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**Original article**

# Effectiveness of endotracheal-tube size by age-based formula for Thai pediatric cardiac patients: a retrospective study

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***Background:*** Pediatric patients with congenital heart diseases may have pathological airway abnormality and delayed development. To predict the appropriate size of endotracheal tube (ETT), a formula between diameter and age has been widely used for Western normal children. However, it is unclear whether this age-based (AB) formula is applicable to Thai pediatric cardiac patients.
***Objective:*** Evaluate the effectiveness of uncuffed ETT size by AB formula for pediatric cardiac patients.
***Methods:*** A retrospective study was conducted using 320 cases of non-cardiac and cardiac patients aged 2-7 years old who were orally intubated with a regular uncuffed ETT at Siriraj Hospital, Thailand. The exclusion criteria were history of tracheostomy, upper airway obstruction, and expected difficult intubation. Demographic data and final ETT used were recorded.
***Results:*** The tube- size predicted by the AB formula could be applied to 54.4% of non-cardiac and 48.1% of cardiac patients ($p= 0.314$), whereas three sizes of tubes (one above and one below the predicted size) covered 96.9% and 94.4% of non-cardiac and cardiac patients, respectively ($p = 0.413$). The ETT with 0.5 mm in ID larger than the predicted size were more often used in 35.0% of cardiac patients compared with 22.5% of non-cardiac patients ($p= 0.019$). There were no significant differences between methods using age (actual, round-up, and truncated) to calculate the AB formula. The Pearson's correlation between the ID of the ETT with height in non-cardiac and cardiac patients were 0.430 and 0.683, respectively ($p <0.001$), whereas correlations with weight were 0.622 and 0.561 ($p <0.001$), respectively.
***Conclusion:*** The AB formula was applicable to non-cardiac and cardiac children aged 2-7 years old. For Thai pediatric cardiac patients, we recommend to use a one-size larger ETT than non-cardiac patients.

***Keywords:*** Age-based formula**,** anesthesia, cardiac patients, endotracheal tube, pediatric

Children have a higher incidence of perioperative cardiac arrest compared with adults [1]. According to the Thai Anesthesia Incidents Study (THAI Study) [2], the incidence of anesthesia-related cardiac arrest in children was 5.1 per 10,000 anesthetics, with 46% mortality rate. Respiratory-related cardiac arrest was the most common cause, and congenital heart disease was the underlying indicator of patient-related risk factors. Therefore, airway management including successful tracheal intubation is essential for these pediatric patients.

The incidence of congenital heart disease at Siriraj Hospital for the year 2000 was 4.36 patients per 1,000 livebirths [3]. Overall, three out of 1,000 livebirths require immediate intervention including cardiac catheterization and surgical intervention during which the anesthesiologists take care of the children's airways.

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Appropriate selection of the size of an endotracheal tube (ETT) is very important in general anesthesia and critical care practice for children. Significant morbidity and mortality may be associated with the placement of inappropriate size of tracheal tubes. A too-small tube may result in ventilatory difficulties related to high airway resistance or large air leaks, including increased risk of pulmonary aspiration. A too-large tracheal tube may lead to multiple attempts at intubation resulting in airway trauma, post-intubation croups, sore throat, and subglottic stenosis [4, 5].

To predict the appropriate size of ETT for children, Cole's age-based (AB) formula [6]) between internal diameter (ID) and age has been widely used. Published data on this formula were based on Caucasian measurements. Since Thai children have different body structure with Caucasians, a guideline for Thai children is needed.

Physical growth and development in pediatric cardiac patients are impaired [7, 8], which is attributed to upper respiratory tract infection and repeated hospitalization leading to malnutrition. Furthermore, there is significant association of tracheobronchial anomalies in children with congenital cardiac disease [9, 10]. The proper sizes of ETT in these patients, particularly in children with cyanotic defects, is most important because the airway problems may further stress an already-tenuous cardiovascular system and lead to significant perioperative morbidity and mortality. Shiroyama et al. [11] investigated the size of the uncuffed ETT in Japanese children, and reported that the ETT sizes were >0.5 mm larger than those estimated by Cole's formula in 29% of patients with congenital heart disease. Japanese health care system is different from Thai system. It is unclear whether this AB formula is applicable to Thais or not. In this study, we evaluated the accuracy of uncuffed ETT size by AB formula in pediatric non-cardiac and cardiac patients.

## Materials and methods

This study was approved by the Institution Ethical Review Board of the Faculty of Medicine Siriraj Hospital, Mahidol University.

We reviewed the anesthetic records of patients (age: 2-7 years) who were orally intubated with a regular uncuffed ETT at Siriraj Hospital between 2007 and 2009. One hundred sixty non-cardiac and 160 cardiac patients were included in this study. The exclusion criteria were history of tracheostomy, upper airway obstruction, and expected difficult intubation. Data collected included age at surgery (in years and month), weight (kg), height (cm), and the final internal diameter (ID) of the ETT (mm) used. For each individual patient, the actual ID of the ETT was compared with the ID predicted by Cole's AB formula as follows:

Internal diameter (ID, mm)
= (1/4) [age (year) +16] (1).

For patients with age 3, 5, and 7 years, we did not use the ID values predicted by AB formula (1), but chose a tube-size 0.25 mm larger than the predicted sizes (see the Discussion).

Sample tube-size estimation was based on specification of 95% confidence interval (CI) of accuracy. A previous study by Takita et al. [12] in Japanese children using AB formula in non-cardiac patients revealed accuracy of 53%. In this study, 95%CI of accuracy was estimated to be $53\pm8\%$ in non-cardiac and $43\pm8\%$ in cardiac patients. Thus, a sample of 150 non-cardiac and 148 cardiac patients was required.

### *Statistical analysis*

Data analysis was done using SPSS version 17. Pearson Chi-Square test was performed to compare the correct tube size between groups. Paired t-test was used to compare ID difference between actual and calculated tube size. Pearson's correlation coefficient was applied to test the correlation between actual tube size and weight and height. A p-value <0.05 was considered statistically significant.

## Results

Number of non-cardiac and cardiac patients is shown in relations between calculated tube-size and actual tube-size in **Fig. 1(A)** and **(B),** respectively.

The size predicted by the AB formula was used in 54.4% of non-cardiac and 48.1% of cardiac patients. There was no significant difference between both groups (p=0.314). Three sizes of tubes (one above and one below the predicted size) covered 96.9% of non-cardiac and 94.4% of cardiac patients (p=0.413) (**Fig. 2 (A))**. The ETT with 0.5 mm in ID larger than the predicted size was more often used in 35% of cardiac patients compared with 22.5% in non-cardiac patients (p=0.019) (**Fig. 2(B))**. However, the ETT with 0.5 mm in ID smaller than the predicted size was not often used in 23.1% of non-cardiac compared with 16.9% of cardiac patients (p=0.208).

**Table 1** shows the ID difference between actual and calculated tube-size using AB formula (1) for non-cardiac and cardiac patients. There was statistically significant difference in tube-size (ID, mean: 0.08-0.20 mm) between used ages (actual, round-up, or truncated) in calculating AB formula. These differences may be not important in clinical practice, because the ID of uncuffed ETT is 0.5 mm different in each size.

The correlation between tube-size (ID) of the uncuffed ETT used and height or weight is shown in **Table 2**. The Pearson's correlation between ID and height were 0.43 and 0.683 in non-cardiac and cardiac patients, respectively (p <0.001), and the correlation between ID and weight were 0.622 and 0.561 in non-cardiac and cardiac patients, respectively (p <0.001).

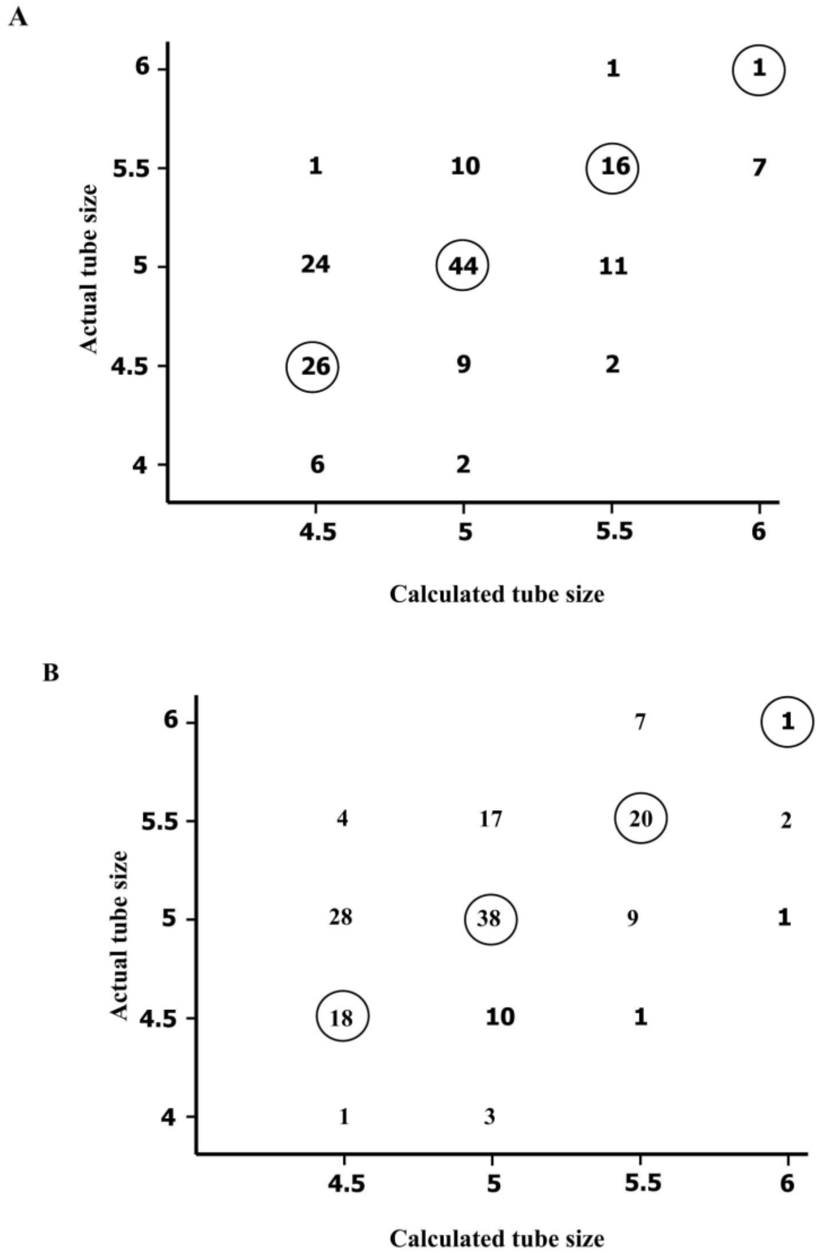


**Fig. 1** Relations between calculated tube size by AB formula (1) and the actual tube size for non-cardiac patients (**A**) and cardiac patients (**B**). Numbers of patients circled represent those with guideline-appropriate ETT.

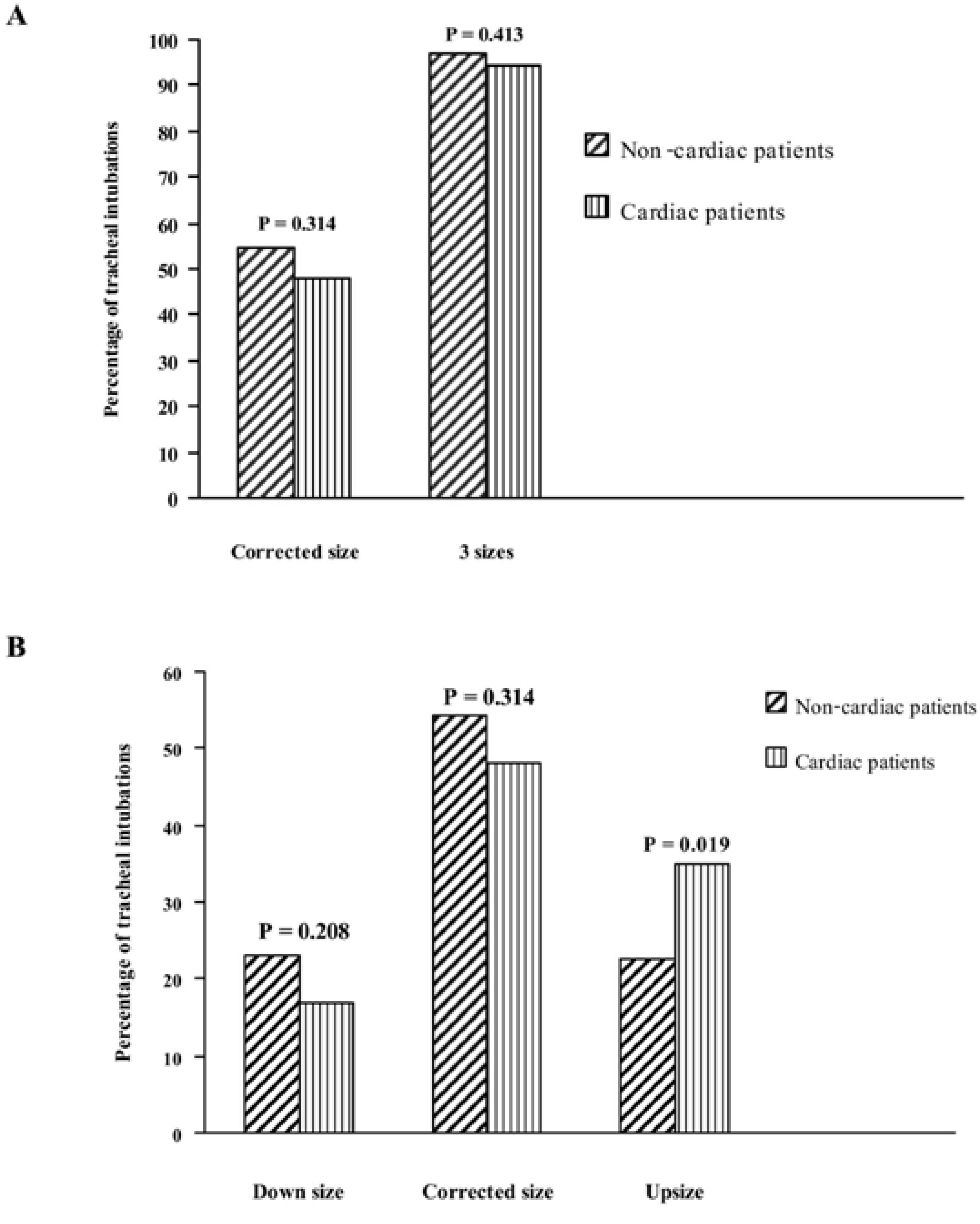


**Fig. 2** Percentages of corrected tube-size predictions by the AB formula for non-cardiac and cardiac patient. **A:** three sizes of ETT (corrected size, one 0.5 mm smaller, one 0.5 mm larger than the predicted size), **B:** down-size (ETT $\leq$0.5 mm smaller than guideline), up-size (ETT $\geq$ 0.5 mm larger than guideline).

**Table 1.** Difference between actual and calculated tube-size using AB formula (1) for non-cardiac and cardiac patients.

| | | ID difference between actual tube-size and calculated tube-size | | |
|---|---|---|---|---|
| | | (mean±SD) (mm) | 95%CI | P-value |
| **Non-cardiac patients** | Actual age | -0.01±0.36 | -0.06, 0.05 | 0.825 |
| | Round-up age | 0.03±0.36 | -0.03, 0.01 | 0.344 |
| | Truncated age | 0.09±0.36 | 0.03, 0.14 | 0.003 |
| **Cardiac patients** | Actual age | 0.20±0.36 | 0.14, 0.25 | <0.001 |
| | Round-up age | 0.08±0.38 | 0.02, 0.14 | 0.011 |
| | Truncated age | 0.08±0.37 | 0.02, 0.14 | 0.008 |

Actual age: age (year) = (age in month)/12. Round-up age: age >6 month = 1 year. Truncated age: age in year (uncounted month).

**Table 2.** Pearson's correlation between ID of uncuffed ETT used and height or weight ( 35 non-cardiac patients were excluded because of no record of height or weight).

| Variables | Non-cardiac patients (n=125) | | Cardiac patients (n=160) | |
|---|---|---|---|---|
| | r | P-value | r | P-value |
| Height | 0.430 | < 0.001 | 0.683 | < 0.001 |
| Weight | 0.622 | < 0.001 | 0.561 | < 0.001 |

## Discussion

It is reported that approximately 70% of pediatric anesthesiologists have used modified Cole's formula (1) for predicting ETT size selection [13], while 30% have used ETT size calculated by similar but different ID [14]. However, of the patients requiring ETT exchange, 51% needed to up-size ETT. This was the reason why we chose a size 0.25 mm larger than the predicted size in patients that were three, five, and seven years old. In the present result, one tube-size predicted by the AB formula could be applied to 54.4% of non-cardiac patients. This is similar to non-cardiac patients for Japanese children under eight years old [12], and for Canadian children aged 1-18 years old [15]. In our study, three sizes of tubes (one above and one below the predicted size) covered 96.9% of non-cardiac patients, which is similar to the Japanese study (97.2%). In another prospective study of Korean children under eight years old [16], the tube-size predicted by AB formula was applicable to only 32% of non-cardiac patients, while three sizes of tubes covered 88%. This difference might be due to the lack of recorded conditions of depth of anesthesia, degree of muscle relaxation during intubation, and uniform definition of leak test of uncuffed ETT. Nevertheless, it is recommended that three sizes of tube are available before tracheal intubation. To be able to evaluate this AB formula more reliable in Thai children, a prospective study with a uniform condition to determine the appropriate tube-size is reguired.

As shown by Maters et al. [17], airways size progressively increases with increasing age. In addition, anthropometric factors such as body length and weight may influence airway size. Several studies reported the influence of length [18-22] and weight [15] on the appropriate ETT size in children. Our study showed weak correlation between the tube-size (ID) and height or weight for non-cardiac and cardiac patients.

In relation to physical growth and development in patients, Daugherty RJ et al. [23] demonstrated that AB formula was accurate to predict ETT size in both normal and pathologically short children (less than 5% length for age on the Centers for Disease Control and Prevention growth chart). According to Shiroyama et al. [11], a one-size larger tube is more suitable for use in pediatric cardiac than in pediatric non-cardiac patients of the same body length. Similar to their result, our study showed that the tube-size predicted by this formula was used in 48.1% of the patients. For Thai pediatric cardiac children, we recommend a prospective study to access the effectiveness of Corfield's formula [24] as follows:

Internal diameter (ID, mm)
= (1/4) [age (year) +18] (2).

Using the above Corfield's formula (2), the calculated tube size is 0.5 mm larger than that estimated by Cole's formula (1).

According to Scott [25], since children with Down syndrome had smaller tracheal airways than normal children, the ETT should be two-sizes smaller for them. Kazim et al. [9, 10] examined patients with tetralogy of Fallot and with conotruncal cardiac defects, including truncus arteriosus, double-outlet right ventricle, and conoseptal ventriculoseptal defect. These types of congenital heart disease were not recorded in our study. More prospective studies will be needed to evaluate the airway size of Thai children with congenital cardiac defects.

Our study showed no clinical differences between used ages (actual, round-up, and truncated) to determine AB formula. We recommend using truncated age that is easily available and practical to employ in calculating this formula.

Our retrospective study has some limitations as follows. 1) One selected ETT size was appropriate for each patient because it was selected based on the individual caregiver (depth of anesthesia and degree of muscle relaxation during intubation). 2) There is no data to show that all our anesthesiologists used this AB formula to determine initial tube selection. 3) Although use of the leak test was our standard of care in pediatric patients undergoing tracheal intubation, it was not documented as part of the anesthesia record and several confounding factors affecting tracheal tube air leak in children, such as level of neuromuscular blockade, head position, tracheal tube depth, and rate of gas flow, could not be controlled. 4) No documented records of postoperative airway complications were made.

In conclusion, the AB formula (1) is applicable for non-cardiac and cardiac children aged 2 to 7 years who require orally uncuffed endotracheal intubation. However, the cardiac children tended to use a one-size larger ETT than the non-cardiac children. Three sizes of tube (the predicted size, one 0.5 mm smaller and one 0.5 mm larger than the predicted size) should be available before tracheal intubation.

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