Original Article

# Derivation and validation of a formula for paediatric tracheal tube size using bootstrap resampling procedure


**Address for correspondence:**
Prof. Sandhya Yaddanapudi, Department of Anaesthesia and Intensive Care, Postgraduate Institute of Medical Education and Research, Sector 12, Chandigarh - 160 012, India.
E-mail: sandhya.yaddanapudi@gmail.com

*M Ganesh Kumar, Meenakshi Atteri[1], Yatindra K Batra[2], Lakshminarayana Yaddanapudi, Sandhya Yaddanapudi*

Department of Anaesthesia and Intensive Care, Postgraduate Institute of Medical Education and Research, Chandigarh, [2]Department of Anaesthesia and Pain Management, Max Superspeciality Hospital, Mohali, Punjab, India, [1]Department of Anesthesiology and Pain Management, John H Stroger Jr Hospital of Cook County, Chicago, IL, USA



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## ABSTRACT

**Background and Aims:** The accuracy of age-, length- and weight-based formulae to predict optimal size of uncuffed tracheal tubes (TTs) in children varies widely. We determined the accuracy of age, length and weight in predicting the size of TT in Indian children, and derived and validated a formula using the best predictor. **Methods:** In the derivation phase, 100 children aged 1-8 years undergoing general anaesthesia and tracheal intubation with an uncuffed tube were prospectively studied. The correct size of the TT used was confirmed using the leak test. A bootstrap resampling procedure was used to estimate the accuracy of the predictors (age, weight, or length alone; length and age; length and weight; and length, weight and age). The best predictor was used to derive a formula (Paediatric Tube Size Predictor, PTSP) to calculate the size of TT. The accuracy of PTSP was tested in 150 children of the same age group in the validation phase. **Results:** Length (L (in meters), $R^2$ = 0.61) was the best single predictor of the size of TT and was used to derive the PTSP as internal diameter = 3L + 2.5. In the validation phase, the PTSP predicted the size of TT correctly in 75% of children. Re-intubation was associated with a higher incidence of respiratory morbidity than one-time tracheal intubation. **Conclusion:** Length of the child predicts the size of an uncuffed TT better than age and weight. The PTSP formula based on length correctly predicts the size of uncuffed TT in 75% of children.



**Key words:** Anaesthesia, body height, endotracheal, intratracheal, intubation, paediatric, tracheal tube size


## INTRODUCTION

Choosing the optimum size of tracheal tube (TT) is essential in children as a larger tube may cause decreased mucosal perfusion and trauma to the airways, while a smaller tube can result in imprecise monitoring of respiratory mechanics and end-tidal $CO_2$, increased pollution of the operating room, and increased cost due to greater consumption of volatile agents.[1,2] The ideal sized TT is the widest tube which passes through the trachea easily and smoothly, and allows a small leak.[3] Correct prediction of TT size also decreases the number of TT changes required to obtain the optimum size.

A number of methods have been used to determine the optimum size of TT in children, including formulae using physical characteristics of the child (age, length, weight, size of finger or finger nail), singly or in combination, radiograph of the neck, and




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more recently subglottic diameter of the airway using ultrasound.[4-8] An ideal method would be one which is easy to use clinically, and at the same time has a high accuracy. Multivariate formulae are usually more accurate but require complex calculations and hence are difficult to use in day-to-day practice.[9] Ultrasound also determines the tracheal size accurately, but is not universally available, specially outside the operation theatre, and predicts the outer and not the inner diameter of the TT.[8]

Formulae based on a single parameter remain easiest to use clinically, though their accuracy varies widely across different studies. This variation may be due to differences in the type of study (retrospective or prospective), method used to assess optimum size, and differences in ethnicity, body habitus, and nutritional status, among others. Correct prediction of TT size by a widely used age-based formula (inner diameter in mm [ID] = [age in years/4] + 4, a modification of the Cole's formula),[10] varies from as low as 31% to as high as 86%.[4,11] Prediction of TT size based on length varies from 55% in European children using Broselow tape,[12] to 82% in Chinese children using the formula ID = 2 + (height in cm/30).[13] Body weight has also been used occasionally to predict the size of TT[14] but has low accuracy (45%).[5]

The primary aim of the present study was to prospectively evaluate age, length and weight as predictors for the size of uncuffed TT in Indian children. The secondary aims were to use the best predictor to derive a new formula to calculate the size of TT and validate the derived formula in another set of children.

## METHODS

A prospective study was conducted in two phases in children aged 1-8 years undergoing surgery requiring general anaesthesia with tracheal intubation. Approval of the Institute Ethics Committee and written informed consent from the parent/guardian of the children was obtained. A total of 110 children were included in the derivation phase of the study from January 2011 to May 2011. Children with known or suspected airway anomalies or use of exceptional TT sizes in previous anaesthetics were excluded. Children in whom the anaesthesiologist planned to use a cuffed TT were not included. Age, length and weight of all the children were recorded preoperatively. Age was rounded to the nearest half year. Weight and length were measured to the accuracy of one decimal place. Length was measured using an infantometer for children unable to stand without support. For older children standing height was measured using a right-angled wooden plank and a measuring tape.

Institutional fasting and premedication protocols were followed. Intraoperative monitoring included the standard ASA recommendations. Anaesthesia was induced with sevoflurane or thiopentone (3-5 mg/kg). Tracheal intubation was facilitated with atracurium (0.5 mg/kg). A polyvinylchloride (PVC) uncuffed TT (Smiths Medical International Ltd., Kent, UK) was used and its correct position was confirmed by capnography and auscultation of bilateral breath sounds. The size of the TT used was selected by the attending anaesthesiologist. The accuracy of the size of the tube used was assessed using the standard leak test with the patient supine and the head in neutral position. The size was considered appropriate if the TT passed smoothly through the glottis and allowed minimal air leak. The leak was assessed by auscultation over the trachea using a stethoscope after closing the APL valve and allowing the airway pressure to rise. If there was air leak at a pressure of 10 $cmH_2O$ or less, the TT was replaced with a one size larger tube. If leak occurred at pressures between 10 and 20 $cmH_2O$, the tube size was acceptable. If there was no air leak even at 20 $cmH_2O$ or if the tube did not easily pass through the glottis, the TT was replaced with a tube one size smaller. The ID of the TT finally used was recorded. If the attending anaesthesiologist decided to use a cuffed tube or a throat pack instead of using a larger tube to prevent the air leak, the case was excluded from analysis.

Anaesthesia was maintained with isoflurane/halothane in $O_2/N_2O$ gas mixture. Children were ventilated with pressure or volume control mode of ventilation, peak inspiratory pressure of 10-15 $cmH_2O$, tidal volume of 7-10 ml/kg, breathing frequency according to patient's age to maintain end-tidal $CO_2$ of 35-40 mm Hg. After completion of surgery, the inhalation agent and $N_2O$ were stopped, and neostigmine (50 μg/kg) and glycopyrolate (10 μg/kg) were used to reverse the neuromuscular blockade. The trachea was extubated when the child was awake and breathing adequately. Patients were shifted to the post-anaesthesia care unit and observed for 2 hours for cough, hoarseness of voice and any complaints of sore throat.

Six models to predict the required tube size were assessed using the following predictors: age alone (A);

weight alone (W); length alone (L); length and age (LA); length and weight (LW); length, weight and age (LWA). A bootstrap resampling procedure with 1000 iterations was used to select the model with the best possible fit to the data out of these six models using the statistical programme R (3.4.2) with the caret package. The model with length as the lone predictor was chosen and a formula (Paediatric Tube Size Predictor, PTSP) was derived from it.

The percentage of correct prediction of the TT size by the following age-, weight- and length-based formulae was calculated and compared using contingency table analysis:

Age-based formula (ABF): ID in mm = (age in years/4) + 4

Length-based formula (LBF): ID in mm = 2 + (height in cm/30)

Weight-based formula (WBF): ID in mm = (weight in kg/10) + 3.5

PTSP was evaluated prospectively in 150 children during the validation phase of the study between February 2014 and October 2014. The same patient selection criteria and the anaesthetic technique were used as in the derivation phase. The size of the TT to be used was calculated using PTSP and rounded to the nearest 0.5 or integer. Assessment of accuracy of tube size was performed using the leak test in the same way as in the derivation phase.

The accuracy of PTSP in predicting the correct TT size was expressed in percentage. A post-hoc analysis was done to compare the accuracy of prediction in younger (1-4 years) and older (>4 years) children using $\chi^2$ test. The incidence of respiratory morbidity in patients who underwent tracheal intubation once was compared with those requiring re-intubation using $\chi^2$ test. A $P$ value $< 0.05$ was considered to be statistically significant.

Sample size estimations for regression analysis are usually not based on $P$ values but on optimising a model fit statistic (usually the $R^2$) and reducing the bias in estimating regression coefficients. The recommendations vary greatly, from 5 subjects per variable (SPV)[15] to 20 SPV[16] to maximise $R^2$. Other recommendations include up to 50 SPV to minimise bias in estimating coefficients based on a simulation study,[17] and a sample size of about 160 for the $R^2$ to stabilise.[18] As we were testing three predictor variables, and had logistic and time constraints, we decided to include about a hundred subjects to develop the model. We had more time for validation of the model and therefore included 150 subjects for this phase.

## RESULTS

A total of 110 children were enrolled in the study during the derivation phase. Of them, 10 children required the use of either a cuffed TT, or a throat pack along with the uncuffed tube, and were excluded from the analysis. The demographic data of these children are shown in Table 1.

The performance metrics of the six models evaluated during the derivation phase are given in Table 2. The best single predictor with the lowest Residual Mean Square Error (RMSE) and Mean Absolute Error (MAE), and highest $R^2$ was Length (L). Adding Age or Weight to Length did not improve the performance of the models. A combination of all three predictors marginally improved the model, but with a great increase in the complexity of the model, making it difficult to use at the bedside. The formula for predicting the tube size from the length-based model was:

$$\text{ID (mm)} = 3 \times \text{L (m)} + 2.6$$

The equation was then simplified for clinical use as follows and labelled as PTSP:

$$\text{ID (mm)} = 3 \times \text{L (m)} + 2.5$$

**Table 1: Demographic data**

| Parameters | Derivation phase (*n*=100) | Validation phase (*n*=150) |
|---|---|---|
| Age (years) | 3.4±1.8 | 3.6±2.3 |
| Weight (kg) | 12.8±3.4 | 13.8±5.5 |
| Length (cm) | 93.0±14.1 | 88.1±16.1 |
| Gender (male:female) | 67:33 (67:33) | 89:61 (59:41) |

Values are expressed as mean±SD or as numbers (%)

**Table 2: Performance metrics of the six models evaluated during the derivation phase using bootstrap resampling procedure**

| Model | RMSE | MAE | $R^2$ |
|---|---|---|---|
| A | 0.33 | 0.25 | 0.52 |
| W | 0.34 | 0.27 | 0.48 |
| L | 0.30 | 0.22 | 0.61 |
| LA | 0.30 | 0.22 | 0.61 |
| LW | 0.30 | 0.22 | 0.61 |
| LWA | 0.29 | 0.21 | 0.62 |

A – Age (in years) alone; W – Weight (in kg) alone; L – Length (in cm) alone; LA – Length and age; LW – Length and weight; LWA – Length, weight and age. RMSE – Residual mean square error; MAE – Mean absolute error; $R^2$ – Square of the Pearson correlation coefficient

In this study, 150 children were enrolled during the validation phase [Table 1]. The PTSP predicted the size of TT correctly in 74.7% (95% CI: 66.9% -81.4%) of children, but under-predicted in 24% and over-predicted in 0.7% of children.

As there appeared to be a difference in the accuracy of the formula in younger and older children on plotting the data, a post-hoc comparison was done between children of age 1-4 years and those older than 4 years. The formula was accurate in significantly higher proportion of younger compared to older children [Table 3].

The standard ABF, WBF and LBF correctly predicted the tube size during the derivation phase in 55% (95% CI: 45.2-64.5), 44% (34.5-53.8) and 67% (57.4-75.7) patients, respectively.

The incidence of postoperative respiratory morbidity, namely, sore throat, cough and hoarseness of voice were significantly higher in children who required re-intubation than those who underwent tracheal intubation only once [Table 4].

## DISCUSSION

Of the three body characteristics assessed, namely, age, length and weight, we found length of the child to predict the size of TT best. Therefore, we used length to derive a new formula, PTSP, to calculate the size of uncuffed TT. We validated this formula in another set of children and found it to be accurate in 75% of children.

We compared the accuracy of the standard ABF, LBF and WBF in predicting the size of TT and found LBF to be the most accurate, followed by ABF, with WBF being the least accurate. There is a wide variation in accuracy of the standard LBF and ABF in the literature. The standard WBF is not used very often and has a low accuracy (45%).[5]

One of the factors affecting the accuracy of LBF could be age. The standard LBF has been observed to be highly accurate (>80%) in children younger than 6 years of age.[12,19] It was somewhat less accurate in our study (67%) where children up to the age of 8 years were included. The accuracy was much less when older children aged 2-10 years (55%-60%) were studied.[4,13] Our formula (PTSP) was also more accurate in children in the age group of 1-4 years (~90%) than in children older than 4 years (50%). Thus LBFs seem to be more accurate in young children up to the age of 4-6 years.

There appears to be some effect of ethnicity too on the accuracy of the standard LBF. It was derived in Chinese children and was more accurate in Asian (Chinese 82%,[13] Korean 87%,[19] and Indian 67% [present study]) than Caucasian children (55%).[12] This effect may be due to the difference in anthropometric measurements of the children based on their ethnicity. Hence LBF derived at regional level is likely to be more accurate in predicting the size of TT than the standard LBF for children of that region.

Unlike LBF, the variation in accuracy of ABF is not easy to explain. In some studies, the standard ABF has correctly predicted the size of TT in a high proportion of children (60%-86%) of variable ages from Asia,[4,8] as well as the US.[20,21] There are other studies from Asia,[9,11] and Europe,[12,22] where the accuracy of ABF was low (24%-47%).

**Table 3: Number (%) [95% CI] of children with correct and incorrect prediction of size of tracheal tube using the PTSP during validation phase**

| Age group | Correct prediction | Incorrect prediction | |
|---|---|---|---|
| | | Under-prediction | Over-prediction |
| All children (*n*=150) | 112 (75) [67-81] | 36 (24) [18-31] | 2 (1) [0-4] |
| Younger children (1-4 years) (*n*=100) | 88 (88) [80-93] | 11 (11) [6-18] | 1 (1) [0-5] |
| Older children (>4 years) (*n*=50) | 24 (48) [34-62] | 25 (50) [36-64] | 1 (2) [0-9] |

PTSP – Paediatric tube size predictor, the formula developed during the derivation phase. Correct prediction in younger vs. older children: $P$<0.001 ($\chi^2$ test)

**Table 4: Number (%) of patients with postoperative respiratory morbidity in relation to tracheal re-intubation**

| Respiratory morbidity | All patients (*n*=259)* | No Re-intubation (*n*=186) | Re-intubation (*n*=73) | $P$ ($\chi^2$ test) (No re-intubation vs. re-intubation) |
|---|---|---|---|---|
| Sore throat | 71 (27.4) | 17 (9.1) | 54 (74.0) | <0.001 |
| Cough | 84 (32.4) | 46 (24.7) | 38 (52.1) | <0.001 |
| Hoarseness | 15 (5.8) | 4 (2.2) | 11 (15.1) | <0.001 |

*In one patient in the derivation phase, the trachea remained intubated at the end of surgery for postoperative ventilation and hence respiratory morbidity could not be assessed

The accuracy of prediction also depends on the method used to detect the optimum size of TT. Generally a leak test at a set pressure is performed to determine the correct TT size. In retrospective studies, the method used to detect the correct TT size is not known.[12,14,23] Even in prospective studies, the leak test may be performed at different pressures; the leak may be assessed by hearing the air leak through the mouth or by auscultation over the trachea using a stethoscope.[11] These differences in methodology can affect the results. We used a standardised leak test at 20 $cmH_2O$ with auscultation over the trachea,[24] which made the selection of the TT objective, thereby reducing the inter-individual variation among the anaesthesiologists.

In case of incorrect prediction of size of TT, under-prediction or prediction of a smaller size, is considered better than over-prediction, as a smaller tube is less likely to cause airway injury than a snugly-fitting larger tube. In the present study, when PTSP did not predict the size of TT correctly: it under-predicted the size in all but two children. On the other hand, the standard LBF over-predicted (18%) more than the under-predict (15%) in our study. As under-prediction appears to be less harmful than the over-prediction, PTSP is better than the standard LBF in this respect.

The proportion of children in whom cuffed TT was used for re-intubation during the validation phase (72%) was significantly higher than those in the derivation phase (19%), indicating the increasing trend in use of cuffed TT in paediatric population.

We studied post-tracheal intubation respiratory morbidities which included sore throat, cough and hoarseness. Sore throat is a subjective finding and therefore it could be accurately elicited in children older than 6 years of age. On the other hand, cough and hoarseness are objective findings and the incidence of these complications is reliable in all ages. Despite this limitation, sore throat was present in a third of our patients in both the phases, which is similar to the incidence (37%) reported earlier.[25] We also found that the children who required re-intubation had a significantly higher incidence of all the respiratory morbidities compared to those requiring tracheal intubation once. It underlines the need to accurately predict the size of TT so that a change of tube is not required to obtain the optimum size. The incidence of re-intubation in the two phases of our study, 31.8% and 25%, is consistent with the re-intubation rates (22%-31%) reported in literature.[20,25,26]

Our study has the following limitations. These results may be applicable to the population of the same ethnicity/geographical residence as that of the study population. Also, the findings of the study are relevant for uncuffed TTs, whereas both uncuffed and cuffed TTs are used in paediatric practice.

The strengths of our study are that it was conducted prospectively and we used objectively defined criteria for determining the correct size of TT. Also, we have compared the commonly used predictors (age, length and weight) in the same population and used the best predictor to develop the formula.

## CONCLUSION

We found length of the child to be a better predictor of the size of uncuffed TTs in children and developed a formula using child's length as: internal diameter of TT = three times the length of the child (m) + 2.5. This correctly predicted the uncuffed TT size in 75% of children aged 1-8 years. This formula now needs to be validated in other parts of the country.

### Previous presentations

First part of the manuscript was presented at (1) European Society for Paediatric Anaesthesiology Congress, Geneva, 5-7 September 2013 and second part at (2) Seventh National Conference of Indian Association of Paediatric Anaesthesiologists, Chandigarh, 20-22 February 2015.

### Ethical approval

Ethical approval was obtained from the Institute Ethics Committee, Postgraduate Institute of Medical Education and Research, Chandigarh, India (NK/1080/MD/13502-503, date 10 September 2013).

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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