Factors affecting leak around tracheal tubes in children

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This study determined which variables affected endotracheal tube "leak" pressures in 80 surgical patients, two weeks to 11 years of age, intubated with uncuffed tracheal tubes. We defined "leak" pressure as the inspiratory pressure needed to cause an audible escape of gas around the endotracheal tube. "Leak" pressure was measured after varying either head position, tracheal tube depth within the trachea, fresh gas flow rate, or degree of neuromuscular block. "Leak" pressure increased progressively from 16.9 ± 1.3 cm H_2O with complete patient paralysis to 30.6 ± 1.4 cm H_2O following 100 per cent recovery of neuromuscular function. Turning the head from a neutral position to one side increased "leak" pressure from 14.7 ± 1.7 cm H_2O to 24.4 ± 2.5 cm H_2O. Varying tracheal tube depth or fresh gas flow rate produced no significant change in "leak" pressure. Thus, there may be marked variability in "leak" pressure, depending on head position and degree of neuromuscular blockade. Keeping the patient fully paralyzed with the head in a neutral position provides a reliable and consistent method for measuring "leak" pressures.

Key words

ANAESTHESIA: paediatric; INTUBATION: endotracheal.

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A tight-fitting tracheal tube ensures the delivery of preset tidal volume and minimizes soilage of the lower respiratory tract. The smallest diameter of a child's airway occurs in the region of the cricoid cartilage[1] where a complete rigid ring makes epithelial and submucosal structures vulnerable to ischaemic injury from tracheal tube compression.[2] Subglottic stenosis may result from the subsequent healing process. Numerous clinical studies implicate tight-fitting tracheal tubes as a major aetiology of subglottic stenosis.[3–5]

A variety of methods have been proposed to aid in selecting the proper size tracheal tube. Chodoff and Helrich recommended using a tube one-half size smaller than the largest endotracheal tube that could be introduced with gentle pressure.[6] Others suggest the airway pressure during controlled inspiration at which gas escapes from between the tracheal tube and the wall of the trachea ("leak" pressure) best estimates the correct fit.[7,8]

No studies define an objective reproducible method for assessing the "leak" pressure. We reasoned that developing a uniform method of "leak" testing constitutes the first step toward clarifying the relationship between leak pressure, tracheal tube fit, and airway damage. Variables which may affect this measurement include magnitude of neuromuscular blockade, head position, depth of tube within the trachea, and fresh gas flow rate. This study examines which of these variables affects the "leak" pressure.

Methods

The Committee for the Protection of Human Subjects of the Children's Hospital of Philadelphia approved this protocol. Eighty patients from two weeks to 11 years of age requiring tracheal intubation for elective surgical procedures served as the study population. Following the induction of anaesthesia and the administration of pancuronium or metocurine to facilitate laryngoscopy, senior anaesthesia residents or staff anaesthestists inserted uncuffed, unlubricated, polyvinylchloride tracheal tubes whose sizes matched the patients, employing the formula: internal diameter (mm) of the tracheal tube = [16 + age (years)] ÷ 4. All endotracheal tubes were connected to Bain circuits, tested prior to induction to ensure integrity of the circuit. Included within the circuit was a calibrated aneroid manometer.

We determined the "leak" pressure as follows:

1 The patient was completely paralyzed.
2 The patient was supine with the head in a neutral position.
3 The tracheal tube tip was in a midtracheal position (midway between high and low positions – see below).
4 Fresh gas flowed into the breathing circuit at $5\,L{\cdot}min^{-1}$.
5 We placed a stethoscope on the skin over the larynx and completely closed the pressure relief valve. Pressure slowly increased in the circuit until an audible "leak" occurred around the tracheal tube. The aneroid manometer pressure necessary to generate this leak was recorded as the "leak" pressure.
6 If airway pressure reached 40 cm H_2O without a "leak," the test was concluded and the measurement recorded as 40 cm H_2O.

Following this control measurement, we altered the following variables:

1 Muscle tone: "leak" pressure was measured with partial (fade with tetanic stimulation) and full (no fade with tetanic stimulation) return of neuromuscular function. For patients requiring a second dose of a neuromuscular blocking agent, "leak" pressure was measured after partial return of motor functon and again following reparalysis.
2 Head position: the "leak" was measured with the head turned to the side and when returned to a neutral position (control).
3 Tube position: we measured "leak" pressure with the tube tip just past the vocal cords (high), with the tip just above the point where breath sounds became unequal (low), and with the tube midway between these locations (control).
4 Fresh gas flow rate: we checked the "leak" pressure at a fresh gas flow of $10\,L{\cdot}min^{-1}$ and again at $5\,L{\cdot}min^{-1}$ (control).

We employed analysis of variance to compare control with experimental conditions. Differences between the means were considered significant if the F statistic was significant and the least significant difference of the means was less than the observed difference for any pair of mean at $p < 0.05$.

Results

The "leak" pressure increased progressively with recovery of neuromuscular blockade. We observed a significant increase in "leak" pressure (23.7 ± 1.5 cm H_2O, mean ± SEM) from control (16.9 ± 1.3 cm H_2O) with partial return of neuromuscular function and a further significant increase (30.6 ± 1.4 cm H_2O) with full recovery (Figure 1-A). "Leak" pressure returned to control levels (18.9 ± 2.3 cm H_2O) when additional doses of neuromuscular blocker provided full muscle relaxation (Figure 1-B).

In the presence of full neuromuscular blockade, turning the head to one side significantly increased "leak" pressure (24.4 ± 2.5 cm H_2O) (Figure 1-C). Leak pressure returned to control levels (14.7 ± 1.7 cm H_2O) with repositioning of the head in the neutral position.

Varying tracheal tube depth within the trachea (Figure 1-D) and the rate of fresh gas flow into the breathing system (Figure 1-D) produced no significant change in "leak" pressure.

The only complication resulting from this study occurred in one child who developed mild postintubation croup.

Discussion

We believe "leak" pressures are higher in the unparalyzed patient because glottic and supraglottic muscle tone approximates supraglottic tissues to the outer wall of the tube, inhibiting the free egress of gas. The cricopharyngeus muscle, which attaches to the cricoid ring and blends with the oesophageal muscles, may draw the oesophagus anteriorly, compressing the trachea and reducing the size of the tracheal lumen. Turning the head causes supraglottic soft tissue to passively envelope the tube and inhibit the passage of gas.

Theoretically, "leak" pressure could vary with anaesthetic depth, a variable we did not measure. However, as shown in Figure 1-B, reparalysis returned "leak" pressure to control values even though anaesthetic depth was likely quite different

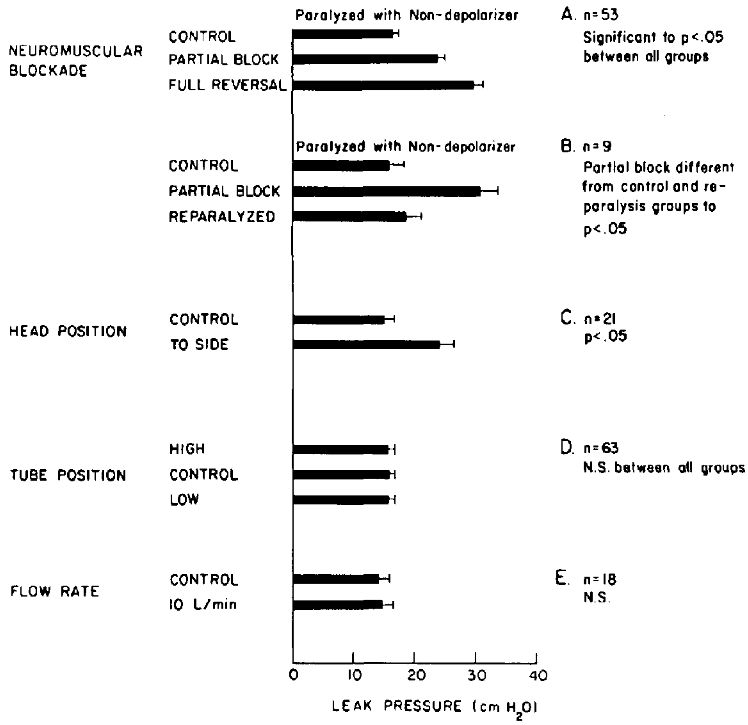

FIGURE 1 Leak pressure results. All control measurements were done with full paralysis, neutral head position, midtracheal tube position, and fresh gas flow at $5\,L \cdot min^{-1}$.

from that at the time of the control measurement. Furthermore, control values in all portions of the study were quite uniform in spite of presumed differences in anaesthetic depth. We believe, therefore, that depth of anaesthesia does not significantly affect the "leak" pressure.

Studies by Koka *et al.* and Lee *et al.* suggest that the incidence of postintubation croup in the operating room increases when leak pressures of greater than 20–25 cm of H_2O exist.[9,10] Bathersby *et al.* and Allen and Steven demonstrated a low incidence of postintubation stridor or subglottic stenosis when "lose fitting" tubes remained in the trachea of patients cared for in an intensive care unit.[7,8] However, none of these investigators defined the conditions under which "leak" testing was done. One may judge a "leak" pressure to be dangerously high in an unparalyzed patient or with the head turned to the side, and thus change to a smaller tracheal tube. If neuromuscular blockade is subsequently instituted, the tube may fit loosely, diminishing the certainty with which a present volume of mechanical ventilation reaches the alveoli or permitting gastric and pharyngeal contents to enter the tracheobronchial tree.

In summary, we have shown that there may be marked variability in "leak" pressure, depending on head position and degree of neuromuscular blockade. Keeping the patient fully paralyzed with the head in a neutral position provides a reliable and consistent method for measuring "leak" pressures.

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Résumé

Cette étude a déterminé les variables qui affectent les fuites autour des tubes endotrachéaux sans ballonnet chez 80 patients âgés de deux semaines à 11 ans, se présentant pour chirurgie. On définit la pression de fuite comme étant la pression inspiratoire nécessaire afin de provoquer une fuite audible de gaz autour du tube endotrachéal. La pression de fuite a été mesurée après variation soit de la position de la tête, soit de la profondeur du tube endotrachéal à l'intérieur de la trachée, soit en variant le débit de gaz frais, ou le degré de blocage neuromusculaire. La pression de fuite augmenta progressivement de 16.9 ± 1.3 *cm* H_2O *avec un patient complètement paralysé à* 30.6 ± 1.4 *cm* H_2O *après reprise à 100 pour cent de la fonction neuromusculaire. En tournant la tête d'un côté ou d'un autre à partir de la position neutre, on a augmenté la pression de fuite de* 14.7 ± 1.7 *cm* H_2O *à* 24.4 ± 2.5 *cm* H_2O. *La variation de la profondeur du tube endotrachéal dans la trachée ou le flot de gaz frais n'a pas produit de changement significatif dans les pressions de fuite. Ainsi il peut exister une variabilité marquée dans la pression de fuite dépendamment de la position de la tête ainsi que du degré du blocage neuromusculaire. En gardant le patient complètement paralysé avec la tête en position neutre, on fournit une méthode fiable et constante pour mesure les pressions de fuite.*