Original Article

Comparison of Formulae for Orotracheal Intubation Depth in the Paediatric Population

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Abstract

Introduction: Multiple formulae have been proposed for calculating orotracheal depth for paediatric intubation. However, literature on the validation of these formulae in the emergency department setting is limited. Three methods described in the local Advanced Paediatric Life Support curriculum include the Broselow tape, endotracheal tube (ETT) size x 3, and the age-based formula of age divided by 2, add 12. We aimed to determine their accuracy. Materials and Methods: Patients with intubation performed in the Children's Emergency from 1 January 2009 to 31 December 2013 were included in this retrospective observational study. The depths of ETT placement based on the formulae were calculated from the actual depth of ETT. ETT position between T2 to T4 vertebral bodies of the chest radiograph was taken as the reference position for radiological accuracy. Results: ETT size x 3 has the highest accuracy of 76.5%, as compared to 67.9% for age-based formula and 63.5% for Broselow tape. When the formulae were inaccurate, Broselow tape often predicted a depth that was too shallow as compared to ETT size x 3 ($P = 0.006$) and age-based formula ($P = 0.011$). The accuracy of Broselow tape was not uniform across the age groups, with highest accuracy in patients 1 to 8 years old. ETT size x 3 had the highest accuracy in patients weighing more than 25 kg. Conclusion: ETT size x 3 was superior for determining orotracheal intubation depth but cannot preclude the confirmation of appropriate placement of ETT by auscultation and chest radiograph.

Ann Acad Med Singapore 2018;47:138-42

Key words: Airway management, Emergency, Resuscitation

Introduction

Tracheal intubation can be a life-saving intervention performed during the emergency setting, with a wide range of indications in critically ill children.[1-2] The paediatric airway has unique challenges due to the patient's age, size, and underlying condition. Therefore, it is important to use an appropriate approach when performing tracheal intubation and anticipate the potential difficulties. Once intubation is done, the endotracheal tube (ETT) has to be secured at the appropriate depth—too shallow and it can lead to excess risk of inadvertent extubation; too deep, and it can lead to inadequate (endobronchial) ventilation and hypoxemia. In both situations, they are considered adverse tracheal intubation associated events,[3-4] having far-reaching consequences such as airway loss, barotrauma and hypoxia. The routine clinical confirmation of appropriate ETT insertion depth is in turn obtained through a chest radiograph.

Numerous formulae (Table 1) have been published to guide the physician in deciding this appropriate depth, with reference to age, body weight and length. As reported by Boensch M et al[5] in their systematic review, 13 different formulae were identified for use in paediatric patients ranging from newborns up to 16 years old. The maximal accordance for any formula when correlating the position of ETT with chest radiographs was 81%. However, existing studies have only examined each formula in isolation.

In our local curriculum of Advanced Paediatric Life Support Course (APLS), 3 formulae—Broselow tape, ETT size (internal diameter) x 3, and the age-based formula of age divided by 2, add 12 (for use in more than 1 year old)—are

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Table 1. Formulae for Estimating Depth of Insertion of Orotrachael Endotracheal Intubation

	Formula
Age-based (years)	Age/2 + 12[*,†,‡]
	Age/2 + 13[§]
Weight-based (kg)	Weight + 6[ǁ,¶,#]
	Weight/2 + 8[§]
	ln (weight) + 6.632[**]
Length-based (cm)	Broselow tape
	(Length + 5) x 0.1[††,‡‡]
Others	Size of endotracheal tube x 3[§§]
	(Gestation x 0.188) + 1.198[**]

[*]Cole F. Paediatric formulae for the anesthesiologist. Am J Dis Child 1957;94:672-3.
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recommended for the calculation for depth of orotracheal intubation.[6] The Broselow tape relates a child's height to weight and provides information on size of resuscitation equipment as well as dosages for medications and energy level for cardioversion/defibrillation. By using the tape to measure the child from the head to heels, the user can get an approximate weight with corresponding information for resuscitation purpose. Drugs for rapid sequence intubation, the size (internal diameter) of ETT and depth of placement are provided on Broselow tape for intubation. We aimed to determine the accuracy of ETT insertion depth based on these 3 formulae against a radiological reference standard. This would allow us to identify any limitations in their clinical applicability in paediatric patients up to 16 years old.

Materials and Methods

Settings

This retrospective review was conducted in the paediatric emergency unit of a tertiary hospital in Singapore with an attendance of more than 170,000/year. One percent of the patients are of the high-priority emergent category. There was no general consensus or recommendation for using any formula to guide depth of placement of ETT for intubations in the department. This decision was often left to the discretion of the attending physician.

Design

Data was retrospectively collected using standardised forms for all intubations performed in the paediatric emergency unit from January 2009 to December 2013. Data fields pertaining to age, weight, gender, diagnosis, indication for intubation, size (internal diameter) and type (cuffed or uncuffed) of ETT and depth of placement measured at the patient's upper incisor were collected.

Patients with intubation performed prior to arrival at the emergency department were excluded. However, if the attending clinician deemed that reintubation was necessary for any reason such as tube dislodgement or persistent air leak due to wrong size in the department, they were included in the study. This study was approved by Institutional Review Board at SingHealth, Singapore.

Accuracy of ETT Insertion Depth against a Radiological Reference Standard

Proper placement of the ETT has been accepted as a position below the thoracic inlet and at least 0.5 cm above the carina.[7] However, the caudal movement of the ETT tip due to neck flexion has been reported to be 0.8 cm in neonates, with larger extent of movements in older children.[8] This suggests that the ETT might still be deep when the neck is not in neutral position.

Position between upper border of T2 to lower border of T4 vertebrae bodies—corresponding to the middle third of the traches—has also been accepted when the carina cannot be visualised.[9,10] The latter was used as a reference for radiological accuracy in our study to minimise the number of cases excluded due to technical difficulty in identifying the carina on chest radiographs. Furthermore, this method was applicable to the emergency unit setting as the other described method of using bronchoscopy[11-13] to determine satisfactory ETT placement would not be practical.

Using the visualised depth of the ETT on the chest radiograph with the corresponding numerical depth recorded in each case as a reference point, the hypothetical depths of ETT placement based on the 3 formulae were plotted with respect to it. Hypothetical depths that were higher than the T2 vertebrae were taken to be inappropriately shallow

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whilst depths that were lower the T4 vertebrae were taken to be inappropriately deep.

Statistical Methods

Statistical analysis was performed using SPSS version 16 and R3.3.1. Median and interquartile range (IQR) were presented for continuous variables while count and percentage were indicated for categorical variables. Kruskal-Wallis rank sum test was used to study the overall correlation of accuracy of each formula with body weight and ad hoc pairwise comparisons were performed using Wilcox test with Benjamini-Hochberg adjustment. The correlation of accuracy with age groups and gender were tested by chi squared test. The level of significance was 0.05.

Results

A total of 207 intubations were performed between January 2009 and December 2013, with an incidence of 1 intubation per 8.82 days on average.

Patient Characteristics

Table 2 describes the patient characteristics. The median age of the patients was 4 years old. A total of 60.9% of the study population required intubation for decreased consciousness and loss of airway reflexes. All intubations performed were successful, with a first attempt success rate of 84.1%.

Performance of the 3 Commonly Used Formulae

ETT size x 3 had the highest accuracy of 76.5%, as compared to the accuracies of age-based formula of age divided by 2, add 12 and Broselow tape (of 67.9% and 63.5%, respectively) (Table 3). When the formulae were inaccurate, Broselow tape often predicted a depth that was too shallow as compared to the formula of ETT size x 3 (P = 0.006) and the of age-based formula of age divided by 2, add 12 (P = 0.011).

Age and Weight Considerations

Age

The performance of the formulae ETT size x 3 (P = 0.034) and age divide by 2, add 12 were consistent across the age groups. Broselow tape performed best for patients between 1 to 8 years old but the accuracy fell below 40% for patients less than 1 or more than 8 years of age (P <0.001) (Table 4).

Weight

ETT size x 3 had the highest accuracy in patients weighing more than 25 kg (P = 0.015) but it predicted a depth that was too deep for children with weight <8 kg (Table 5). The higher accuracy in patients weighing more than 25 kg was

Table 2. Patient Characteristics

Demographics	
Age (years)	Median: 4; IQR: 11 months to 8 years
Weight (kg)	Median: 15; IQR: 8 to 25
Gender (male)	54.1%
Top 5 diagnostic categories*	
Neurological	109 (52.7%)
Trauma	28 (13.5%)
Respiratory	27 (13.0%)
Cardiology	22 (10.6%)
Infectious disease	14 (6.8%)
Indication for tracheal intubation	
Decreased consciousness and loss of airway reflexes	126 (60.9%)
Failure to ventilate	40 (19.3%)
Failure to oxygenate	35 (16.9%)
Anticipated clinical course or deterioration	6 (2.9%)

IQR: Interquartile range
*The remaining cases are intubated for metabolic, allergy, haematology and toxicology causes.

Table 3. Performance of the 3 Formulae

	Accurate Depth n (%)	**Depth Too Shallow n (%)**	**Depth Too Deep n (%)**
ETT x 3 (n = 187)	143 (76.5)	17 (9.1)	27 (14.4)
Age/2 + 12 (n = 140*)	95 (67.9)	18 (12.9)	27 (19.2)
Broselow tape (n = 178)	113 (63.5)	43 (24.2)	22 (12.3)

ETT: Endotracheal tube
*Only patients more than 1 year of age were included in analysis for this formula.

Table 4. Accuracy of 3 Formulae by Age Groups

	Less than 1 Year	**1 to 8 Years**	**More than 8 Years**	***P* Value**
ETT x 3 (n = 143)	32/47 (76.5)	72/96 (75.0)	35/35 (79.5)	0.628
Age/2 + 12* (n = 95)	NA	66/96 (68.8)	29/44 (65.9)	0.4
Broselow tape (n = 113)	17/44 (38.6)	83/91 (91.2)	13/43 (30.2)	<0.001

ETT: Endotracheal tube; NA: Not applicable
*Only patients more than 1 year of age were included in analysis for this formula.

Table 5. Performance of 3 Formulae by Weight Groups

		n (%)			
		Less than 8 kg	**8 to 25 kg**	**More than 25 kg**	***P* Value**
ETT x 3 (n = 187)	Correct	34 (65.4)	68 (74.7)	41 (93.2)	0.015
	Shallow	5 (9.6)	10 (11.0)	2 (4.5)	
	Deep	13 (25)	13 (14.3)	1 (2.3)	
Age/2 + 12* (n = 140)	Correct	5 (100)	63 (67.8)	27 (64.3)	0.16
	Shallow	0 (0)	15 (16.1)	3 (7.1)	
	Deep	0 (0)	15 (16.1)	12 (28.6)	
Broselow tape (n = 178)	Correct	26 (59.1)	53 (58.2)	34 (79.1)	0.202
	Shallow	12 (27.3)	25 (27.5)	6 (14.0)	
	Deep	6 (13.6)	13 (14.3)	3 (6.9)	

ETT: Endotracheal tube
*Only patients more than 1 year old were included in analysis for this formula.

also observed for Broselow tape, though the result was not statistically significant ($P = 0.202$).

Repositioned ETT

In this study, inappropriate depth of ETT post-intubation as confirmed on chest radiograph occurred in 32 (15.5%) cases. Twenty-seven (84.4%) of the cases were due to an initial insertion depth that was too deep from clinical examination and/or verification by chest radiograph, according to the discretion of the attending team. However, the retrospective nature of this study precluded further exploration into this observation as the formula used by the physician at the time of intubation was unknown.

Discussion

Variability in tracheal length across all age groups in the paediatric population makes accurate ETT placement critical and challenging. Incorrect placement of ETT can lead to significant morbidity or potential mortality. A depth that is too deep can lead to main stem bronchus intubation with potential for barotrauma and air leak syndromes in one lung, and insufficient ventilation and atelectasis of the other. A depth that is too shallow is at a higher risk of inadvertent extubation especially during transfer of these critically ill children. Despite the common use of the 3 methods of estimating depth of orotracheal intubation, there is limited medical literature to directly compare their use in the same patient population.

Performance of the Formulae

Our study directly compared the 3 commonly used methods of determining ETT depth in the emergency department setting which was not available in current literature. ETT size x 3 was the most accurate formula with an accuracy of 76.5% that was similar to that of 75% as reported by Phipps et al[7] in patients admitted to the paediatric intensive care unit. However, Mariano et al[13] reported an accuracy of a mere 42%. We postulated that this could be related to the difference in the definition of accuracy used in the studies. Like our study, Phipps et al used position of the ETT on the chest radiography to determine accuracy of the formula as per the practice of many clinicians. However, Mariano et al based the accuracy of the formula by determining depth with markers on the ETT after deliberate endobronchial intubation with subsequent withdrawal of the tracheal tube 2 cm above the carina (which was less feasible in our emergency department setting).

Like the depth of ETT insertion, several formulae for the determination of ETT size exist— of which Broselow tape and Advanced Paediatric Life Support (APLS) age-based formula of age divided by 4, add 4—are commonly used. The variable by which ETT size and type (cuffed vs uncuffed ETT) was determined may have subsequent effect on the depth of ETT placement if the formula ETT size x 3 was used and could not be accounted for in this retrospective study. Furthermore, narrowing of the airway as a result of infection, oedema and local trauma in critically ill children may lead to the use of a smaller ETT by the clinician during the intubation process, affecting the accuracy of the formula ETT size x 3 in predicting depth of ETT placement.

Length-based formula using the Broselow tape for selection of ETT size has been reported to be superior to age-based formula.[7,14-16] However, this comparison for the depth of ETT placement was not evaluated previously. Our study showed a slightly higher accuracy for the age-based formula as compared to the Broselow tape across all age groups. However, on closer examination across the age groups, the accuracy of Broselow tape was highest at 92.1% for the prediction of ETT depth in patients between 1 to 8 years old. This was consistent with the findings of a previous local study on the validation of Broselow tape for weight estimation in 1- to 10-year-olds by Loo PY et al.[17] Together, it seemed to suggest that Broselow tape may perform better for local children aged between 1 to 8 years. This was supported by reports of variable performance of Broselow tape across the age groups by validation studies in the non-United States population.[16,18-20]

ETT size x 3 and possibly Broselow tape were more accurate in patients weighing more than 25 kg. The clinician would need to be aware of this limitation in patients weighing 25 kg or less, and consider the use of other formulae to determine depth of ETT insertion (e.g. using weight-based formulae in neonates or infants less than 1 year of age).

Readjustment of ETT Depth

Orf et al[21] has reported that adjustment of tracheal tube insertion depth occurred in 33.3% of cases with 97% being inappropriately deep. The study population involved patients who were intubated by non-specialist teams and subsequently transferred to a specialist paediatric hospital. In our study, 15.5% required adjustment of tracheal tube insertion depth. This lower proportion of cases could be attributed to the presence of paediatric specialists to perform these intubations within the Children's Emergency. Nonetheless, inappropriately deep insertion formed the majority (84.4%) of cases requiring readjustment of ETT.

Limitations

The most significant limitation of our study was that we were unable to obtain information on the intended formula used by the clinician at the point of intubation for the depth of insertion. Therefore, we needed to calculate the depths of insertion for the 3 formulae based on the actual depth of insertion using the chest radiographs of the patients. The final number of cases analysed was also lower than the total number of intubations performed in the department due to no information on actual ETT depth due to missing documentation, or missing chest radiographs from the image viewer database.

It should also be mentioned that the effect of neck movement on position of ETT would be more pronounced in the paediatric population—neck flexion can move the tip of the tube towards the carina while neck extension can result in the tip moving away from the carina; and both of which affect the final position on the chest radiograph. As this was a retrospective study, we were not able to confirm that all radiographs were taken with the head in neutral position to minimise the effect of neck movement on ETT position seen on the chest radiograph. Given that these chest radiographs have been reviewed by the attending team after intubation with readjustments made—if indicated—it would be fair to assume that the radiographs were taken in a satisfactory position to make clinical decisions post-intubation.

Conclusion

Generally, ETT size x 3 was the superior formula across all age groups for determining orotracheal intubation depth. It has an accuracy of 76.5%, as compared to 67.9% and 63.5%, for the age-based formula of age divided by 2, add 12 and Broselow tape, respectively. ETT size x 3 was most accurate in patients weighing more than 25 kg, and Breslow tape had the best performance for paediatric patients aged between 1 to 8 years old. While the search for a more reliable formula to determine the appropriate depth of ETT placement in children continues, such a formula cannot preclude the confirmation of appropriate placement of ETT by auscultation and chest radiograph.

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