Recommendations for endotracheal tube insertion depths in children

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ABSTRACT

Background Endotracheal tube (ETT) malposition is frequent in paediatric intubation. The current recommendations for ETT insertion depths are based on formulae that hold various limitations. This study aimed to develop age-based, weight-based and height-based curve charts and tables for ETT insertion depth recommendations in children.

Methods In this retrospective single-centre study, we determined the individual optimal ETT insertion depths in paediatric patients by evaluating postintubation radiographic images. Age-based, weight-based and height-based ETT insertion depth recommendations were developed using regression analysis. We compared the insertion depths predicted by the models with previously published formulae.

Results Intubations of 167 children (0–17.9 years) were analysed. Best-fit curves generated with logistic regression analysis revealed R^2 values between 0.784 and 0.880. The insertion depths predicted by the models corresponded well with published age-based and height-based formulae. However, they demonstrated the unsuitability of weight-related linear formulae to predict ETT depth in children.

Conclusion The recommendations developed in this study facilitate a fast and accurate determination of recommended ETT insertion depths in children. Our recommendations provide greater accuracy than previously published formulae and demonstrate that weight-related linear formulae are unsuitable for predicting ETT depth in children.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The incidence of endotracheal tube (ETT) malposition in children is significant.
⇒ Published linear formulae to predict the correct ETT insertion depth do not account for the non-linear growth of children.

WHAT THIS STUDY ADDS

⇒ We calculated accurate insertion ETT depth recommendations using non-linear regression analysis.
⇒ Our recommendations demonstrate that weight-related linear formulae are unsuitable for predicting ETT insertion depth in children.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Developed curves and tables have the potential to facilitate a fast and accurate determination of ETT insertion depths in children.
⇒ Clinicians should use age-based and height-based formulae rather than weight-related linear formulae to predict ETT insertion depth in children.

INTRODUCTION

Endotracheal intubation in children is a crucial procedure in the prehospital setting, emergency department, intensive care unit and before surgery. Precise positioning of the endotracheal tube (ETT) is essential to reduce the incidence of complications, including atelectasis, pneumothorax, tracheal damage, unplanned extubation and postextubation stridor.[1] The gold standard for confirming the correct ETT position is chest radiography.[2 3] Nevertheless, as prompt postintubation ventilation is mandatory and instant bedside radiography is not consistently available, methods to reliably estimate the optimal ETT insertion depth are required. Numerous formulae, most of which refer to the patient's age or weight, have been proposed to estimate the correct depth of tube placement within the trachea in children.[4–11] Unfortunately, commonly used formulae for ETT insertion depth lack optimum accuracy, resulting in a significant incidence of ETT malposition.[12 13] A formula-based approach may be unreliable because it relies on linear equations. Paediatric growth, however, does not follow a linear relationship, so the ETT insertion depth is unlikely to be optimally predicted by a linear formula.[14 15]

This study's aim was to develop and compare age-based, weight-based and height-based recommendations for correct ETT insertion depths in children.

METHODS

Study design and subjects

We retrospectively evaluated the CXRs of intubated paediatric patients older than 28 days admitted to our University Medical Centre's paediatric intensive care unit from January 2017 to August 2020. All clinical patient data were obtained from the hospital's healthcare information systems (Soarian, Siemens Healthcare, Erlangen, Germany; ICM, Draeger, Luebeck, Germany). Extracted information included sex, age, weight, height, intubation route and ETT insertion depth. ETT depth was documented from the front teeth. Our institutional policy is to intubate neonates via the nasotracheal route. Therefore, we included only children older

Table 1 Age-based, weight-based and height-based categories with the corresponding optimal ETT tip-to-carina distance

Category	Age (years)	Weight (kg)	Height (cm)	Average tracheal length (cm)	Optimal ETT tip-to-carina distance (cm)
1	0–0.25	>3–6	>48–60	4.2	1.4
2	>0.25–2.0	>6–12	>60–88	5.1	1.7
3	>2–4	>12–16	>88–105	6.4	2.1
4	>4–10	>16–35	>105–140	8.0	2.7
5	>10–14	>35–50	>140–165	10.0	3.3
6	>14–18	>50	>165	12.0	4.0

The optimal ETT tip-to-carina distance is defined based on the average tracheal lengths determined by Griscom and Wohl and Luscan *et al*; Conrardy *et al* recommend a target ETT tip position between the middle third and distal third of the trachea.[14–16]

than 28 days in this study evaluating orotracheal ETT depth. Patients with airway anomalies or a tracheostomy were excluded.

Intubation was performed with cuffed tubes (Novo Klinik-Service, Bergheim, Germany). Postintubation chest radiography was routinely performed in all children. Our institutional policy is to obtain radiographs in an anterior–posterior position, with the child's head in a neutral position. The tip-to-carina distances were independently measured on the radiograph images by two different investigators. Interobserver discrepancies were resolved by re-evaluation. Patients were excluded if the radiograph's quality was insufficient to identify the exact tip position.

Based on data from Griscom and Wohl and Luscan *et al*, who measured tracheal lengths in children, optimal ETT tip-to-carina distances were categorised into different age, weight and height groups (table 1).[14 15] The patients were allocated to these predefined categories for each age, weight and height to develop regression models. Following the recommendations of Conrardy *et al*, the target ETT tip position was between the middle third and distal third of the trachea to ensure a margin of safety during neck extension or flexion.[16] To determine the individual optimal ETT insertion depth for each patient, the difference between the ETT tip position on the radiography and the optimal position defined by table 1 was added or subtracted from the recorded insertion depth accordingly. To exclude cluster effects in patients who underwent multiple intubations, only the first episode was included in the analysis.

Statistical analysis

Patient demographic data were expressed as the median and range for continuous variables and as counts and percentages for categorical variables. The individual optimal ETT insertion depth was plotted against age, weight and height for all children. The best-fit curves for proposed ETT insertion depths were calculated using a regression analysis for each of the following predictors: age, weight and height. A four-parameter logistic regression model generated best-fit curves with the highest accuracy.[17] Four-parameter logistic regression is a model that employs four parameters (minimum value, maximum value, point of inflection and Hill slope) to generate a best-fit curve. Ninety-five per cent prediction intervals were generated to enclose the area that includes 95% of future data points. The goodness-of-fit for each regression analysis was determined by calculating R^2 values. The target ETT insertion depths generated in this study and previously published recommendations were plotted for comparison.

Statistical analysis was undertaken using SPPS V.27 and GraphPad Prism V.9 (GraphPad, La Jolla, California, USA).

Patient and public involvement

Patients or the public was not involved in the design, conduct, reporting or dissemination plans of this retrospective study.

RESULTS

Demographic characteristics

The data of 167 intubated children (age range: 0–17.9 years) were analysed. The basic demographic characteristics are shown in table 2.

Best-fit curves and tables for proposed ETT insertion depth

The determined optimal ETT insertion depth for each patient plotted against age, weight and height and the best-fit curves generated with logistic regression analysis are presented in figure 1. Significant differences in the determined optimal ETT insertion depths between male and female genders were observed in children older than 13 years and weighing more than 40 kg. No significant differences between male and female children were observed in ETT depths based on height.

The R^2 values revealed a more accurate fit for the regression models for height-related curves than age-related or weight-related curves (figure 1). Therefore, values for the recommendation of height-based ETT insertion depths interpolated from the best-fit curves are presented in table 3.

Comparison of the proposed ETT insertion depth curve charts with historical formulae

Five previously published formulae for ETT depth estimation (table 4) were compared with our curves (figure 2).

Table 2 Patient characteristics of 167 children included in this study

Age group	Female, n (%)	Weight (kg)	Height (cm)	ETT diameter (mm)
1 month–4 years (n=45)	22 (44.4)	10.2 (3.1–25.0)	80 (51–108)	4.0 (3.0–5.0)
>4–10 years (n=39)	20 (51.3)	20.0 (11.4–42.0)	116 (80–143)	5.0 (3.5–6.0)
>10–14 years (n=43)	20 (46.5)	40.0 (20.0–80.0)	151 (120–171)	6.0 (5.0–7.5)
>14–<18 years (n=40)	21 (52.5)	60.0 (35.0–100)	165 (145–185)	7.0 (5.0–8.0)

Values are given as the median (range) unless stated otherwise.
ETT, endotracheal tube.

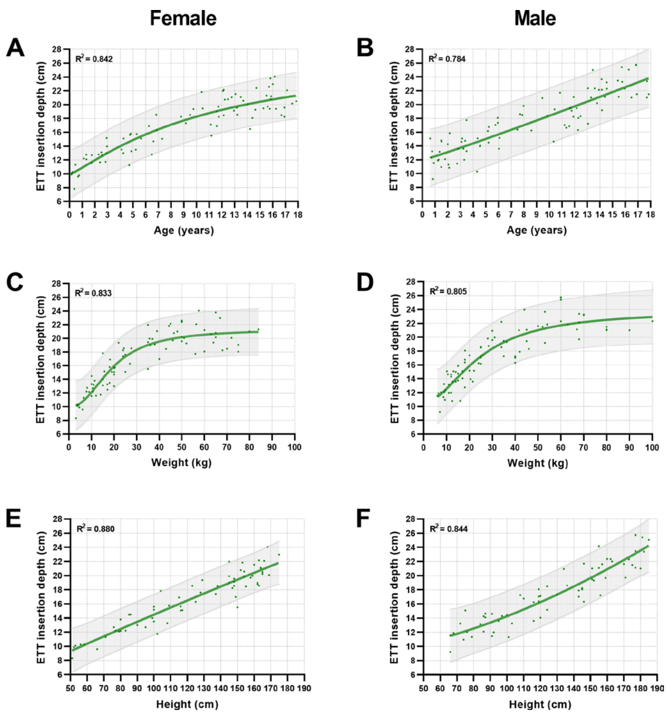

Figure 1 Relationship between age (A,B), weight (C,D), height (E,F) and proposed ETT insertion depth in children. Best-fit curves and 95% prediction bands were generated using non-linear regression models. ETT, endotracheal tube.

The age-based formulae demonstrate high proximity to our curves. However, the line of the PALS formula is closer to ours in infants aged 1–4 years, and the formula by Lau *et al* is closer to ours in children older than 4 years (figure 2A). Compared with our corresponding curve, the weight-based formula for orotracheal intubation by Morgan and Steward fits well with our curve in children weighing 20–40 kg but increasingly overestimates the ETT insertion depth in children weighing more than 40 kg (figure 2B).[18] The height-based formulae by Lee *et al* and Morgan and Steward demonstrate decent proximity to our corresponding curve (figure 2C).[8 18]

DISCUSSION

ETT malposition after intubation remains a frequent event within the paediatric population. We present recommendations for ETT insertion depths based on a dataset of children calculated using a logistic regression model.

The goodness-of-fit of the generated best-fit curves, represented by the R^2 value, varied depending on the associated anthropometric parameter. The best accuracy was observed in the height-based curve charts (R^2=0.844–0.880) compared with the weight-based (R^2=0.805–0.833) or age-based (R^2=0.784–0.842) estimations. An advantage of the height-based approach is its potential to compensate for growth discrepancies related to gender, race and congenital or chronic diseases. Also, one advantage of using height is that it can easily be measured using the Broselow tape.[19]

Various methods based on age, weight, height and ETT ID have been described to predict accurate tube positioning.[6–11] A characteristic all published formulae share is that the generated equations assume a linear relationship between the dependent variable and the length of the upper airways. However, figure 1 demonstrates a non-linear correlation of the proposed

Table 3 Data table with height-related ETT insertion depth recommendations interpolated from the corresponding best-fit curves

Height range (cm)	ETT depth (cm)
43–48	9.5
49–54	10.0
55–60	10.5
61–66	11.0
67–72	11.5
73–78	12.0
79–83	12.5
84–89	13.0
90–94	13.5
95–99	14.0
100–104	14.5
105–109	15.0
110–114	15.5
115–119	16.0
120–123	16.5
124–128	17.0
192–133	17.5
134–137	18.0
138–142	18.5
143–146	19.0
147–151	19.5
152–155	20.0
156–160	20.5
161–164	21.0
165–168	21.5
169–173	22.0
174–177	22.5
178–181	23.0
182–185	23.5

ETT, endotracheal tube.

ETT insertion depth with increasing age, weight and height. Consequently, linear formulae are reliable only during a limited child development period and induce considerable malposition rates.[12 13 20]

We compared our chart curves with five previously published formulae for orotracheal intubation based on anthropometric parameters in children from 4 weeks to 16 years (figure 2). Age-based and height-based formulae corresponded well with our chart curves and remained within our 95% prediction bands. We observed an underestimation with the PALS formula in children over 4 years.[9] These discrepancies should be considered when applying the PALS recommendations or the Broselow

Table 4 Formulae for the estimation of the accurate orotracheal ETT insertion depth in children

Authors, year	Study cohort, n, range	Target age group	Formula (cm)
Morgan and Steward, 1982[18]	50, 3–16 years	All ages	Height (cm)×0.1+5
		All ages	Weight (kg)÷5+12
PALS guidelines, 2000[9]	No information available	>1 year	Age (years)÷2+12
Lau *et al*, 2006[6]	85, 1 –15 years	>1 year	Age (years)÷2+13
Lee *et al*, 2018[8]	813, 1–15 years	>1 year	Height (cm)×0.1+3

PALS, Paediatric Advanced Life Support.

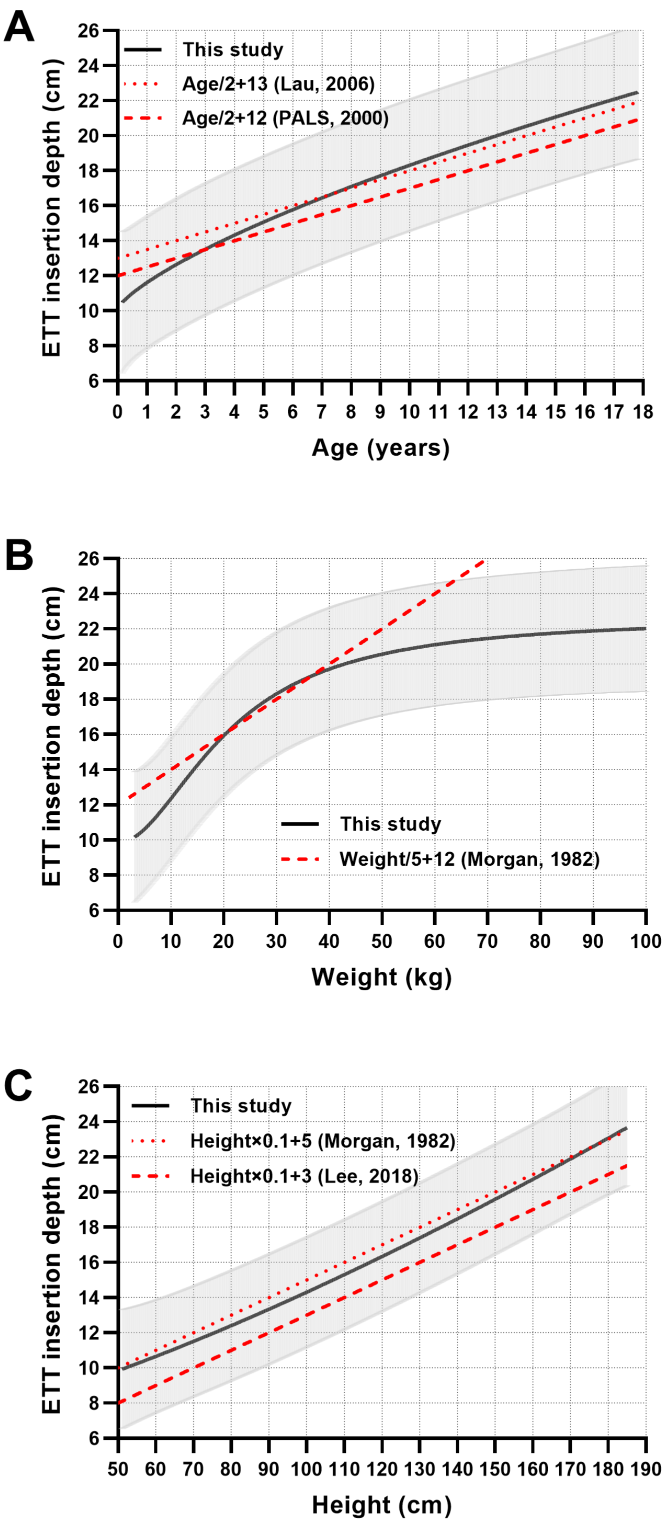

Figure 2 Comparison between our generated curve charts with 95% prediction bands and published formulae for the recommendation of ETT tip insertion depths in children. ETT, endotracheal tube.

tape.[19] Also, the formula by Morgan and Steward demonstrated an underestimation in all height groups, which is in line with a study by Hunyady *et al*, who found that this formula would have resulted in ETT malposition in 21% of the infants studied.[18 21] When plotted against the corresponding generated curve chart, the weight-based formula by Morgan and Steward showed an acceptable accuracy during a limited weight range, which underlines the unsuitability of weight-related linear formulae.[18]

Various formulae based on the ETT internal diameter (ID) have also been published, with the most commonly used being ETT ID (mm)×3 for orotracheal intubation.[9] However, such formulae rely on the appropriate tube diameter being selected, and as ETT diameters are available in 5 mm intervals, ETT depth intervals calculated with these formulae have a minimum step interval of 15 mm. This represents a considerable distance, especially in small infants.

This study has some limitations. Rather than defining individual optimal ETT depths, children were allocated to six categories. Also, the recommended ETT depth for a child can slightly differ, depending on the anthropometric parameter (age, weight and length) referred to. Although it is part of clinical routine to conduct CXRs with the head in a neutral position, the degree of the head–neck flexion in this retrospective study could not be verified.

The charts and table presented in this study facilitate a rapid estimation of ETT insertion depths and can serve as an initial guiding tool for intubation in paediatric patients. However, they do not substitute for evaluating the correct ETT placement by visualisation of thoracic movement and auscultating the chest and epigastrium. Chest radiography remains the gold standard for ETT position confirmation. The recommendations provide greater accuracy than previously published formulae. However, the accuracy and performance of the recommended tools require prospective validation.

Contributors CUE: conceptualisation, methodology, formal analysis, writing of the original draft and project administration; KS: methodology, formal analysis and investigation; SA, MW, JH and DS: visualisation and writing (review and editing); PD: methodology, formal analysis, writing (review and editing), supervision and project administration. CUE is the guarantor.

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Patient consent for publication Not applicable.

Ethics approval This study involves human participants, and ethical approval (WF-x159/20) was provided by the ethical committee of the Medical Chamber of Hamburg, Germany.This was a retrospective study with anonymised data. Consent for participation was not required by the ethical committee.

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