Many methods are taught and used clinically to determine what size uncuffed endotracheal tube is required for the pediatric patient. The purpose of this study was to compare the effectiveness of two methods of selection used clinically: (1) the traditional age-based (AB) formula; (age in years + 16) divided by 4, and (2) the method based on body length using the Broselow pediatric resuscitation tape.

Following institutional review board approval, 174 patients were prospectively studied after informed consent was obtained. Uncuffed endotracheal tube size selection was determined by randomly assigning the patient to one of the two groups. The appropriateness of the tube selection was assessed using an audible air leak around the endotracheal tube.

No difference was found between the AB group and the resuscitation tape group with respect to selecting the appropriate size of endotracheal tube. Retrospective analysis of all patients found another AB formula that is occasionally used ([age in years + 18] divided by 4) to be correct in only 20 (11%) of 174 cases. This was significantly different from the other methods (P < .001).

Since the AB formula ([age in years + 16] divided by 4) is reliable and easily applied, it appears acceptable for routine anesthesia cases in the pediatric population requiring endotracheal intubation. The AB formula ([age in years + 18] divided by 4) should be used cautiously because of the high failure rate. In circumstances in which general information, such as age, is not available and endotracheal intubation is needed, the Broselow tape allows reliable endotracheal tube size identification and should be readily available.

Key words: Broselow pediatric resuscitation tape, endotracheal intubation, pediatric.

Introduction
The pediatric patient requiring endotracheal intubation presents many challenges. One such challenge is the selection of an appropriately sized endotracheal tube, which is vital for the prevention of perioperative complications due to the unique structure of the pediatric airway.

The pediatric airway is small in comparison with the adult airway, with the cricoid ring being the narrowest upper airway structure. Even the smallest amount of airway edema can result in airway compromise in a small child. The effect of 1 mm of edema on the cross-sectional area at the level of the cricoid ring in a pediatric airway decreases airway opening 75%, while the adult air-
way opening decreases only 19%. The use of an endotracheal tube larger than needed in a small child has been shown to result in postextubation croup, and tracheal stenosis can eventually result. Use of an endotracheal tube that is too small results in difficulty with ventilation due to the large leak of delivered volume around the small tube. Therefore, use of a properly sized uncuffed endotracheal tube is critically important to the pediatric patient.

Numerous methods are taught and used clinically to determine the selection of an appropriate size of endotracheal tube for the pediatric patient. An age-based (AB) formula is one of the more commonly used methods for children undergoing surgery since age data are so readily available. However, when age information is not readily available, another method for endotracheal tube selection becomes paramount to reduce complications. A tape measure, the Broselow pediatric resuscitation tape (BRT) to aid in drug dosing and resuscitation efforts in the pediatric patient, has been introduced into practice. The tape is more accurate than calculations based on estimated age or weight. Endotracheal tube size has recently been added to the tape to provide appropriate endotracheal tube selection based on height. However, endotracheal tube selection based on this tape has not been sufficiently validated. In this study, we present data comparing the AB formula to the BRT for the appropriate selection of endotracheal tubes in the pediatric population.

Methods

The study protocol was approved by the institutional review board of Wake Forest University Baptist Medical Center, Winston-Salem, North Carolina. Informed consent was obtained from the parent(s) or guardian(s) of each subject. The study included 174 subjects, ASA physical status I or II, age 6 months to 8 years and 7 months, who were having elective surgery requiring intubation of the trachea with an uncuffed endotracheal tube.

Subjects were excluded from the study if they had a history of an airway anomaly, such as tracheal stenosis, that could alter the size of the trachea. Patients with Down syndrome were excluded because of the increased incidence of subglottic stenosis in this syndrome. Patients having surgery on the airway and those with a history of intubation lasting longer than 3 days also were excluded. Patients with characteristics affecting their height, such as cerebral palsy or failure to thrive, were excluded.

Patients were randomly assigned to one of two groups. Group one was BRT, endotracheal tube selection using Broselow resuscitation tape, and group two was AB, endotracheal tube selection using the AB formula, [(age in years + 16) divided by 4]. Body length was measured from the crown of the head to the heel of the foot, and endotracheal tube size selection was accomplished based on the BRT measurement. Age was calculated from the subject’s date of birth, and endotracheal tube selection was calculated by using the formula.

Following induction, all patients received a nondepolarizing muscle relaxant. After the onset of neuromuscular blockade, the anesthesia provider intubated the subject using the selected size of endotracheal tube, defined as the internal diameter expressed in millimeters, according to the BRT measurement or the AB calculation. Immediately following confirmation of tracheal placement of the tube, equal bilateral breath sounds and positive end-tidal carbon dioxide, a standardized leak test was performed. This test was performed when the patient was fully paralyzed, as evidenced by no twitches on train-of-four with a peripheral nerve stimulator. The subject’s head was in direct alignment with the body to avoid this variable affecting the leak pressure. The leak test was performed by occluding the pressure relief valve, allowing pressure to slowly build in the circuit. During this time, a stethoscope was placed over the trachea, and a leak pressure was measured, in centimeters of water, as soon as a leak of air was audible. A leak pressure within the range of 10 to 35 cm of water was used to indicate an appropriate size of endotracheal tube. This was chosen since a large leak at the lower leak pressure of 10 cm of water still allows adequate ventilation, while the small leak at the higher pressure of 35 cm of water still allows perfusion of the airway mucosa. If an inappropriately sized tube was inserted, as determined by leak pressure, the tube was changed to the next larger or smaller size, and another leak pressure was measured.

Statistical analysis was done using the chi square to test for differences in appropriate endotracheal tube size selection between groups. A P value of < .05 was considered significant.

Results

The study included 174 subjects ranging in age from 6 months to 8 years and 7 months. There were 96 boys and 78 girls. The ages of subjects were equally distributed between groups. However, more subjects in both groups were 1 to 2 years old, and fewer were 7 to 9 years old. Subjects’ heights were equally distributed compared with national standards.

Prospectively, 79 subjects were assigned to
group AB and 95 to BRT (Table I). The AB formula selected the correct tube size in 54 (68%) of 79 subjects, while the BRT measure was correct in 62 (65%) of 95 subjects. This difference was not statistically significant. The incidence or reintubation in the AB group was 21 (27%) of 79 subjects, while 23 (24%) of 95 subjects required reintubation in the BRT group. This difference was not statistically significant.

### Table I

<table>
<thead>
<tr>
<th>Factor considered</th>
<th>BRT</th>
<th>AB</th>
<th>(P) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct tube based on leak pressure</td>
<td>65% (62/95)</td>
<td>66% (54/79)</td>
<td>.79</td>
</tr>
<tr>
<td>Tube changed</td>
<td>25% (23/95)</td>
<td>27% (21/79)</td>
<td>.75</td>
</tr>
<tr>
<td>Tube predicted used for case</td>
<td>73% (69/95)</td>
<td>76% (60/79)</td>
<td>.75</td>
</tr>
<tr>
<td><strong>Overall analysis</strong></td>
<td>62% (108/174)</td>
<td>61% (106/174)</td>
<td>.92</td>
</tr>
</tbody>
</table>

\(AB = \) Age-based formula ([age in years + 16] divided by 4) group

BRT = Broselow pediatric resuscitation tape group

Groups were compared using chi-square statistical analysis.

*Data are given as percentage (numbers of cases/total).

A comparison was also made using all subjects and retrospectively assigning a tube size based on each method (Table II). By using these data, heights of subjects were compared with national standards for instances in which the BRT measurement was incorrect in selecting the appropriate size of endotracheal tube. This comparison was performed to determine whether subjects were unusually small or large for their age. The BRT measurement was incorrect in 66 (38%) of 174 subjects. Twenty-eight subjects (51%) needed a smaller tube than suggested, and 35 (53%) needed a larger tube than suggested. Three patients (1%) had tubes not within the leak range, but the tubes were not changed; therefore, correct tube size based on leak pressure was unknown. Of those 28 subjects requiring a smaller tube, 16 (57%) were taller, and 12 (43%) were shorter than the national 50th percentile. Of the 35 subjects who needed a larger tube than suggested by the BRT measurement, 25 (71%) were shorter than the 50th percentile of the national average for height. Three patients (1%) had tubes out of leak range that were not changed; therefore, correct tube size based on leak pressure was unknown.

### Table II

<table>
<thead>
<tr>
<th>Overall comparison of Broselow tape and the age-based formula for endotracheal tube selection in pediatric patients*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broselow tape and age predicted same size</td>
</tr>
<tr>
<td>Broselow tape and age correct</td>
</tr>
<tr>
<td>Broselow tape and age incorrect</td>
</tr>
<tr>
<td>Age only correct</td>
</tr>
<tr>
<td>Tape only correct</td>
</tr>
</tbody>
</table>

*Retrospective overview of all patients in the study combining age-based formula ([age in years + 16] divided by 4) and the Broselow tape data for all patients entered into the study and grouped according to results of methods. Data are given as percentage (number of cases/total).

Heights of subjects also were compared with national standards in the instances in which the AB formula was incorrect. The AB formula was incorrect for 69 (40%) of 174 patients. Forty-two subjects (61%) of 69 needed a smaller tube, and of these 36 (66%) were shorter than the 50th percentile. Of 69 subjects, 24 (35%) required a larger endotracheal tube than suggested by age, and 16 (66%) were taller than the 50th percentile of the national average.

Finally, a retrospective analysis was conducted using the AB formula, ([age in years + 16] divided by 4) (Table III). This formula was found to be correct in only 20 (11%) of 174 cases. This is significantly different from the other AB formula and the BRT.

The majority of anesthesia providers agreed with the correct tube size as suggested by leak pressure and left this tube in place for surgery. There were some outliers. Age selected the correct tube according to leak pressure in four subjects, but a larger tube was inserted due to difficulties encountered with ventilation. The larger tube also had a leak pressure within the range required by the

### Table III

<table>
<thead>
<tr>
<th>Comparison of age-based formulas*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in years + 16</td>
</tr>
<tr>
<td>Correct</td>
</tr>
</tbody>
</table>

*Groups were compared using chi-square statistical analysis. The age-based formula ([age in years + 16] divided by 4) was significantly more reliable than the age-based formula ([age in years + 18] divided by 4). Data are given as percentage (number of cases/total).
study. Three subjects had no tube within the range of the study's leak pressure even when the endotracheal tube was changed. There were three instances in which the BRT selected a tube size out of range of the suggested leak pressures but was left in place because of the short nature of the surgery. Three similar incidents occurred with the AB formula. One anesthesia provider chose to change the suggested endotracheal tube even though it fell within range of leak pressures for the study. This tube was out of range of the study but was left in place.

Discussion

The results of this study support the BRT as being as effective as the AB formula ([age in years + 16] divided by 4) for selecting endotracheal tubes for pediatric patients. The AB formula ([age in years + 18] divided by 4) was found to be very unreliable for selecting the correct tube size based on the leak test criteria in this study (correct in only 20 [11%] of 174 cases).

Our findings contradict those of Luten et al who found that the BRT measurement was significantly more effective than the traditional AB formula for selection of correct uncuffed endotracheal tube size. In their study, BRT was found to be accurate in 77% of the cases versus 47% for the AB formula. The validation of the BRT in selection of endotracheal tube size was done as part of the same study and by the same team that determined the length-based endotracheal tube sizes to be placed on the tape. The fact that this was done by the same group may have allowed bias to affect the results. We, therefore, believe that our results are more reliable and that there is no difference between the two methods of endotracheal tube selection since our results are unbiased.

Based on the findings of this study, BRT would be of little benefit in selecting endotracheal tube size in the pediatric patient undergoing elective procedures. The AB formula would be easier to use under these circumstances since age information is readily available. However, the BRT method would be beneficial in emergency situations in which a patient's age would be estimated, since Broselow tape has been found to be more accurate than weight or age estimations.

There are several limitations of this study. Many different anesthesia providers assessed leak pressures. Experienced anesthesia providers can arrive at different leak pressures, especially at higher leak pressures. Another limitation is that three subjects had two tubes within the given leak pressure range for the study. It is impossible to know whether this could have occurred with other subjects in this study, and this may have introduced some discrepancy when the data were studied retrospectively, including all patients in all methods of endotracheal tube selection. In addition, the study sample was obtained at only one hospital in the southeastern United States, and different height-tracheal diameter relationships may exist in other parts of the country.

Despite these limitations, clinicians should keep in mind that methods currently used for pediatric endotracheal tube selection are far from ideal. Results of the present study support that subjects who were taller or shorter than the 50th percentile of the national average for height often require a larger or smaller tube, respectively. This information, along with the clinician's experience, could improve the success rate of selecting an appropriately sized tube. The success rate also can be improved by adjusting endotracheal tube selection depending on how a disease process affects the trachea. Perhaps there is no formula or external body dimension that would allow a more accurate prediction of required endotracheal tube sizes due to normal variations in tracheal size. However, data comparing subglottic size in pediatric patients do not support this possibility.

As previously recommended and taught, two extra endotracheal tubes should be available, one larger and one smaller, than predicted by any method. The results of this study support this recommendation because only five subjects required an endotracheal tube size out of this range, three in the AB group and five in the BRT group (the three patients in the AB group were also in the BRT group). Thus, if endotracheal tubes 0.5 mm larger or 0.5 mm smaller than predicted are readily available, the correct tube size will be at hand 95% to 96% of the time using the BRT or the AB formula.

One possible alternative may be the use of cuffed endotracheal tubes instead of uncuffed tubes. Deakers et al studied the incidence of postextubation complications in pediatric patients having cuffed and uncuffed endotracheal tubes while in pediatric intensive care. Their findings support that no significant difference exists in the incidence of stridor between patients with a cuffed endotracheal tube and those with an uncuffed endotracheal tube. However, to allow the least resistance to breathing through the endotracheal tube, the largest internal diameter tube should still be selected. A cuff on the tube effectively increases the outer diameter, thereby decreasing the internal diameter of the tube that can be placed. This results in greater resistance to breathing. Some method of selecting a tube in the range appropriate for the size of the child's airway must still be
used to limit resistance as much as possible. Thus, a cuffed endotracheal tube would not eliminate this need to select appropriate tube size, but may reduce the need to intubate the trachea more than one time, particularly in children who would otherwise receive an endotracheal tube too small for adequate positive pressure ventilation resulting from air leakage. However, until a more effective method of pediatric endotracheal tube selection and use is developed, current methods and practice should be continued.

Based on these results, the AB formula \(\left(\frac{\text{age in years} + 16}{4}\right)\) has a much higher failure rate and should be used cautiously. In circumstances in which general information, such as age, is not available (the emergency room or in trauma cases) and endotracheal intubation is needed, the BRT method allows accurate identification of endotracheal tube size and should be readily available.

REFERENCES


AUTHORS

Diane Davis, CRNA, MSN, is a nurse anesthetist at Gaston Anesthesia Associates, Gastonia, North Carolina.

Lisa Barbee, CRNA, MSN, is former assistant director, Wake Forest University Baptist Medical Center and University of North Carolina at Greensboro, Nurse Anesthesia Program, Winston-Salem, North Carolina. She currently works for Piedmont Anesthesia and Pain Consultants at Medical Park Hospital, Winston-Salem, North Carolina.

Douglas Ririe, MD, is assistant professor of Anesthesiology, Wake Forest University Baptist Medical Center, Winston-Salem, North Carolina.