ETT size. The prediction of body weight in children, by the use of the particular formula, led to underestimation. In children aged 2 to 5 years, the application of the inner diameter calculation of the ETT formula also underestimated the appropriate ETT size. It seems that the traditional age-based formulas often fail to predict the correct ETT size in smaller children which probably does not seem to apply to older children.

## INTRODUCTION

The pediatric surgical patients have significant anatomical and physiological differences compared to adults, which must be taken into consideration when selecting techniques, tools and equipment.<sup>1</sup> Endotracheal intubation in children presents many challenges. If the predicted size of ETT is inappropriate, either larger or smaller, the number of intubation attempts increases, leading to prolonged intubation time, tracheal edema or air leakage<sup>2</sup>. Multiple intubation attempts may result in hypoxemia and in increased morbidity and mortality<sup>3</sup>.

Many formulas and algorithms have been proposed for the selection of the appropriate size of an ETT<sup>3</sup>. Due to variable rate of child development, demographic data-based prediction of the ETT size has been considered controversial<sup>3</sup>. The most commonly used formula for ETT size is the modified age-based Cole's formula for children aged 2 and older<sup>4-6</sup>:  $ETT\ size = 4 +$

$+(age/4)$ . Sometimes pediatric patients do not conform to these formulas<sup>7</sup>.

Body Weight (BW) estimation is of paramount importance in pediatrics, especially in emergency situations. There are many different methods used to estimate children's weights. One of the most popular is the age based Advanced Pediatric Life Support (APLS) formula. In the recent edition of the APLS manual, three different formulas are being suggested for the estimation of weight in children according to their age: one for children between 1-5y.o., another one (Luscombe and Owens) for those aged 6-12y.o. and a specific infant formula for those aged less than 1y.o.<sup>8,9</sup>.

The goal of this study was to determine the accuracy of commonly used formulas for body weight and appropriate E.T.T. size estimation, in the pediatric population who present for surgery in our Institution.

## MATERIAL AND METHODS

After the approval of the Institutional Ethics Committee and parent's informed consent, 353 consecutive pediatric surgical patients ASA I and II, aged between 2 and 12 years, undergoing surgical procedures, were enrolled in this prospective, observational study. All study patients submitted to elective or non-elective surgical procedures requiring general anesthesia and oral endotracheal intubation using pharmacological paralysis.

Exclusion criteria aimed at eliminating patients who might be at increased risk of intubation-related and/or other study-related complications such as: suspected difficulty with mask ventilation and intubation and children with certain congenital disorders (Pierre Robin sequence, Treacher Collins, Down's syndrome, Goldenhar syndrome, Crouzon syndrome, Pfeiffer syndrome, Saethre-Chotzen syndrome, Hurler's/Hunter's syndrome, Beckwith-Wiedemann syndrome). Additional exclusion criteria were: known allergy to anesthetics, patients' or family history of malignant hyperthermia, history of prematurity, asthma, bronchospasm or cardiac disease.

Study patients were divided into two age groups: group 2-5y.o. and group 6-12y.o.

On arrival to the operating theater, an intravenous (IV) access was established. Standard monitoring {electrocardiogram, noninvasive

blood pressure, peripheral oxygen saturation (SpO<sub>2</sub>)} was applied. Anesthesia was induced with atropine 0.01 mg/kg, fentanyl 2μg/kg, propofol 3 mg/kg, titrated to loss of consciousness and loss of eyelash reflex and endotracheal intubation was facilitated with rocuronium bromide 0.6 mg /Kg. After intubation, the lungs were ventilated mechanically with FiO<sub>2</sub> 0.4 and sevoflurane was used for anesthesia maintenance. Ventilation was adjusted to keep P<sub>ET</sub>CO<sub>2</sub> in the range 4.5-5.5 pKa.

The choice of ETT type (cuffed or uncuffed) and size was made by the anesthetist appointed for each case. All the ETT tubes used in the study were of the same brand (RÜSCHELIT®). The appropriate ETT size was estimated with the formulas as follows: Internal diameter (mm) = (age / 4) + 3.5 for cuffed ETT and internal diameter (mm) = (age / 4) + 4 for uncuffed ETT<sup>6</sup>. According to the pediatric anesthesia department protocol, additional tubes one half size larger and smaller than the calculated were always available, during endotracheal intubation attempts, regardless of whether an uncuffed or cuffed endotracheal tube was used. The ETT size was regarded as suitable when it smoothly passed the glottis, provided minimal air leakage as the ventilation circuit was subjected to pressure of 15-25 cmH<sub>2</sub>O. When cuffed ETT type was used, cuff pressure was measured using a cuff manometer and was adjusted appropriately. Extubation was taking place in the operating

room after completion of the surgical procedure.

After surgical procedure, an anesthesiologist who was not involved in the perioperative treatment of the patient, recorded the demographic data, the size and type (cuffed or uncuffed) of ETT used. The formulas used to estimate the body weight (BW) based on age were: 2-5y.o.,  $BW (kg) = (2 \times \text{age in years}) + 8$  and for children 6 to 12y.o.<sup>8,9</sup>  $BW (kg) = (3 \times \text{age in years}) + 7$ .

All data recorded were analyzed using "SPSS Statistics for Windows, v.17.0 (SPSS Inc., Chicago, Ill., USA)". Data were expressed as the mean (SD) and number of cases (%). Shapiro-Wilk normality test was conducted for each parameter. Paired t-tests were used to analyze the differences between actual and predicted values. The level of significance was set at  $p < 0.05$ .

## RESULTS

The study included 353 patients aged 2 to 12 years. Patients demographic and anesthesia-surgery related data are shown in Table 1. All patients in group 6-12 and 74.7% (n=59) of patients in group 2-5 were intubated with cuffed ETT (Table 1). Cuffed ETT was used in 94.3% of all patients (n=333). Thirty patients undergoing CABG surgery were enrolled into this study. Patient characteristics and comorbidities are described in Table 1.

**Table 1.** Demographic and anesthesia-surgery related data

	All study groups (n=353)	Group 2-5 (n=79)			Group 6-12 (n=274)
		Cuffed ETT (n=59)	Un-cuffed ETT (n=20)	Total (n=79)	Cuffed ETT (n=274)
Age* (yr)	8 (3.7)	3.9 (1.1)	2.5 (1.1)	3.5 (1.3)	9.1 (2.2)
Weight* (kg)	32.7 (16.2)	18.2 (5.6)	13.1 (2.9)	16.9 (5.5)	36.2 (13.2)
Height *(m)	1.5 (5.7)	1 (0.1)	0.9 (0.1)	1.3 (0.1)	1.4 (0.1)
BMI (kg)/(m <sup>2</sup> )	17.5 (3.98)	16.2 (3.1)	15.2 (2)	15.7 (2.9)	18.2 (4.1)
Gender (M/F) N (%)	163/190 (46/57)	34/25	8/12	42/37 (53/46)	121/153 (44/55)
ASA ps(I/II) N (%)	307/46 (87/12)	48/11	16/4	64/15 (81/19)	243/31 (89/10)
Type of surgery N (%) elective /emergent	240/113 (68/32)	29/30	14/6	43/36 (54/45)	197/77 (72/28)

\*Values are mean (SD), N= number of patients

In patients of group 2-5, regardless the type of ETT used (cuffed or uncuffed), the predicted ETT size was significantly lower than the actual size used ( $p < 0.05$ ) (Table 2).

**Table 2.** Group 2-5 ETT internal diameter predicted and used

	Group 2-5yo uncuffed ETT (n=20)	Group 2-5yo cuffed ETT (n=59)
<b>Predicted size</b>	4.56(0.32)	4.58(0.38)
<b>Selected size</b>	5(0.6)	4.82(0.67)
<b>p-value</b>	0,016*	0.000*
<b>CI (95%)</b>	(0.24-0.72)	(0.108-.036)

Values are mean(SD), \*p<0.05, CI: Confidence interval 95%

In patients of group 6-12 no statistically significant difference was noted between the predicted and selected internal diameter of the ETT (Table 3).

**Table 3.** Group 6-12 ETT internal diameter predicted and used

	Group 6-12yo cuffed ETT (n=274)	p-value	CI (95%)
<b>Predicted size</b>	5.8(0.5)	0.462	(-0,106-0,002)
<b>Selected size</b>	5.78(0.5)		

Values are mean(SD), \*p<0.05, CI: Confidence interval 95%

In the individual age groups, the predicted body weight was significantly lower than the measured body weight (Table 4).

**Table 4.** Body Weight (BW) comparison using the APLS formula in study's age groups

	Measured BW	Predicted BW	p-value	CI (95%)
<b>Group 2-5yrs (n=79)</b>	16.9(5.5)	15.1(.5)	0.002*	(0.85-2.77)
<b>Group 6-12yrs (n=274)</b>	36.2(13.2)	34.4(6.2)	0.003*	(1.21-3.62)

Values are mean(SD), \*p<0.05, CI: Confidence interval 95%

## DISCUSSION

This study demonstrated that in our hospital, the traditional age -based Cole's formula for selecting the appropriate ETT size, was not reliable for children 2 – 5y.o. On the other hand, Cole's formula was quite reliable when applied in children 6-12y.o. Also, this study suggested that the APLS formula, for the estimation of body weight, tends to underestimate the weight of children.

In children undergoing general anesthesia, with the application of oral ETT, is very important to use the correct size ETT, in order to reduce morbidity and mortality related to post-intubation complications<sup>2,3</sup>. Many different algorithms and formulas, sometimes complex, have been described in order to accurately choose the correct ETT size<sup>4-6</sup>. Cole's formula was introduced in 1954 and since then it has been used widely in anesthetic practice. Today,

still remains one of the most used formulas in children<sup>4,5</sup>. Although this formula gives a good estimation of the optimal internal diameter of the ETT, based on patient's age, it's not always accurate<sup>7,10,11</sup>. Schramm et al demonstrated that the rate of agreement of age based Cole's formula for ETT selection is low as 47-77%<sup>12</sup>. Raphael et al showed that ultrasound measurement of subglottic diameter had a significant advantage. The rate of agreement between clinically optimal and ultrasound guided ETT size was 98.5%. The rate of agreement between clinically optimal and formula-derived ETT size was 95.9%<sup>11</sup>. Another limitation of Cole's formula is that this formula cannot consider variation of growth in various internal organs during childhood. In our days also, the epidemic of childhood obesity means that a large population of overweight or obese children undergo surgery under general anesthesia. In these children the appropriate size of ETT cannot be accurately estimated due to the comparative increase in their airways size. Consequently, Cole's formula which was applied more than 60 years ago, is likely to significantly underestimate the appropriate ETT size. Shibasaki et al noted that age based formulas generally predicted larger sizes than proved clinically optimal, sometimes by two or even three sizes<sup>13</sup>. This does not follow our results, where age based formula significantly underestimated the correct ETT size in small

children (2 to 5 years). In older children (6 to 12 years) the predicted ETT size was slightly, but not significantly, larger compared to the ETT size that was finally used. Our findings agreed with the results of Shiroyama et al where ETT size estimated by Cole's formula tended to be smaller than practically appropriate ETT size for pediatric cardiac anesthesia patients<sup>14</sup>.

The number of study patients of age group 2-5 who received uncuffed was small (n=20). That shows that the majority of anesthesiologists who delivered anesthesia in this age group preferred cuffed ETTs over uncuffed. In the past, cuffed ETTs were recommended only for use with specific circumstances in children below 8 years<sup>15,16</sup>. Since then many authors suggested the use of cuffed ETTs in children younger than 8 years<sup>15,17</sup>. The advantages are less gas leak around tracheal tube with improved efficiency of ventilation, reduced atmospheric pollution and more reliable end-tidal CO<sub>2</sub><sup>15,18</sup>. Furthermore, with cuffed ETT there is a decreased risk of aspiration and reduced need to change ill-fitting ETT and less use of over large uncuffed ETT, a main cause of subglottic stenosis<sup>15</sup>. Khine et al found that the rate of reintubation required with uncuffed ETT was 30% in children younger than 2 years and 18% in children 2 years and older<sup>7,17</sup>. Also, Clementes et al showed that, in elective anesthetized children between 1 to 8 years, the rate

of ETT change in 251 children randomized to cuffed ETT was significantly lower compared to 237 children randomized to uncuffed ETT<sup>19</sup>. In 2003, Litman et al examined the airways in children aged 2 months to 13 years with magnetic resonance imaging (MRI). The authors found an elliptical cricoid ring and that the narrowest portion of the larynx is at level of the vocal cords, although the functionally narrowest portion is at level of the non-distensible cricoid ring. These findings have implications for the fitting of uncuffed ETT, which provides adequate sealing not within a circular cricoid ring, where pressure would be distributed evenly upon the mucosa, but within an eclipse, where a leak around the tube could be present despite increased pressure against areas of the mucosa<sup>20,21</sup>. In our study, we used a cuff manometer in order to measure the cuff pressure, when cuffed type ETT was used. It is known that proper management of cuff pressure is very important to the patient's airway, especially in the pediatric patient<sup>22</sup>. One cross-sectional study performed among the pediatric population recommended that cuff pressures be set and monitored with a pressure manometer<sup>23</sup>.

Body weight is one of most important measurements in pediatric anesthesia. BW is used to determine intravenous fluid requirements, shock volume administered during cardio-respiratory arrest, endotracheal tube size and to

assess nutritional status. Given that the majority of pediatric drug doses are calculated per kilogram of bodyweight basis, it is essential that the anesthesiologist have an accurate knowledge of the child's BW. There are number of methods used to estimate weight in children<sup>24-27</sup>. The most commonly used is the age based Advanced Pediatric Life Support (APLS) formula. Several studies have shown that the original APLS formula tended to underestimate the actual weight and the margin of error increased with age<sup>9,28,29</sup>. Following this, Luscombe and Owens developed a new formula, which had been found to be more accurate than APLS<sup>9,30</sup>. So, as of July 2011, the APLS guidelines for weight estimation based on age have been altered according to child's age. So, the original APLS formula is applied for children between the ages of 1–5, the Luscombe and Owens formula for those aged 6–12 and a specific infant formula for those aged less than 1 year old<sup>8</sup>. These formulas were applied in our study population. Our findings suggest that the formulas used to predict BW underestimated all study patients BW. That means that both the original APLS formula and the Luscombe and Owens formula seem to be unreliable regarding BW estimation. The results of this study agreed with several subsequent studies in Australia and the UK, which also demonstrated the tendency of the APLS formula to underestimate BW in chil-

dren<sup>8,9,29,31</sup>. On the other hand, studies from India and South Africa found the original APLS to be more accurate. However, these populations are regarded as (rapidly) developing countries and perhaps these findings are not to be generalized, given the variation in body habitus between children from developed and developing countries<sup>30</sup>. Also, it must be noted that in this study the patient's weight was measured before surgery, although the parental estimation of child's weight is considered a reliable method of BW estimation<sup>26</sup>.

There are several limitations in this study. We assumed that the ETT size used in this study was the correct one, because we routinely checked the audible air leakage around the tube, to verify the accepted level between 15 and 25 cmH<sub>2</sub>O. Many different anesthesiologists delivered anesthesia in study patients, which means that many different leak pressures were assessed. In addition, this study includes patients from a single center and lack of control for other variables, which may have influenced the ETT size.

## CONCLUSION

This study suggests that Cole's formula for predicting the correct ETT size (cuffed or uncuffed) is applicable in children aged 6 to 12 years. In younger children (2 to 5 years) it seems as if the above formula does not apply neither for cuffed nor for uncuffed ETT. We

can speculate that larger population and a more accurate ETT estimation formula will affect clinical outcome. Our study also demonstrates that when the actual body weight cannot be obtained, the widely used APLS formula, tends to underestimate the weight of children in our geographical region.

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