Accuracy of a Chest X-Ray–Based Method for Predicting the Depth of Insertion of Endotracheal Tubes in Pediatric Patients Undergoing Cardiac Surgery

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Objectives: **The incidence of endotracheal tube (ETT) malposition in children with various described methods is 15% to 30%. Chest x-ray (CXR) is the gold standard for confirming appropriate ETT position. The aim of this study was to measure the accuracy of a preoperative CXR-based method in determining depth of insertion of ETTs and to compare it with methods based on the intubation depth mark or formulae (age, height, and ETT internal diameter) in children undergoing cardiac surgery.**

Design: **Prospective observational study.**

Setting: **University-affiliated tertiary care hospital.**

Participants: **Sixty-six consecutive children scheduled for elective pediatric cardiac surgery.**

Interventions: **None.**

Measurements and Main Results: **The distance from carina to mid-trachea was measured for each child preoperatively on the CXR displayed as a computed radiography image in a picture archival and communications system computer. Following intubation, ETTs deliberately were pushed endobronchially and then pulled back to the carina; they were further withdrawn by the previously measured carina to mid-tracheal distance and secured. CXRs postoperatively were repeated to confirm ETT position. The ETT position was measured with other methods using the picture archival and communications system ruler on the postoperative CXR and compared with the CXR method. The proportion of appropriate ETT position with the CXR method was 98.5% ($p \leq 0.001$ *v* other methods). In children younger than 3 years, the appropriate proportion was 97.4%.**

Conclusion: **The appropriate positioning of ETTs in the trachea by the CXR method is superior to other methods.**

KEY WORDS: airway, anesthesia, cardiac surgery, carina, chest x-ray, children, depth of insertion, endotracheal tube

CHILDREN UNDERGOING cardiac surgery usually are ventilated electively in the postoperative period. In this population, the trachea is short, and extension or flexion of the neck may cause displacement of the endotracheal tube (ETT). This can result in serious complications such as accidental extubation or endobronchial intubation.[1,2] Ideally, a mid-tracheal position of the ETT would allow a margin of safety during head and neck movement.[3,4] Various methods based on age,[5,6] height,[7] ETT internal diameter (ID),[8] and intubation depth mark[4,9] are described for accurate tube positioning. However, the incidence of malposition with most methods is 15% to 30%[5,10-12]; this may be because standardized formulae do not factor for individual variations in tracheal length and facial characteristics.

Although ETT position can be determined correctly with either flexible fiberoptic bronchoscopy (FOB) or fluoroscopy, it may not be routinely feasible intraoperatively. In cardiac surgery, a mid-tracheal position in children is even more imperative, as the ETT can be displaced easily by manipulations of the chest during sternotomy or during transesophageal echocardiography (TEE) examination, which often is performed in this category of patients. Moreover, once the patient is under drapes, it may be difficult to adjust the position of the ETT should displacement occur.

Chest x-ray (CXR) remains the gold standard for confirmation of correct position of ETTs.[13] In the authors' institute, x-ray pictures are displayed on the picture archival and communication system (PACS) (IMPAX, version 6.5.1, Agfa Healthcare, Belgium) as computed radiography images. With PACS, x-ray images can be viewed on any computer workstation inside the hospital. The CXRs of all patients are archived similarly in this system. The advantages of PACS include magnification and measurement of selected areas, contrast adjustment, and superior picture clarity.

With this background, the authors hypothesized that the depth of insertion of an ETT based on each patient's preoperative CXR will be the most accurate method compared with methods based on either the intubation depth mark or established formulae (age, height, and ETT ID), since the CXR method would account for individual variations in the tracheal length or facial characteristics, such as variations in the size of the jaw. A secondary aim of the study was to see whether the CXR method also was accurate in children younger than 3 years compared with the other methods, since a higher incidence of malposition has been reported in this age group.[14]

METHODS

Children (0-12 years) undergoing elective cardiac surgery with an expected duration of postoperative ventilation of at least 6 hours were included consecutively in this prospective study after institute ethics committee (IEC) approval (IEC no: 232/2009); parental informed written consent was obtained during the preanesthetic visit. Exclusion criteria were emergency cases, tracheal or vertebral column abnormalities, preoperative tracheostomies, children in whom deliberate endobronchial intubation failed despite 2 attempts, or those in whom the first postoperative CXR was suboptimal (either rotated film or neck position other than neutral).

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For the purpose of the present study, the authors defined a priori the mid-tracheal position to be the interspace between the second (T2) and the third (T3) thoracic vertebrae, ie, T2-3.[11] On the preoperative CXR, the vertebral level of the carina was identified and the distance from the carina to the T2-3 measured. In case the carina was not visible, the interspace between the body of the fourth (T4) and fifth (T5) thoracic vertebrae, ie, T4-5, was chosen (because tracheal bifurcation usually occurs at this level, corresponding to the angle of Louis or manubrio-sternal junction) and the distance from T4-5 to T2-3 measured.

Following induction of anesthesia with sevoflurane in oxygen, an intravenous cannula was secured, and injections of fentanyl for analgesia and of vecuronium or pancuronium bromide for muscle paralysis were administered. With the head in neutral position, children were intubated either orally or nasally with the appropriate size portex ETT (Portex, Smiths Medical, UK) that allowed air leak at a pressure of 20 cmH_2O. Uncuffed ETTs of 3.5- or 4.0-mm ID were used for infants younger than 6 months, and 4.0- or 4.5-mm ID uncuffed ETTs were used for children between 6 and 24 months. For children older than 2 years, oral tube sizes were determined by the formula, age (years)/4 + 4. If air leak was audible at an inflating pressure of <15 cmH_2O, tubes were replaced with one size larger; whereas if there was no audible leak with 30 cmH_2O, they were replaced with one size smaller.

Cuffed Portex ETTs were used in older children if uncuffed tubes were inappropriate. The choice of oral or nasotracheal intubation was at the discretion of the attending anesthesiologist. Confirmation of tracheal intubation was carried out with end-tidal capnography and auscultation of bilateral breath sounds over the chest wall.

During intubation, when the ETT intubation depth mark was at the level of the vocal cords, the tube mark in cm that corresponded to the alveolar ridge (for oral intubations) or alae nasae (for nasal intubations) was noted and recorded for each patient. Subsequently, the authors followed previously described methods,[1] wherein the ETT was advanced into a mainstem bronchus as evidenced by loss of auscultatory breath sounds over the opposite hemithorax and increase in stiffness of the reservoir bag. It then was pulled back gently until return of bilateral equal breath sounds along with a decrease in the stiffness of the reservoir bag and/or a decrease in the peak inspiratory airway pressures; this position denoted the carinal level of the tube. From this position, the ETT was pulled back by the previously measured preoperative carina to T2-3 or T4-5 to T2-3 distance for that patient and secured at the alveolar ridge or alae nasae (depending on oral or nasal intubation, respectively).

A postoperative CXR was obtained for all children with the head in neutral position. The authors defined the appropriate position of the ETT tip to be between the body of T1 and T3 vertebrae, as this would allow for some degree of head and neck movement without inadvertent extubation or endobronchial intubation. Accordingly, the tube was considered to be malpositioned if the ETT tip was above the body of T1 or below the body of T3 vertebrae. If the ETT was found to be malpositioned, the distance between the ETT tip and T2-3 (ie, the mid-tracheal level) was measured on the postoperative CXR, and the tube was adjusted by this distance and re-secured. In addition, the depths of insertion for each child also were determined in the PACS computer using the intubation depth mark method and age-, height-, and ETT ID-based formulae methods by marking on the postoperative CXR using the PACS ruler (Fig 1).

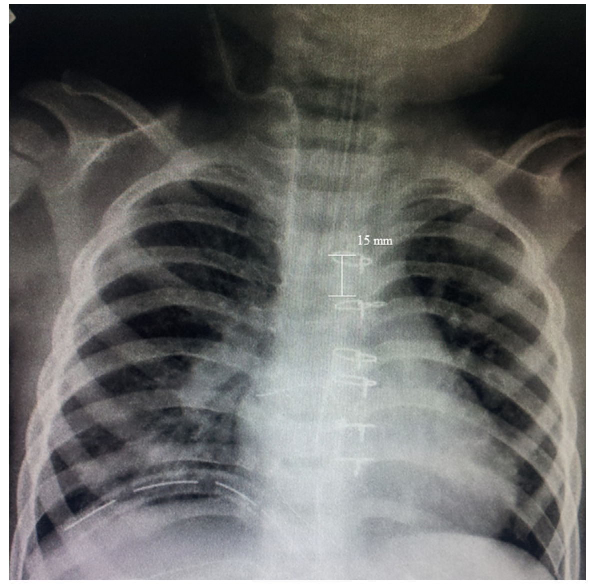

Fig 1. Use of the postoperative CXR to determine the depth of insertion of ETTs for all methods using the PACS ruler. The depth of insertion for this patient intubated with a 5-mm ID uncuffed tube was 13.5 cm by the CXR method. By the 3 × (ETT ID) formula method, the depth of insertion would have been 3 × 5 = 15 cm. Thus, had the formula method been used to determine the depth of insertion of the ETT, the actual position would have been 1.5 cm below the current tube tip, which would have resulted in a carinal position. CXR, chest x-ray; ETT, endotracheal tube; ID, internal diameter; PACS, picture archival and communications system.

For an age-based formula, the predicted depth of insertion for oral tubes was 9 cm for 0 to 6 months, 10 cm for 6 to 12 months, and 11 cm for 1 to 2 years; 2 cm were added for nasal tubes.[5] In children older than 2 years, the authors used the pediatric advanced cardiac life support (PALS) formula, ie, age (years)/2 + 12 for orotracheal intubations, and added 2 cm for nasotracheal intubations.[6,20] For a height-based formula, the authors used the Morgan and Steward formula,[7] ie, the height (cm)/10 + 5, to determine the depth of insertion for oral tubes, and for an ETT ID-based formula,[8] 3 × (ETT ID) formula was used for oral tubes; 2 cm were added for nasotracheal tubes in both these methods.

Statistical Methodology

Assuming a malposition incidence of 30% and that a 20% decrease in this incidence with the CXR method could be considered significant, a total of 57 children would be required with a type-1 error rate of 5% and a power of 80%. The McNemar test was used to test the difference between paired proportions, ie, the CXR method versus all other methods, and significance was determined at $p < 0.05$. Data were analyzed for all children as well as for children younger than 3 years.