

Front Teeth–to–Carina Distance in Children Undergoing Cardiac Catheterization

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Background: **Knowledge of normal front teeth–to–carina distance (FT-C) might prevent accidental bronchial intubation. The aim of the current study was to measure FT-C and to examine whether the Morgan formula for oral intubation depth, *i.e.*, endotracheal tube (ETT) position at front teeth (cm) = 0.10 × height (cm) + 5, gives appropriate guidance when intubating children of different ages.**

Methods: **FT-C was measured in 170 infants and children, aged 1 day to 19 yr, undergoing cardiac catheterization. FT-C was obtained as the sum of the ETT length at the upper front teeth/dental ridge and the distance from the ETT tip to the carina. The latter measure was taken from an anterior–posterior chest x-ray.**

Results: **There was close linear correlation between FT-C and height: FT-C (cm) = 0.12 × height (cm) + 5.2, R^2 = 0.98. The linear correlation coefficients (R^2) for FT-C *versus* weight and age were 0.78 and 0.91, respectively. If the Morgan formula had been used for intubation, the ETT tip would have been at 90 ± 4% of FT-C. No patient would have been bronchially intubated, but the ETT tip would have been less than 0.5 cm from the carina in 13 infants.**

Conclusions: **FT-C can be well predicted from the height/length of the child. The Morgan formula provides good guidance for intubation in children but can result in a distal ETT tip position in small infants. Careful auscultation is necessary to ensure correct tube position.**

TRACHEAL intubation is usually guided by direct visualization, and the endotracheal tube (ETT) is advanced until an appropriate depth marking is at the level of the vocal cords. Still, too-distal ETT placement is not uncommon, especially if the intubation is performed by less experienced practitioners.[1] In absence of radiographic confirmation, knowledge of normal upper front teeth–to–carina distance (FT-C) might be helpful in preventing bronchial intubation. We therefore measured FT-C in children of different ages. A second objective of the study was to examine whether the guideline for intubation depth suggested by Morgan and Steward[2] for children older than 4 yr—ETT position at upper front teeth (cm) = 0. 1 × height (cm) + 5 (the Morgan formula)—is also useful in young children and infants.

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Materials and Methods

Orally intubated children undergoing cardiac catheterization during anesthesia with or without muscle paralysis were included in the study. All patients were mechanically ventilated with pressure-controlled ventilation set at a peak end-inspiratory pressure of 11–23 cm H_2O, a rate of 13–45/min, a positive end-expiratory pressure of 3–5 cm, and a fraction of inspired oxygen of 0.21–1.0. The patients were supine and faced straight upward or 15°–45° laterally. The length mark of the ETT (Mallinckrodt Inc., Hazelwood, MO) at the upper front teeth/dental ridge (A) was recorded, and the distance from the ETT tip to the carina (B) was measured on an anterior–posterior chest x-ray, using the outer diameter of the ETT as reference (fig. 1). FT-C was calculated as A + B. If the resolution of the printed image did not allow precise identification of the structures, the higher resolution cine images were reviewed for guidance. Weight, height, and age were obtained from the patient's chart. The study was approved by the institutional review board at Children's Hospital and Regional Medical Center, Seattle, Washington, and the requirement for written informed consent was waived.

Because the outer diameter of the endotracheal tube was used as reference for the B measurement, parallax errors due to x-ray "spread" were negligible,[3] but parallax errors due to the trachea not being exactly perpendicular to the anterior–posterior plane might be important. To estimate the latter error, the angle between the trachea and the horizontal plane was measured in 20 patients, aged 7 days to 10 yr, in whom lateral images had been obtained as part of the catheterization procedure. The angle between the trachea and the horizontal plane was 4°–26° (median, 16°). If the largest angle (26°) had been present in all study patients, it would have resulted in an underestimation of FT-C of 0.1–2.7% (median, 1.2%). No correction was made for this in the data.

Statistical Analysis

Statistical analysis was performed with Stata/SE 9.0 software (Stata Corporation, College Station, TX). Unless otherwise indicated, data in the text are mean ± SD. Using the method of least sum of squares, linear regression equations and 95% prediction interval bands were calculated for FT-C *versus* height, weight, and age, respectively. Multiple regression analysis was used to as-

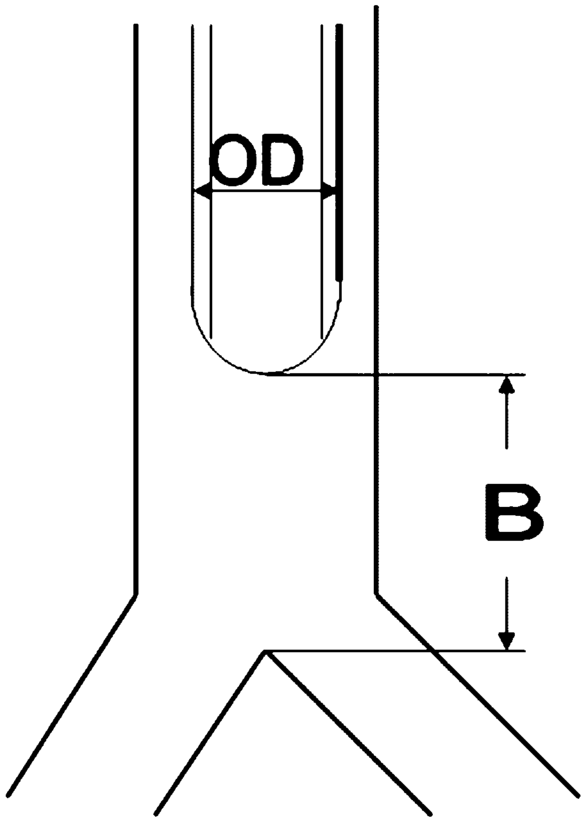

Fig. 1. The outer diameter (OD) of the endotracheal tube was used as reference when measuring the distance from the endotracheal tip to the carina (B).

sess whether adding factors for sex, or a diagnosis associated with unusual airway features, would improve the linear regression model. *P* values less than 0.05 were considered statistically significant.

Results

Measurements were obtained in 170 patients aged 1 day to 19 yr. Sixty-two patients were younger than 1 yr, and 26 were younger than 1 month. Patient characteristics for all patients and for the infant subgroup are summarized in table 1. A cuffed ETT was present during 162 of the measurements.

When compared with standard growth charts,‖ 36% and 45% of the patients were below the 25th percentile for height and weight, respectively. The deviation from normal growth was most noticeable in the infant subgroup, where 60% were below the 25th percentile for height and 66% were below the 25th percentile for weight. In children aged 1–19 yr, the corresponding figures were 27% for height and 31% for weight.

No patient had severe dental, head, or neck abnormalities or markedly elevated abdominal pressure, but 6 patients had Down syndrome, 1 had DiGeorge syndrome, 1 had Goldenhar syndrome, 1 had velocardiofacial syndrome, 1 had CHARGE syndrome, and 1 had a history of premature birth at 30 weeks of gestation. Multiple regression analysis did not indicate that these 11 patients deviated from the rest of the group, and their measurements were therefore included in the regression analysis, but they have been assigned different symbols in figures 2 and 3.

For the whole group (fig. 2), FT-C *versus* height and FT-C *versus* age were best described by linear regression equations, whereas the best fit model for the FT-C–*versus*–weight relation was a power equation: FT-C = $7.76 \times \text{weight}^{0.28}$, $R^2 = 0.96$. The closest correlation was obtained for FT-C *versus* height: FT-C (cm) = $0.12 \times \text{height} + 5.2$, $R^2 = 0.98$. Adding sex as an independent variable to the linear multiple regression model did not affect the FT-C–*versus*–weight or the FT-C–*versus*–age model but gave a small improvement in the FT-C–*versus*– height model ($P < 0.05$). Sex differences were small (for a given height, FT-C was only 1.4–3.3% greater in boys than in girls), and the regression lines for boys and girls combined are therefore presented in figure 2. In the infant subgroup (fig. 3), all three relations were best described by linear regression equations. The closest correlation was again obtained for FT-C *versus* height (fig. 3A). There was no sex difference in FT-C in the infant subgroup.

If the ETT had been placed according to the Morgan formula, the ETT tip would have been at 90 ± 4% (range, 79–100%) of FT-C. No patient would have been bronchially intubated if the formula had been used, but in 14 patients (12 infants younger than 3 months, one 5-month-old infant, and one 6-yr-old girl), the formula would have resulted in an ETT tip–to–carina distance of less than 0.5 cm.

Discussion

The key finding of this study is that FT-C can be predicted from patient height. Although FT-C is also closely correlated to weight and age, the FT-C–*versus*–weight relation is not well described by a linear equation, and prediction interval bands are wider for both this relation and FT-C *versus* age (figs. 2 and 3). The current study group probably reflects the normal variation in a pediatric cardiac catheterization setting. The 1- to 19-yr-old patients did not differ much from standard growth curves, but many infants were small for age. It is therefore possible that different relations would have been obtained between FT-C and weight, and between FT-C and age, if the study group had consisted of healthy children, rather than children with cardiac disease. We

‖ National Center for Health Statistics and the National Center for Chronic Disease Prevention and Health Promotion. Available at: http://www.cdc.gov/growthcharts. Published May 30, 2000. Modified April 20, 2001. Accessed January 15, 2008.

Table 1. Patient Characteristics

	n	Sex, F/M	Age	Weight, kg	Height/Length, cm
All patients	170	80/90	4.5 yr (1 day–19 yr)	15.4 (1.9–180)	100 (45–185)
Infant (<1 yr) subgroup	62	28/34	1.4 mo (1 day–10.5 mo)	4.2 (1.9–8.7)	55 (45–74)

Age, weight, and height/length values are median (range).

propose, however, that the observed FT-C–*versus*-height relation is valid for the general population, because the length of the airway seems to increase in direct proportion to the length of the individual, and there is no indication that the presence of cardiac disease affects airway growth and the growth of the individual disproportionately. In six patients who returned for new examination within 6–12 months after the primary measurements, the FT-C/height ratios were thus 0.19–0.18, 0.21–0.20, 0.20–0.22, 0.19–0.20, 0.20–0.20, and 0.16–0.16. That the FT-C/height ratio remains rather constant during growth agrees with the fact that the FT-C–*versus*–height equation obtained in the infant subgroup and the equation obtained in all patients give similar FT-C estimates for infants. The corresponding FT-C estimates would be 11.1 and 11.2 cm for a 50-cm infant and 14.1 and 13.6 cm for a 70-cm infant, respectively. For practical purposes, the FT-C–*versus*–height equation for the whole group (fig. 2A) can therefore be used in infants as well. The finding that airway length is best correlated to the length of the individual is in agreement with previous studies in both children[2,4] and adults.[5,6] Eagle[5] measured FT-C in adult patients and found that the expected FT-C values would be 21 and 26 cm in 140- and 180-cm individuals, respectively, which are close to the corresponding values of 22 and 27 cm given by the FT-C–*versus*–height equation in figure 2A.

Many formulas have been suggested for estimating intubation depth in children.[2,7,8,9] The one we have found most reliable clinically was suggested by Morgan and Steward in 1982.[2] They estimated the distance from the incisors to mid-trachea in children aged 4–16 yr by combining measures of upper airway distances, taken from radiographs in 206 children, and lower airway distances, measured during rigid bronchoscopy in 50 children. The current findings (fig. 2A) suggest that the Morgan formula is also a useful guide when intubating younger children. The average distance from the ETT tip to the carina would have been approximately 1 cm in a 50-cm baby and 2 cm in a 100-cm child, had the Morgan formula been used. In some small infants, however, it can result in a distal ETT tip position (fig. 3A). Clinically, we have therefore used a modified version of the formula in infants younger than 3 months: ETT length at front teeth/dental ridge (cm) = 0.10 × height (cm) + 4.[10] Lau *et al.*[7] have proposed another formula: ETT length (cm) = 0.5 × weight (kg) + 8. In the infants younger than 3 months included in the current study, the ETT tip–to–carina distance would have been 1.0–3.2 cm if the modified Morgan formula had been used and 0.5–3.3 cm if the Lau formula had been used.

Age and weight information is sometimes more accessible in the operating room than height. Age- or weight-based linear formulas can give adequate guidance if the age/weight range is limited, but they are less reliable over greater age and weight ranges, and they are clearly useless in adults because the length of the airway does not automatically increase with increasing age or weight. For similar reasons, they are also less reliable in obese children and in children who have lost weight or stopped growing because of chronic disease. Bronchial intubation can have serious consequences in patients with cardiac disease, and the current FT-C data were therefore used to assess two commonly recommended formulas: ETT length (cm) = 0.5 × age (yr) + 12; and ETT length (cm) = 0.2 × weight (kg) + 12.[11,12] If applied only in children aged 3–14 yr (n = 74), as is usually suggested, the age formula would have resulted in bronchial intubation in 1 of 74 patients, and the position of the ETT tip would have been at 81 ± 6% of FT-C (range, 69–104%). The weight formula would have placed the tube closer to the carina at 91 ± 8% of FT-C (range, 77–115%), and 6 of 74 would have been bronchially intubated. A lower age limit of 2–3 yr is indeed appropriate for the age- and weight-based formulas; if applied in all 170 patients in our study, these formulas would have resulted in bronchial intubation in 43 and 74 patients, respectively. In contrast, no patient would have been bronchially intubated if the Morgan formula had been used.

Although an ETT placed at the distance given by the Morgan formula rarely needs to be repositioned, a formula based on height cannot be expected to give useful guidance in patients with disproportional length-growth, *e.g.*, patients with chondrodysplasia, and adjustments may have to be made in patients with severe facial or dental abnormalities. Also, it should be noted that interventions can change the ETT tip–to–carina distance. Böttcher-Haberzeth *et al.* measured the changes in carina position during laparoscopy, and found that 20° head-down tilt combined with capnoperitoneum resulted in a cranial displacement of the carina by 1.2 + 0.11 × age in centimeters.[13] Had the Morgan formula been used for ETT positioning, such a change would have resulted in bronchial intubation in 54% of our patients. Consequently, sole reliance on a specific formula is not advisable, and careful auscultation is necessary to ensure appropriate position.

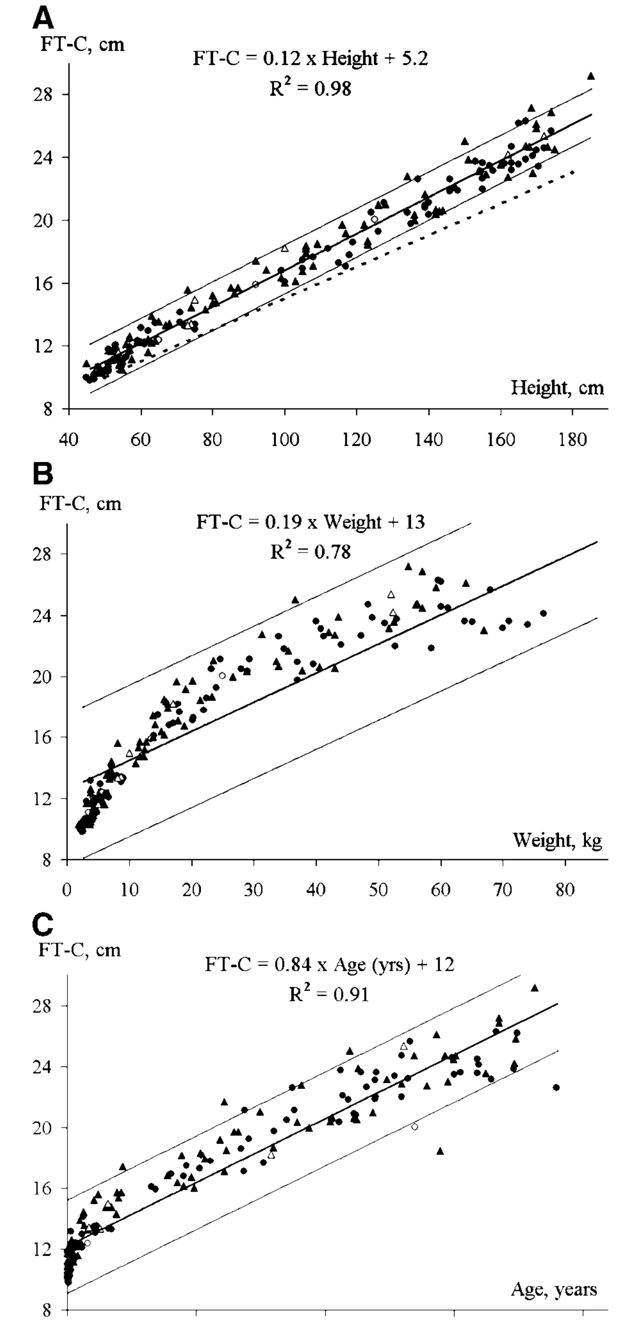

Fig. 2. Front teeth–to–carina distance (FT-C) *versus* height (*A*), weight (*B*), and age (*C*) in children aged 0–19 yr. *Filled circles* = girls; *filled triangles* = boys. *Unfilled symbols* represent children with syndromes that could affect airway growth (see Results section, third paragraph). Linear regression lines, their equations, and 95% prediction interval bands are shown. Note that the FT-C–*versus*–weight relation was best described by a power equation (Results, fourth paragraph). The *dashed line* in *A* represents intubation depth calculated from the Morgan formula.[2] For practical reasons, one patient (age, 18 yr; weight, 180 kg; height, 185 cm) is not shown in the FT-C–*versus*–weight graph, but the data are included in the regression equation.

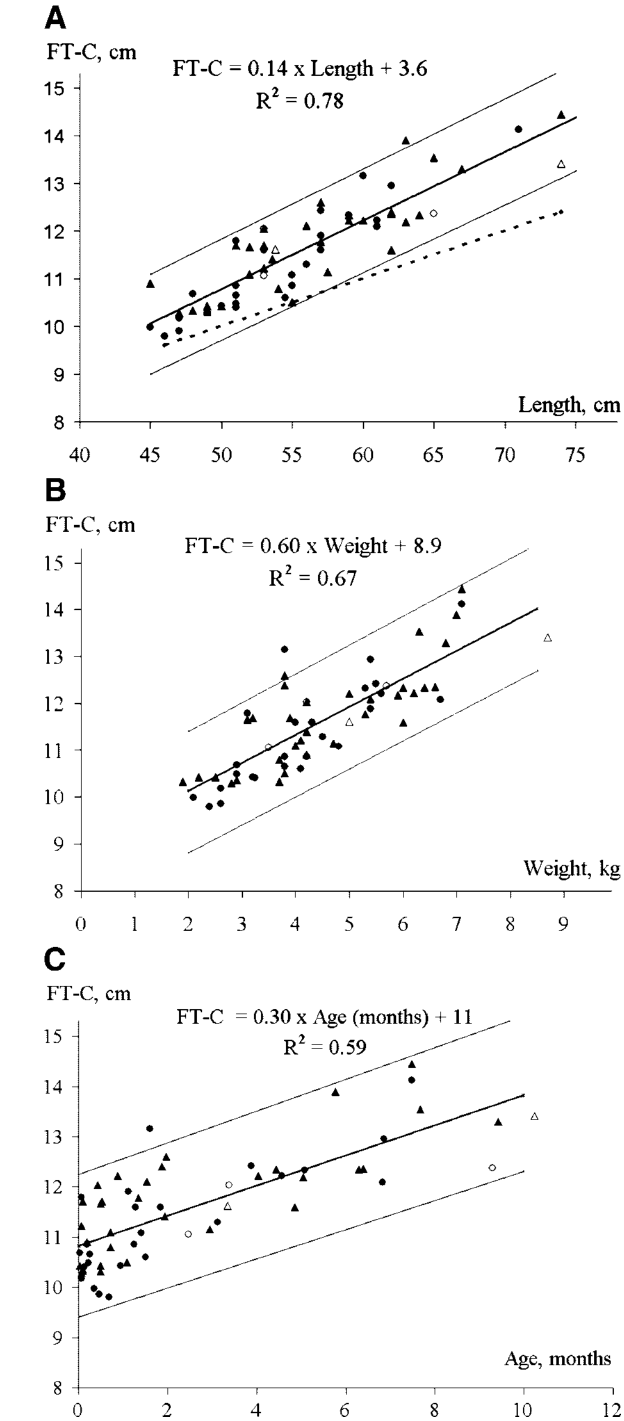

Fig. 3. Front teeth–to–carina distance (FT-C) *versus* height (*A*), weight (*B*), and age (*C*) in the infant (<1 yr) subgroup. *Filled circles* = girls; *filled triangles* = boys. *Unfilled symbols* represent infants with syndromes that could affect tracheal length (see Results section, third paragraph). Linear regression lines, their equations, and 95% prediction interval bands are shown. The *dashed line* in *A* represents intubation depth calculated from the Morgan formula.[2]

Some methodologic issues should be noted. One limitation of our study is thus that the FT-C-*versus*-weight and FT-C-*versus*-age relations for the infant subgroup might not reflect the relation in the general population. Second, FT-C will depend on how the distance is measured. Using the ETT itself as measuring device, as was done in the current study, will likely give different but perhaps more clinically relevant values than those obtained by rigid or fiberoptic bronchoscopy. The definition of intubation depth is also important. Measuring the ETT length at the upper front teeth, as suggested by Morgan and Steward,[2] will give somewhat greater but probably more reproducible values than measuring the ETT length at the corner of the mouth. No correction was made for parallax errors, but, as outlined above, the resultant underestimation is small. Although the position of the carina normally varies little with ventilation, our measurements were not timed with the ventilatory cycle, and the ventilatory pressures varied considerably, especially in infants. This might be one explanation for the greater FT-C variation observed in the infant subgroup (fig. 3). Finally, the head position varied: Some patients faced straight upward, whereas others had their head turned to the side. It is unlikely that this had an important effect on the FT-C measurements.[14] It was appreciated, however, that flexion and extension of the neck results in a more caudal and cranial ETT tip position, respectively,[15] and that extension also increases the tracheal length,[16] and care was therefore taken to place the neck in a neutral anterior/posterior position.

In summary, there was a close relation between the front teeth–to–carina distance and the length/height of the child. The Morgan formula provides good guidance for intubation in children but can result in a distal ETT tip position in small infants.

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