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ORIGINAL ARTICLE

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Comparative study of different formulae for prediction of best fit endotracheal tube size in children

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Abstract

Background Various formulae have been used to predict appropriate endotracheal tube (ETT) size in children, but there is no consensus regarding the best predictor. Recent use of ultrasonography (USG) to predict the ETT size may not always be feasible leaving the physical parameters as most useful and practical option. The present study was planned to compare age-, height- and weight-based formulae for ETT size prediction in children.

Results The accuracy in predicting ETT size was found to be 88.67%, 73.33% and 32.67% for height-based formula (HBF), age-based formula (ABF) and weight-based formula (WBF), respectively. Pearson correlation coefficient was best for HBF (0.968 with 95% *CI* of 0.937–0.999), followed by ABF (0.942 with 95% *CI* of 0.887–0.996) and WBF (0.874 with 95% *CI* of 0.794–0.953). HBF was found to be best suited for children 1–3 years, ≤ 90 cm and weight < 15 kg with accuracy of > 98%, while WBF was unsatisfactory across all age, height and weight groups.

Conclusions HBF is the best predictor of ETT size across all age groups with marginal superiority over ABF, especially in age group < 3 years. WBF was least effective in predicting ideal ETT size. It is recommended that HBF should be preferred over ABF and WBF for selection of ETT size in paediatric patients. This practice assumes greater importance especially in emergency situations where exact age and weight cannot be ascertained while height is easily obtainable.

Keywords Endotracheal tube, Age, Height, Weight, Formulae, Children

Introduction

Airway management in paediatric patients with appropriate endotracheal tube (ETT) size remains an integral component of anaesthetic management. Selection of inappropriate ETT size significantly increases morbidity since a smaller ETT predisposes to leakage of anaesthetic gas, inadequate ventilation and pulmonary aspiration. Too large, an ETT predisposes to sore throat, airway oedema, trauma and subglottic stenosis (Koka et al. 1977; Lee et al. 1980). Moreover, multiple trials of intubation may also result in hypoxemia in patients (Cook and MacDougall-Davis 2012). In order to prevent the abovementioned complications, many formulae have been designed to predict appropriate ETT size in children.

Age-based formula (ABF) of Cole and Motoyama has been in widespread use since many years (Cole 1957; Motoyama et al. 1996). Height-based formula (HBF) and weight-based formula (WBF) were also developed and used to find out the appropriate ETT size (Shih et al. 2008; Eipe et al. 2009). To date, there is no consensus regarding the best formula, and repeated laryngoscopies are often needed to place the appropriate-sized ETT.

Recent studies suggest that ultrasonography (USG) can provide the better estimation of ETT size in paediatric age group than the conventional physical indices-based

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formulae (Shibasaki et al. 2010; Gunjan and Faseehullah 2020). However, the operator skill for USG as well as the USG facility in operating room (OR) may not be available at all the centres world over. Also, USG gives an estimate of outer diameter (OD) of the ETT, which varies for a given ETT size among manufacturers and hence can lead to inappropriate size selection (Gnanaprakasam and Selvaraj 2017). Moreover, USG measures only transverse diameter of subglottis as the measurement of anteroposterior (AP) diameter is not possible. Since AP diameter is larger than the transverse diameter, USG may give an underestimation of the actual tracheal diameter and selection of smaller ETT (Singh et al. 2019). Another prerequisite is the child's cooperation to lie still and allow the scan, which may not be always possible. The more advanced and expensive methods such as computed tomography and magnetic resonance imaging (MRI) are impractical and may not be justifiable to be used for estimating ETT size. Therefore, physical indices remain the most easily available and useful parameters to predict appropriate ETT size.

The present prospective observational study was conducted to compare actual tracheal tube size used with the size predicted by using the age-, height- and weight-based formulae in paediatric patients.

Methods

The study was conducted after approval by the institutional ethics committee and in accordance with the Helsinki Declaration 2013. One-hundred fifty children of age group 1–10 years undergoing surgery under general anaesthesia were included in the study. Sample size was calculated on the bases of data from previous study (Turkistani et al. 2009), with the level of significance of 5%. Children with known laryngeal and tracheal pathology, congenital developmental disorder, malformation associated with head and neck and face, upper airway obstruction and history of tracheostomy were excluded from the study. In the operating room, children were monitored by electrocardiography, noninvasive blood pressure, end-tidal CO_2 and pulse oximetry.

General anaesthesia was induced by inhalational or intravenous induction agent and maintained with inhalational agent in oxygen and nitrous oxide mixture. After complete muscle paralysis was achieved by using muscle relaxant, first attempt of tracheal intubation was carried out using an uncuffed endotracheal tube which was selected based on height-based formula (internal diameter {ID} in mm = {height in cm ÷ 30} + {2}). Immediately after intubation, correct endotracheal placement was confirmed by capnography and bilateral chest auscultation method.

After confirming endotracheal placement of tube, leak pressure was measured by closing the pressure relief valve, and air leakage was observed by auscultation over the skin of the larynx. The absence of leak at an airway pressure of 10 to 25 cmH_2O was considered as appropriate ETT size for the children. Leak at an airway pressure of less than 10 cmH_2O was considered as a small ETT size, and no leak at airway pressure of 25 cmH_2O was considered as a large ETT size for the children. If ETT size used was found to be too small or large, it was replaced with appropriate-sized tube as indicated. Patients were ventilated according to indication as per normal settings.

The final ETT tube size was correlated with the size predicted by ABF, HBF and WBF.

- The ABF used was as follows: Age in years/4 + 4 mm ID.
- WBF used was as follows: Weight in kg/10 + 3.5 mm ID.
- HBF used for primary selection of tube was as follows: Height in cm/30 + 2 mm ID.

After extubation, children were monitored for sore throat, hoarseness of voice, cough, aspiration, stridor and any other complication in the postoperative period.

Statistical analysis

The Statistical Package for Social Sciences (SPSS) version 21.0 was used for statistical analysis. The quantitative variables were expressed as mean with 95% confidence interval (95% CI) and compared using paired t-test. The data was subjected to statistical test using Kruskal-Wallis test for quantitative variables, chi-square test and Fisher's test for qualitative variables, Bhapkar test was used for prediction of accuracy, Pearson correlation coefficient for association of various parameters for ETT selection and inter-rater kappa agreement for strength of agreement. The $p < 0.05$ was considered significant.

Results

The mean age of the patients in the study was 4.08 years (1.58–6.58 years). Majority of the patients were in the age groups 1–3 years followed by 4–5 years. The mean height of the patients was 94.14 cm (76.64–111.64 cm). The mean weight of the patients was 12.89 kg (8.38–17.4 kg). The study included 82.67% boys and 17.33% girls. Majority of the children underwent gastrointestinal surgeries (52%) followed by genitourinary surgeries (27.33%). Remaining 20.67% of the children were subjected to operation of retroperitoneum, thoracic region and miscellaneous (orthopaedic, ophthalmic, head and neck region) surgeries.

The ETT size ranging from 4.5 to 6.5 mm, used for the mean age, height and weight, was inferred. Significant association was seen between age, height and weight with final ETT size ($p < 0.0001$) (Table 1).

Accuracy in prediction of ETT size (Fig. 1)

HBF was the best predictor of ETT size. It predicted ETT size accurately in 88.67% of patients. The error of size in 11.33% was of magnitude ± 0.5 mm only with large incidence of under-prediction in 88.2% and over-prediction in 11.8%.

ABF was next best indicator with accurate prediction in 73.33% of patients. Error in prediction in 26.67% was again of magnitude ± 0.5 mm with a larger incidence of under-prediction (90%) and a much smaller proportion of over-prediction (10%).

WBF formula found to be least effective predictor. Accurate prediction is found in only 32.67% with inaccurate prediction in the rest. The error too was of a larger magnitude up to ±1.0 mm with predominantly under-prediction in 99% of patients in whom the ETT size was inappropriate.

Association of demographic characteristics in prediction accuracy by each formula

ABF was accurate in predicting the ETT size in majority of patients. The proportion of accurate prediction was comparable for all age, height and weight groups and for both males and females with no significant difference between them ($p < 0.05$) (Fig. 2).

HBF was found to be best suited for children 1–3 years, ≤ 90 cm and weight < 15 kg with accuracy of > 98%. It was least accurate in age groups 6–7 years, height groups 91–110 cm and weight groups 16–20 kg with correct prediction of 69.57%, 78.05% and 60.71%, respectively. This difference was statistically significant ($p = 0.0005$). Prediction accuracy of ETT size by HBF was comparable between males and females with no significant difference between them (Fig. 3).

Table 1 Demographic characteristics and final ETT size distribution

Demographic characteristics		Final ETT size					
		4.5 (*n* = 53)	5 (*n* = 35)	5.5 (*n* = 21)	6 (*n* = 35)	6.5 (*n* = 6)	*p*-value
Age in years	Mean	1.69	3.3	5.13	6.96	9.25	< .0001
	95% CI	0.7–2.68	2.76–3.84	4.65–5.61	5.65–8.27	7.84–10.66	
Height in cm	Mean	75.13	89.86	105.71	114.71	126.5	< .0001
	95% CI	71.73–78.57	86.94–92.78	103.56–107.86	109.54–119.88	124.24–128.76	
Weight in kg	Mean	8.47	11.4	14.57	18.63	21.33	< .0001
	95% CI	7.54–9.4	10.55–12.25	13.28–15.86	16.33–20.93	20.81–21.85	

Values are mean⁄D; *ETT* Endotracheal tube

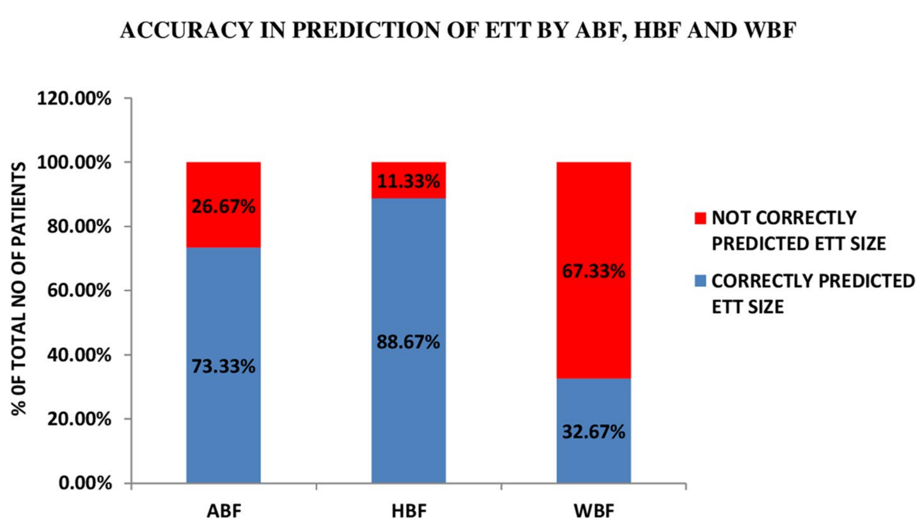

Fig. 1 Accuracy in prediction of endotracheal tube (ETT) size by height-based formula (HBF), age-based formula (ABF) and weight-based formula (WBF)

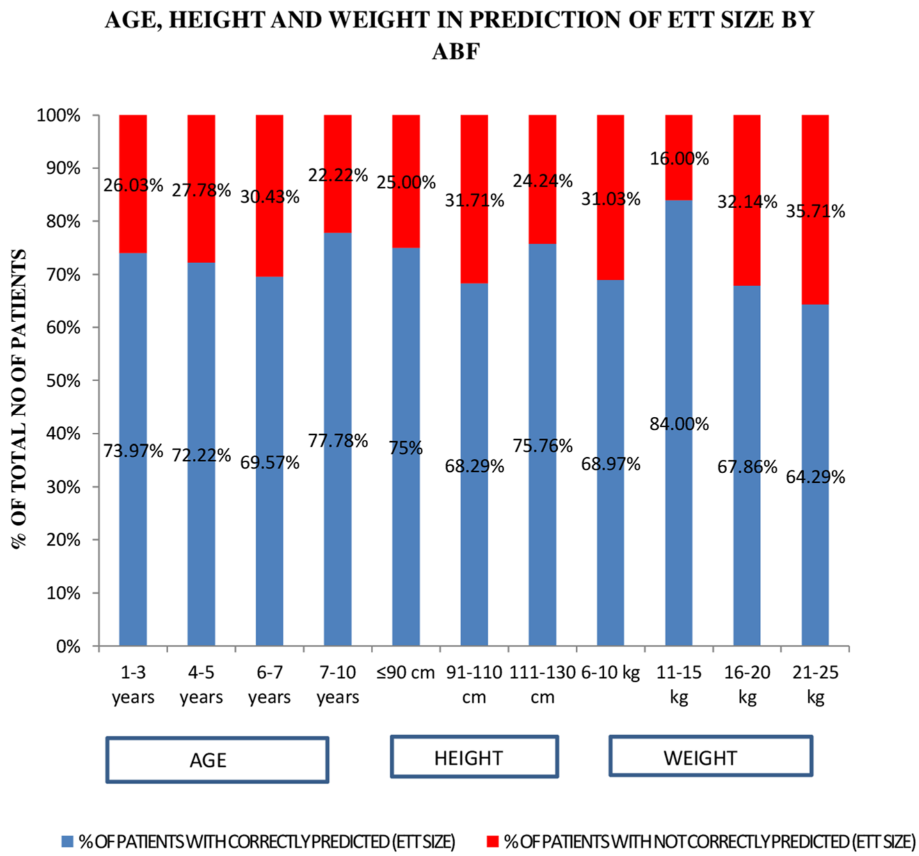

Fig. 2 Association of demographic characteristics in prediction accuracy of ETT size by age-based formula (ABF)

Although the overall prediction accuracy of WBF was not satisfactory for either of the age groups, height groups and weight groups, it was proportionally better for age groups 1–3 years, height < 90 cm and weight 6–10 kg, and the difference was statistically significant ($p < 0.05$) (Fig. 4).

Correlation between final ETT size and the predicted size by individual formula

The final ETT size correlated best with the HBF, as indicated by the highest Pearson correlation coefficient of 0.968 (95% *CI* 0.937–0.999) for HBF (Table 2).

Comparison of the three formulas for association of accuracy in predicting ETT size

While comparing HBF and ABF for "association of accuracy" in prediction of ETT size, HBF was found to be more accurate than ABF. HBF correctly predicted ETT size in 88.67% of patients while ABF correctly predicted in 73.33% of patients only. The difference was statistically highly significant ($p < 0.0001$).

ABF was found to be better than WBF, as it correctly predicted appropriate ETT size in 73.33% of patients as compared to only 32.67% by WBF ($p < 0.0001$).

On comparing HBF with WBF in predicting appropriate ETT size, HBF correctly predicted ETT size in 88.67% of patients while WBF correctly predicted in 32.67% of patients only ($p < 0.0001$).

Reliability of each formula for correct prediction of ETT size

Kappa value was calculated as a "measure of agreement" to see the reliability of ABF, HBF and WBF in prediction of appropriate ETT size. The kappa value was found to be highest for HBF (0.849), indicating it to be most reliable followed by ABF and WBF for predicting the final ETT size in children ($p < 0.0001$) (Table 3).

Complications

No intraoperative complications were noted in any of the patients. Two patients developed laryngospasm after extubation, and eight patients developed post-operative cough.

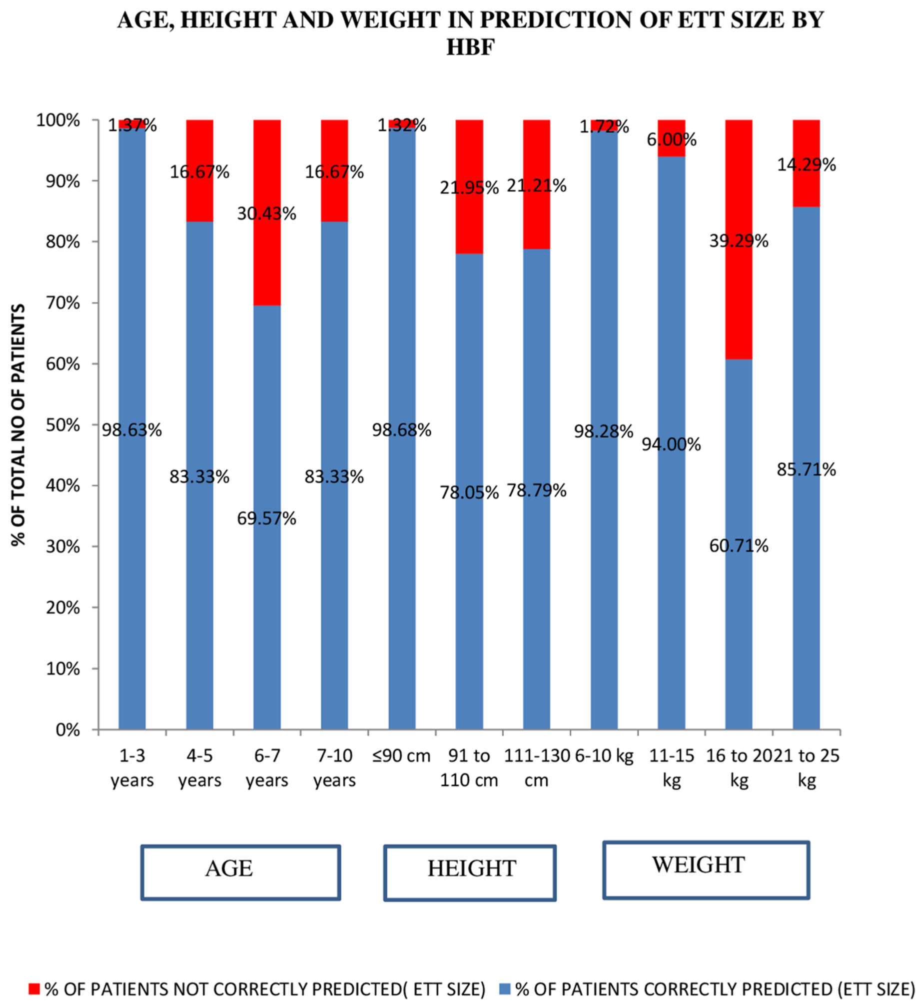

Fig. 3 Association of demographic characteristics in prediction accuracy of ETT size by height-based formula (HBF)

Discussion

Intubation of the trachea with appropriate ETT is very important in children to ensure airway protection and adequate ventilation. There have been numerous studies to predict correct ETT size using age, weight, height and diameter of distal phalanx of index or little finger, etc., and many formulae have been proposed and used worldwide (Turkistani et al. 2009; King et al. 1993; Keep and Manford 1974; Hofer et al. 2002). Yet, there are only a few studies which compared HBF with other formulae (Turkistani et al. 2009; Keep and Manford 1974). The present study was conducted to comparatively evaluate the age-, height- and weight-based formula for ETT size prediction in paediatric patients.

In this study, final ETT size of 4.5 mm, 5 mm, 5.5 mm, 6 mm and 6.5 mm was used in patients with mean age of 1.69 ± 0.99 years, 3.3 ± 0.54 years, 5.13 ± 0.48 years, 6.96 ± 1.31 years and 9.25 ± 1.41 years, respectively. The findings are similar to those of Keep and Manford who compared reliability of age, height and weight measurements for correct ETT size which was assessed by means of laryngeal sound (Keep and Manford 1974). In contrast, Turkistani, Abdullah, Delvi and Al-Mazroua have reported use of smaller ETT size of 4.5, 5.0. 5.5 and 6.0 mm ID for higher mean age of 4.05, 4.85, 6.65 and 8.22 years, respectively (Turkistani et al. 2009). The difference is most likely due to difference in leak pressure accepted in the two studies.

Turkistani, Abdullah, Delvi and Al-Mazroua reported accuracy of 86.0% in prediction of ETT size by ABF, but unlike the present study, they reported no under-prediction and only over-prediction in the remaining 14.0% of the patients (Turkistani et al. 2009). King, Baker, Braitman, Seidl-Friedman and Schreiner have also reported a very high accuracy of prediction of ETT size with ABF (97.5%) (King et al. 1993). However, they considered a wider range of size, 0.5 mm smaller to 1.0 mm larger as clinically acceptable ETT. In contrast, a

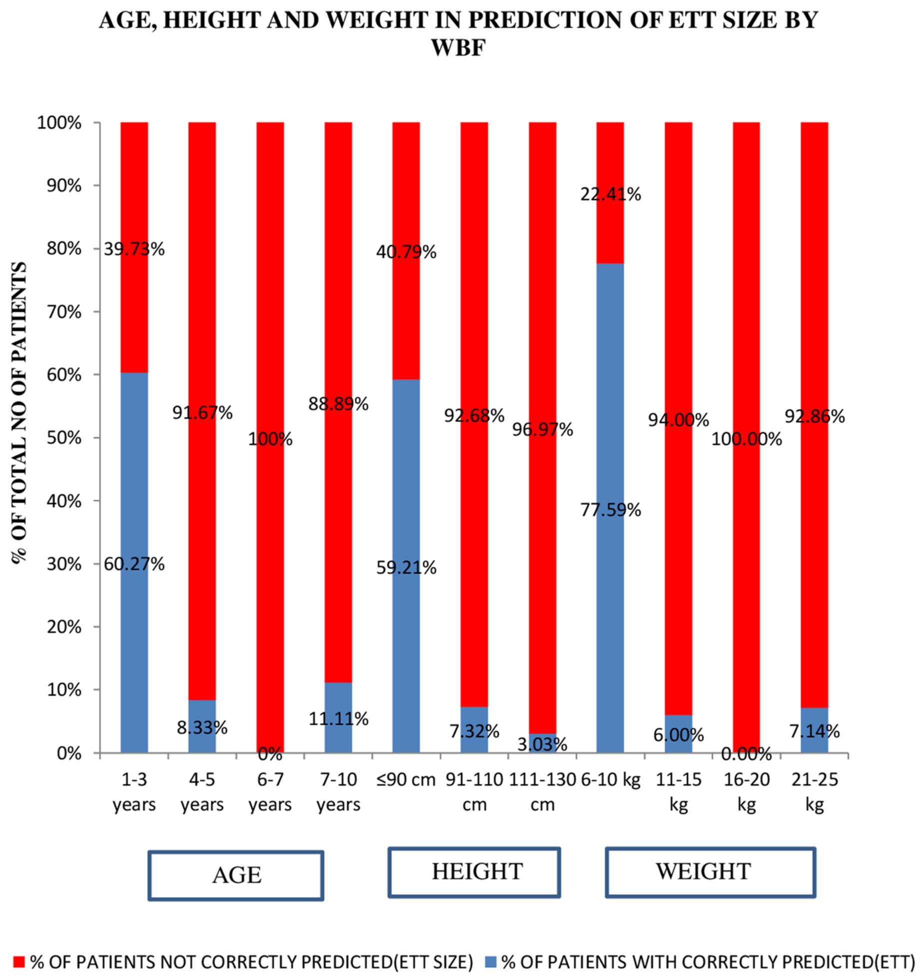

Fig. 4 Association of demographic characteristics in prediction accuracy of ETT size by weight-based formula (WBF)

Table 2 Correlation coefficient of ETT size predicted by ABF, HBF and WBF with final ETT size

	Correlation coefficient	95% *CI* (confidence interval)	*p*-value
ABF	0.942	0.887–0.996	< 0.0001
HBF	0.968	0.937–0.999	< 0.0001
WBF	0.874	0.794–0.953	< 0.0001

ETT Endotracheal tube, *ABF* Age-based formula, *HBF* Height-based formula, *WBF* Weight-based formula

Table 3 Measure of agreement (kappa value)

	Kappa value	*p*-value
ABF	0.663	< 0.0001
HBF	0.849	< 0.0001
WBF	0.083	< 0.0001

ABF Age-based formula, *HBF* Height-based formula, *WBF* Weight-based formula

lower accuracy with ABF has been reported in various studies (Gnanaprakasam and Selvaraj 2017; Hofer et al. 2002) with reporting predominantly over-prediction (Hofer et al. 2002; Berg and Mphanza 1997). WBF was found to be least effective in predicting correct ETT size in most of the studies (Eipe et al. 2009; Keep and Manford 1974).

Similar to our findings an accuracy of > 80% for HBF in prediction of ETT size in age groups of 1–3 years has been reported by Shih, Chung, Su, Hung, Wong and Wong (Shih et al. 2008). Few researchers have reported a lower accuracy with HBF with the error to be predominantly over-prediction (Turkistani et al. 2009; Subramanian et al. 2018).

No other studies reviewed have commented on relationship of HBF with various age, height and weight subgroups. To our knowledge, none of the studies reviewed ABF and WBF with different age, height and weight subgroups.

While comparing the correlation coefficient, few studies have reported correlation value of more than 0.8 for HBF as well as ABF (Turkistani et al. 2009; Subramanian et al. 2018). Much lesser but strong correlation of 0.77 between ABF and ETT size has been reported by Eipe, Barrowman, Writer and Doherty (Eipe et al. 2009). Similar to our results, they also found ABF to be a better predictor of ETT size than WBF (51.3% accuracy vs 44.8%). We also found HBF to be better than ABF and WBF in predicting ETT size.

Though Shih, Chung, Su, Hung, Wong and Wong concluded that HBF had high accuracy in predicting appropriate ETT size in children, they did not subject their data to Cohen's kappa analysis (Shih et al. 2008). In our study, strength of agreement between ETT size predicted by ABF with final ETT size was good and significant with kappa value of 0.663 (p < 0.05), very low kappa value (0.083) for strength of agreement between ETT size predicted by WBF and final ETT, indicating poor measure of agreement yet statistically significant (p < 0.05). The findings of Eipe, Barrowman, Writer and Doherty are different (Eipe et al. 2009). They reported a much lesser kappa value of 0.35 for ABF, indicating poor agreement between ABF and final ETT size, and a kappa value of 0.27 for WBF, indicating fair measure of agreement between actual ETT size used and tube size predicted by WBF but still lesser than ABF.

Regarding postoperative complications, Koka, Jeon, Andre and MacKAY have reported incidence of 1% croup in their study group (Koka et al. 1977). Among those who developed croup, tight fitting endotracheal tube was found to be responsible in 50%; change in position while intubated was responsible in 25%. Other factors leading to croup were reported to be age > 1 year (97.5%), more than one attempt at intubation (21.25%), duration of intubation greater than 1 h (87.5%) and operation in the neck (11.25%). They further reported cough to be responsible in 46.2% patients developing post-operative croup. In our study, two patients (1.33%) developed laryngospasm after extubation. In both patients, tube size was satisfactory after first intubation, and no change of tube was required. In both cases, the duration of intubation exceeded 1 h. More than one compounding factors as described by Koka, Jeon, Andre and MacKAY were noted in 8 patients who developed cough. These included a change in ETT, prolonged duration of surgery and surgery in the neck region. Lee, Templeton and Dougal have reported an overall incidence of 7.6% croup in children undergoing tracheal intubation (Lee et al. 1980). They further remarked that this incidence rises to 30% in patients who give a history of past intubation and croup.

There are few limitations of this research. Firstly, the study was conducted for uncuffed tubes as the microcuffed tubes were unavailable at our centre at the time of planning and execution of this study. Our findings may prove useful at the various centres especially in developing countries, where uncuffed tubes are still being used and the microcuffed tubes and cuff pressure monitor are unavailable due to cost constraints. Further research is required to extrapolate our findings to select the appropriate size microcuffed tube. Secondly, there were predominantly male subjects in the study (82.67%). Other studies have also encountered male preponderance as most of the elective surgeries in paediatric age group are done for genitourinary and gastrointestinal disorders which are more common in males (Subramanian et al. 2018; Ajao and Adeniran 2022; Obili et al. 2020). Thirdly, we selected HBF for selecting the initial ETT size which incidentally came out to be the best predictor. There is a possibility of multiple attempts at intubation for placing the appropriate size tube if we would have selected ABF or WBF as the initial formula.

Conclusions

HBF is the best predictor of ETT size across all age groups with marginal superiority over ABF, especially in age group < 3 years. WBF was least effective in predicting ideal ETT size. It is recommended that HBF should be preferred over ABF and WBF for selection of ETT size in paediatric patients. This practice assumes greater importance especially in emergency situations where exact age and weight cannot be ascertained while height is easily obtainable.

Abbreviations

ETT	Endotracheal tube
HBF	Height-based formula
ABF	Age-based formula
WBF	Weight-based formula
ID	Internal diameter
CO_2	Carbon dioxide
USG	Ultrasonography
OR	Operating room

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None.

Authors' contributions

MP, PK and SS designed the study. SS, MP, AG and PGV performed endotracheal intubation and collected the data. SS, MP and PK analysed and interpreted the patient data regarding the formula for correct size of endotracheal tube. SS, AG and PGV were involved in relevant literature search. SS, MP and PK prepared the manuscript, while it was edited by AG and PGV. MP, PGV and AG were major contributor in writing the manuscript. All authors read and approved the final manuscript.

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Nil.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Approval was taken from the Institutional Review Board of Lady Hardinge Medical College (LHMC). The Ethics Committee of Human Research, LHMC gave clearance for conducting the research (LHMC/ECHR/2017/166). The trial was further registered with CTRI (Clinical Trials Registry - India). Trial registration: CTRI, CTRI/2018/05/013755. Registered 08 May 2018. Written and informed consent was taken individually from the parent/ legal guardian of each study participant (study age group is 1-10 years). Written and informed consent was provided by the parent/ legal guardian of all study participant.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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