MATHEMATICAL ANALYSIS OF THE UPPER RESPIRATORY TRACT FROM AN ANTHROPOMETRIC STUDY

G. JANVIER, L. BORDENAVE, P. REVEL, W. ELLISON, A. M. CROS AND S. WINNOCK

SUMMARY
In order to design a new, preformed tracheal tube adapted to the shape of the upper respiratory tract, we have undertaken an anthropometric study from lateral x-rays of the neck in 130 patients with the head in a fixed position. In order to assess different clinical situations, we studied three groups of patients: group 1 = sitting, no tracheal tube; group 2 = supine, no tracheal tube; group 3 = supine, trachea intubated. We defined a standard coordinate system and determined mathematical curves for segments of the upper respiratory tract by a polynomial regression method. With these data it was possible to study the effects of physiological variations on the shape of the curves. It was then possible to determine at which region changes occur and the factors influencing these changes. We found that the relative position of the larynx was constant, whereas the hypopharynx exhibited the greatest change with the position of the head. These observations should allow us to construct a new, preformed tracheal tube with elastic compliance properties to fit the changes occurring in the region of the hypopharynx. (Br. J. Anaesth. 1993; 70: 186-191)

KEY WORDS

Prolonged nasal intubation is complicated by laryngeal lesions in a small number of patients [1]. These are produced by mechanical contact and abrasion at the level of the posterior laryngeal commissure [2, 3]. The semilunar shape of tracheal tubes exerts pressure almost exclusively on the posterior laryngeal area and forces the structure backwards. Movement of the larynx during swallowing causes friction in this area. Modification of the angle at which the tracheal tube enters the larynx may limit contact with the posterior larynx.

The first breakthrough was the introduction of polyvinylchloride tubes with thermal deformation properties. This material has improved laryngeal tolerance of tracheal tubes. However, the rate of deformation of the tube is gradual, and contact pressures are still sufficient to cause ulcers.

A second, more sophisticated, approach was the design of a preformed tube by the Swedish School of Uppsala. This tube was designed with a distal part fitting the laryngotraceal airway. In order to limit the pressure of the tube on the posterior commissure of the larynx, the shape was designed using standard anatomical features of the upper airway. Unfortunately, these tubes produced other problems (positioning problems, pharyngeal intolerance). Indeed, apart from the designers and promoters, few anaesthetists have used this tube.

It is possible that this failure may be explained by poor material conformation to the upper airway and failure of a model based on standard anatomical features.

We have undertaken a mathematical analysis of the pharyngolaryngeal anatomy of the airway based on radiological data and determined the most variable area of the upper airway as a function of factors such as cervicocephalic angulation, height, gender and age.

The goal of this work is to design a new tube in a material which adapts to upper airway morphology, in order to limit further the frequency of post-intubation laryngeal lesions.

PATIENTS AND METHODS
The study was approved by the Ethics Committee of Bordeaux University of Medicine, in accordance with the Helsinki Declaration. The patients studied were taken from three different departments: general surgery, traumatology and otorhinolaryngology.

Lateral cervicocephalic x-rays were taken with the same enlargement and corrected to actual size. For each examination, the patient’s head was maintained in a fixed predetermined position by a frame which enabled us to adjust the plane of view with respect to a vertical line. The plane of view was either horizontal or vertical, depending on the patient group.

We studied three groups of adult patients: Group 1 (sitting) consisted of 30 conscious patients (department of otorhinolaryngology) in the sitting position. In this group, the plane was horizontal.

G. JANVIER, M.D.; P. REVEL, M.D.; A. M. CROS, M.D.; S. WINNOCK, M.D.; Department of Anaesthesiology, Hospital Pellegrin, Bordeaux, France. L. BORDENAVE, INSERM U306, Bordeaux, France. W. ELLISON, PH.D., CNRS, University, Bordeaux I, France. Accepted for Publication: August 18, 1992.
UPPER RESPIRATORY TRACT: ANTHROPOMETRIC STUDY

Fig. 1. X-ray-derived diagram of the cervicocephalic region showing the co-ordinate system and the three relevant zones.

TABLE I. Subdivision of the three groups of patients according to cervicocephalic angle (9). Group 1 = sitting position, no tracheal tube; group 2 = supine position, no tracheal tube; group 3 = supine position, trachea intubated

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. angle</td>
<td></td>
<td>35</td>
<td>43</td>
<td>53</td>
<td>—</td>
</tr>
<tr>
<td>Max. angle</td>
<td></td>
<td>47</td>
<td>53</td>
<td>69</td>
<td>—</td>
</tr>
<tr>
<td>Mean angle</td>
<td></td>
<td>43.5</td>
<td>48.4</td>
<td>60.1</td>
<td>—</td>
</tr>
<tr>
<td>sd</td>
<td></td>
<td>5.1</td>
<td>4.8</td>
<td>5.1</td>
<td>—</td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. angle</td>
<td></td>
<td>19</td>
<td>34</td>
<td>44</td>
<td>—</td>
</tr>
<tr>
<td>Max. angle</td>
<td></td>
<td>33</td>
<td>42</td>
<td>60</td>
<td>—</td>
</tr>
<tr>
<td>Mean angle</td>
<td></td>
<td>25.1</td>
<td>37.5</td>
<td>50.2</td>
<td>—</td>
</tr>
<tr>
<td>sd</td>
<td></td>
<td>4.4</td>
<td>2.6</td>
<td>4.7</td>
<td>—</td>
</tr>
<tr>
<td>Group 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min. angle</td>
<td></td>
<td>7</td>
<td>31</td>
<td>43</td>
<td>55</td>
</tr>
<tr>
<td>Max. angle</td>
<td></td>
<td>29</td>
<td>42</td>
<td>54</td>
<td>70</td>
</tr>
<tr>
<td>Mean angle</td>
<td></td>
<td>21.5</td>
<td>36.6</td>
<td>48.4</td>
<td>56.2</td>
</tr>
<tr>
<td>sd</td>
<td></td>
<td>7.3</td>
<td>3.6</td>
<td>3.9</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Group 2 (supine position, non-intubated trachea) consisted of 70 conscious patients (department of traumatology) in the supine position. All the patients had bone fractures of the lower part of the body; patients with trauma to the upper body were excluded. In this group, the plane was vertical (perpendicular to the table).

Group 3 (supine position, trachea intubated and lungs ventilated) consisted of 30 anaesthetized patients (department of general surgery) with a nasotracheal tube. In this group the plane was vertical (perpendicular to the table).

All tracheal intubations were with Portex Blue Line tracheal tubes.

For each x-ray the same orthogonal co-ordinate system was used to trace the shape of the pharyngo-laryngeal airway. The co-ordinate axes were defined as follows: the Y axis was the prolongation of the line passing through the upper plane of the vertebral body of the 6th cervical vertebra (C6); the X axis was the line perpendicular to the Y axis and passing through the lower posterior part of the subglottic radio translucency at the C6 level (fig. 1).

Each x-ray was defined with respect to these axes. The points which define the curve of the upper airway were chosen on the posterior wall of the airway. The curve representing the shape of the pharyngo-laryngeal airway was obtained by measuring the airway co-ordinates at 1-cm intervals along the X axis, starting at the upper face of C6 and continuing to the bony palate. The upper face of C6 was chosen to define the Y axis because it is situated just below the vertebral body of C5 which, in the adult, is at the same level as the glottis. Moreover, in the median plane, the region C6-7 is in a zone which is inflexible. Thus the co-ordinate axes are not modified by possible extreme lordosis or "straight neck".

The zones studied (fig. 1) were:

Zone L. The region between the upper face of C6 and the projection of the large horn of the hyoid bone on the airway. This region corresponds to the larynx.

Zone H. The region between the hyoid bone and the bony plane of the palate. This region corresponds to the hypopharynx.

Zone V. The region between C6 and the palate, which corresponds to the upper airway.

The set of curves for the same zone varied considerably. This is a reflection of the individual morphological variations in each of the three groups. Consequently, and in accordance with data in the literature [4-7], certain factors were taken into account. These were:

The cervicocephalic angle (the angle between Y axis and the straight line passing by the orbital floor and the external occipital protuberance). This is a good index of individual anatomical variations in cervical
rotation. In each of the three groups, the cervicocephalic angle covered a wide range of values and it was necessary to divide the angles into three or four homogenous subgroups (table I).

**The subject’s height.** The patients were classified into two subgroups according to body height: subgroup T1 = patients of height less than 1.65 m (mean 1.6 (SD 0.03) m); subgroup T2 = those of height greater than 1.65 m (mean 1.72 (0.03) m). The mean height of all patients was 1.66 (0.06) m.

**The subject’s gender.**

**The subject’s age.** Patients were classified into two subgroups: subgroup A1 = patients younger than 50 yr (mean 32 yr, range 18–60 yr; subgroup A2 = patients older than 50 yr (mean 68 yr, range 61–87).

The mean age for all patients was 53 yr.

X-rays were analysed as follows. First we describe the shape of each of the upper airway curves by a polynomial regression technique. The entire upper airway zone V is well approximated by a cubic polynomial and when the analysis is restricted to either zone L or H, the “best” cubic polynomial has the coefficient of X⁰ equal to zero—that is, it is a quadratic polynomial. In all cases, the correlation coefficient for the polynomial regression was > 0.95. This indicates that all the experimental curves were well approximated by the polynomials. Thus we can say that the shape of an upper airway curve in the zones V, L and H can be described adequately by a polynomial of maximum degree of 3.

The second step was to compare the curves for each of the three groups of subjects and the four variation factors in the three zones L, H and V. We chose to use the area between the curve and the X axis for the cervicocephalic angle subgroups. The area was calculated from the polynomial equation defining the curve in the zone L, H or V. If two curves are the same, then the areas are the same; if areas are not the same, the two curves are different; if two areas are the same, one cannot conclude anything about the curves. This relatively crude indicator was sufficient for our purposes according to the following reasoning: in a random group of subjects in identical clinical situations, there are wide differences in the cervicocephalic angle and the area under the curve. Large differences in the areas in zone H imply differences in the curves.

Thus one can say that in a clinically homogeneous group of subjects there are large variations in the morphology of the upper airway in the zone H and no “standard” model exists.

**RESULTS**

**Shape of the averaged curves**

The average curve of all three groups for zone V is shown in figure 2. When the curves of each group are considered separately, major variations become apparent (fig. 3). The difference in the subject’s position (supine or sitting), whilst the head is maintained in an apparently controlled position (i.e. horizontal or vertical, depending on the groups), is responsible for these differences.
UPPER RESPIRATORY TRACT: ANTHROPOMETRIC STUDY

Fig. 4. Representation of correlation between cervicocephalic angle and area under curve for group 2 (supine, no tracheal tube) in zone V. \( y = -14.6419 - 1.072x; r = 0.66 \).

<table>
<thead>
<tr>
<th>Zone L</th>
<th>Angle</th>
<th>Height</th>
<th>Sex</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( r = -0.33 )</td>
<td>( P &lt; 0.05 )</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone H</th>
<th>Angle</th>
<th>Height</th>
<th>Sex</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( r = -0.52 )</td>
<td>( P &lt; 0.01 )</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zone V</th>
<th>Angle</th>
<th>Height</th>
<th>Sex</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( r = -0.66 )</td>
<td>( P &lt; 0.01 )</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

The relative importance of each of the factors on the morphology of the three regions is summarized in table III. In terms of the correlation coefficient, \( r \), there was a statistically significant correlation between the areas under the curves and the patient's ages (table IV). For the two groups A1 and A2, the difference in the mean areas was significant for zones H and V and non-significant for zone L.
be reported by Alexopoulos and his colleagues in their work on a new intubation device [8–13]. The changes in cervicocephalic angle imply significant deformations in the pharyngolaryngeal structures. There is great mobility in the vertebral segments of the spinal column in zone H; the anatomical representation of the larynx (zone L) is more constant. The small amplitude of movement and the rigidity of the thyroid cartilage are probably responsible for the small amount of variation in position of the larynx in the median plane. Obviously, our study cannot take into account the superoinferior movements of the larynx, because the radiographic analysis was static.

The anatomical variations are essentially individual. They are caused by changes in body position without the head being either in flexion or in hyperextension. This accentuates the opening or closing of the cervicocephalic angle and thus it is difficult to predict the position of the cervical spine and the upper airways as a function of head position.

The anatomical variations induced by the cervicocephalic angle are of prime importance in the change in position of the airway. Analysis of age showed that young adults have a more pronounced pharyngeal convexity than older subjects. This may be explained by greater suppleness of the tissues which surround the cephalic extremity. The other variables which we studied (gender, height) were less important in our population.

Any new type of intubation device which has minimum contact pressure in the larynx should be constructed of a material which deforms in the median plane and adapts to the anatomical variations observed in this study. This is particularly true for the hypopharyngeal region.

REFERENCES
11. Alexopoulos C, Larsson S, Lindholm CE. The anatomical...
