Prediction of tracheostomy tube size for paediatric long-term ventilation: an audit of children with spinal cord injury

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Background. There are no published data to predict tracheostomy tube size as growth proceeds in children requiring long-term ventilation.

Methods. A retrospective audit was undertaken of children having long-term ventilation, managed from the Southport spinal injuries unit. The dates of step-up in size of tracheostomy tube were noted together with the tube inside and outside diameters (ID and OD) and the lateral tracheal diameter. The data were aggregated for each increment in tube size to calculate the Pearson correlation coefficients for age and weight of the children. Linear regression was then used to generate predictive equations based on age and weight.

Results. Out of 12 children, data from seven boys and two girls, with a mean age of 5.9 (range 1.5–13.75) yr, were obtained. Average length of follow-up was 7 yr, with an average of 3.5 tube changes per patient equating to a larger tube every 2 yr. The inside and outside tracheal tube diameters, as well as the lateral tracheal diameter, correlated significantly with age and weight ($P<0.01$). The appropriate tracheostomy tube internal diameter is conveniently expressed by the formula:

$$\text{ID (mm)} = \frac{\text{age (yr)}}{3} + 3.5$$

Conclusions. The step-up in size of the tracheostomy tube as growth proceeds should be undertaken as a planned procedure at least every 2 yr to avoid nocturnal desaturation. Age appears to be a convenient and reliable predictor.

Br J Anaesth 2005; 94: 88–91

Keywords: children; complications, growth; complications, spinal cord injury; equipment, tubes tracheostomy, uncuffed; ventilation, mechanical

Accepted for publication: August 23, 2004

The use of uncuffed tracheostomy tubes for long-term ventilatory support of children with neurological weakness without dysphagia is well established.12 The ability to maintain an adequate minute ventilation is ensured by pressure control ventilation with an appropriate tracheostomy tube. This tube should be small enough to allow the child to speak and yet not so small that a large insufflation leak causes hypoventilation, especially during sleep.3 Unlike adults, children need to have their tracheostomy tube size increased as they grow. If this is delayed, there may be nocturnal dips in oxygen saturation or low-pressure ventilator alarms may be triggered. Adjustment of ventilator settings may buy time until a larger tracheostomy tube can be introduced. The time factor is important in this scenario as planning is required to order the appropriate product, to arrange admission to the tertiary centre, to assess the need for a general anaesthetic for stomal dilatation and to review the ventilator parameters.

In order to define a convenient method for predicting the appropriate interval for tube replacement, we have audited longitudinal data relating to tracheostomy tube management in ventilated children.

Methods

Patients

After review by the local research ethics committee, this study was deemed to be an audit. Therefore individual patient consent was not required. Children aged <15 yr presenting with spinal cord injury to the Southport spinal injuries unit over the last 12 yr were identified. Among these, records of children requiring long-term ventilatory support were then reviewed. A total of 12 children, nine boys and
three girls, were admitted between the years 1990 and 2003. The majority had spinal cord injury following a road traffic accident, except one who had tetraplegia following meningitis. Two boys whose follow-up period was <2 yr and a girl with congenital growth retardation were excluded from the study.

The mean age of the children at the time of presentation was 5.9 (range 1.5–13.75) yr (the median age was 4.4 yr). The mean follow-up time for the nine children was 7 yr. One of the girls died after 5 yr from an unrelated condition. Following rehabilitation and discharge, all children were being ventilated at home on room air. The majority were on mechanical ventilation using the Puritan Bennett Companion 2801 ventilator, one used the Breas 501 ventilator with a pressure-limiting valve and one used the Breas 401 ventilator. The uncuffed tracheostomy tubes used for management of these children included Portex Blue Line, Shiley Pediatric, Bivona pediatric and TRACOE® comfort.

The inside diameters (IDs) of all the tubes used ranged from 4.0 to 7.0 mm in incremental steps of 0.5 mm, and the outside diameters (ODs) ranged from 6.0 to 10.7 mm in unequal steps because of material differences. Figure 1 illustrates the range of OD and length of size 6 tubes from different manufacturers.

### Data collection and analysis

Retrospective data were collected by reviewing the children’s clinical records and a note was made in the event of an unscheduled step-up in tracheal tube size triggered by reported hypoventilation.

The initial tracheostomy tube product on referral to the Southport centre was recorded together with its ID and OD. The date of each subsequent change in tube size was noted together with the child’s age (yr), body weight (kg) and lateral tracheal diameter (LTD) (mm). The LTD was measured directly from the anteroposterior chest radiographs, which were available at the time of each tube change as the distance between the inner tracheal walls at the level of the tip of the tracheostomy tube. Possible magnification was assessed by comparing the tracheostomy tube outside diameter, measured on the film, with that specified by the manufacturer. For every step tube change in each child, tracheal tube ID, OD and LTD were compared with age and body weight. The mean age and weight of all children when they first used a given tube size were averaged at each incremental step of 0.5 mm (ID and LTD) and at irregular steps between sizes because of the differing thicknesses of various tracheal tubes (OD).

In some cases, at the time of the initial admission to the spinal injuries unit, the tracheal tube or the tube cuff was deemed too large with consequent impairment of swallowing or speech. Such tubes were changed to smaller-diameter uncuffed tubes shortly after admission and the size data for this tube were used for analysis. Once the data were tabulated, graphical displays were available to compare age and weight separately with ID, OD and LTD.

### Statistical analysis

The data were entered into SPSS version 9, and Pearson correlation coefficients (r) were obtained for each match of dependent variables (tracheostomy tube ID, OD and LTD) and independent variables (age and weight). Linear regression relating these variables was then used to obtain equations with constants expressed to one decimal place. P-values <0.05 were considered statistically significant.

### Results

Among the nine children, one child had signalled the need for a larger tube by recurrent oxygen desaturations during sleep at two separate stages during his growth. Four children required a brief stomal dilation under general anaesthesia to facilitate insertion of a larger tube. Two of these children later required general anaesthesia for the next change in
tube size. However, one child who was given a planned anaesthetic did not in the event need stomal dilatation in order to insert a larger tube. The mean time of follow-up was 7 yr during which period tubes were upsized on average every 2 yr. A typical tracheostomy tube progression with age is shown in Figure 2, but another child only needed two changes in tube size over a 6 yr period.

**Age**

There was a steady increase in tracheostomy tube ID with increasing age ($r=0.984$, $P<0.01$). Linear regression analysis showed a close approximation of observed and linear values (Fig. 3) as expressed by the relationship

\[
\text{ID} = (\text{age} \times 0.3) + 3.5.
\]

OD also related to age ($r=0.895$, $P<0.01$). Linear regression analysis revealed the following relationship between the two variables:

\[
\text{OD} = (\text{age} \times 0.3) + 5.5.
\]

LTD was also found to increase with increasing age ($r=0.940$, $P<0.01$). Linear regression analysis gave the relationship

\[
\text{LTD} = (\text{age} \times 1.2) + 4.6.
\]

**Weight**

ID correlated closely with weight ($r=0.963$, $P<0.01$). The relationship between the two variables obtained by linear regression analysis was

\[
\text{ID} = (\text{weight} \times 0.08) + 3.1.
\]

OD correlated well with weight ($r=0.907$, $P<0.01$) (Fig. 4). Linear regression analysis gave the following relationship between the two variables:

\[
\text{OD} = (\text{weight} \times 0.1) + 4.7.
\]

LTD also showed good correlation with weight ($r=0.905$, $P<0.01$), and linear regression analysis gave the relationship

\[
\text{LTD} = (\text{weight} \times 0.3) + 2.7.
\]

**Conclusion**

No apparent gender differences were noted in this series. ID and LTD were found to correlate best with age and OD is also closely correlated with age.

**Discussion**

This retrospective study arose out of the need to develop a simple predictor to plan the staged increase in tracheostomy tube size in community-based ventilator-dependent children in a manner which could subsequently be audited internally. In the investigation of correlations of the tube and tracheal lateral diameters with the independent variables, different...
numbers of data were available at different incremental points. Within the small cohort here, there was considerable individual variation in the number of step-ups in tracheostomy tube size and in the time intervals between changes, but on average a size increase of 0.5 mm ID can be expected every 2 yr.

In view of the good correlation expressed in the regression equations, the following simplified formulae for calculating ID or OD from the age of the child were derived:

\[
\text{ID} = \frac{\text{age}}{3} + 3.5 \\
\text{OD} = \frac{\text{age}}{3} + 5.5.
\]

These are analogous to many of the formulae used to select the ID of endotracheal tubes based on age,\(^9\) such as the widely used Cole’s formula:

\[
\text{ID} = \frac{\text{age}}{4} + 4.
\]

Again, no gender difference has been found.\(^5\)\(^6\)

There have been many radiographic studies of tracheal growth,\(^5\)\(^6\)\(^8\)\(^9\) and the trachea has been shown to have an almost cylindrical cross-section. The use of ultrasound as an alternative to radiographic assessment of tracheal size requirements has recently been described in four children with long-term tracheostomy.\(^9\) Significant impairment in growth as a consequence of traumatic paraplegia was reported in a study of 70 boys and 44 girls aged >9 yr.\(^10\) The authors noted that because of the variability in time of onset and levels of lesion and spasticity, it was impossible to derive regression equations. The tetraplegic children without height data in the present study are likely to have stunted growth, especially in the lower limbs, and may have been either over- or under-weight. Thus, while there is a workable formula linking weight and tracheal tube size, for long-term ventilation, the age-related formula seems to be more reliable and convenient.

In the acute stage of ventilatory support, children usually have oro/nasotracheal intubation. With the cricoid forming the narrow point in the major airways, there has been a reluctance to use cuffed orotracheal tubes, and although a study has given some reassurance on this point\(^11\) the available cuffed tracheal tubes have shortcomings.\(^12\) If the lungs and airway reflexes are normal, ventilating through an uncuffed tracheostomy tube has advantages provided that the insufflation leak is assessed according to blood gas trends over day and night. The OD size relative to the tracheal lumen is crucial in preventing hypoventilation, and does vary considerably among products (Fig. 1).

When the child’s trachea is large enough for a larger tube, the stoma may require dilatation and this cannot always be anticipated. The larger tube needs to be planned for and ordered in advance, and the tube length, which may be excessive in the abrupt transition to the adult range (i.e. size \( \geq 7.0 \)), must also be taken into consideration.

The placement of a larger tube can affect minute volume ventilation and the proximal airway pressure. Therefore ventilator settings and alarm thresholds may require adjustment and it may be necessary to prepare fresh documentation for the home situation. If a short general anaesthetic is required for dilatation, it provides the opportunity to confirm the adequacy of ventilation during sleep.

Our data indicate the benefit of using a simple formula relating age and internal diameter to facilitate follow-up planning for tracheostomy changes in children.

References