Normal growth and development of the trachea

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ABSTRACT A quantitative study of the trachea has been made in 452 children with apparently normal tracheas ranging from 28 weeks' gestation to 14 years. In the neonatal period the trachea is funnel shaped with the upper end wider than the lower end. It becomes cylindrical with increasing age. The ratio of cartilage to muscle remains constant throughout childhood. The trachea appears to grow at a greater rate, in relation to crown-rump length, during the age of 1 month to 4 years than in utero or around puberty. Normal measurements for formalin-fixed tracheas related to crown-rump length are presented.

With the increasing recognition of structural anomalies of the trachea causing clinical symptoms\(^1\)\(^2\) it has become necessary to provide more information on the ranges of normal structure of the trachea in children. Our knowledge of the functional structure of the whole of the tracheobronchial tree is limited, largely because of the problems that restrict study of the respiratory system during life. Most of the data available on the size and shape of the trachea have been obtained from dead tissues, either by direct measurement\(^3\)\(^4\) from tracheal casts\(^5\)\(^6\) or by using urethral dilators.\(^7\) As the trachea increases in length and diameter during inspiration and becomes shorter and narrower during expiration\(^8\)\(^9\) postmortem studies can only give information on gross form as a hint of physiological function.

This study has been done on necropsy material and is designed to assess the variability of some gross structures of the tracheal wall and their pattern of change throughout childhood.

Methods

The routine necopsy procedure in the Children's Hospital, Sheffield, is that the larynx is opened to expose the vocal cords and the interior of the main bronchi is exposed by incising their posterior walls from the carina downwards. The unopened trachea is fixed, with the lungs, in 10% formol calcium for about four days before a standard block is cut out, transversely, midway along the trachea between the larynx and the tracheal bifurcation. Paraffin sections are cut at a thickness of 6 \(\mu\)m and stained with Goldner's Trichrome.

The standard midtracheal sections from 1000 sequential necropsies were used for this study. The tracheas were taken from children of all ages dying sequentially in the Sheffield Area during 1967-77. When the slides were taken for measurement the age, the clinical histories, and the postmortem findings were not known.

The slides were projected through a photography enlarger at a standardised magnification (\(\times 15\)) on to a flat white surface to show the gross structure of the tracheal wall. The only criteria used in selecting specimens were based on the quality of the image produced. All specimens in which the rings were incomplete by artefactual loss of tissue, folding of the cartilage, or irregularity of the mucosal surface were discarded. With the use of a map measure, the following measurements were made of the enlarged image of the trachea ring: (a) the length of the tracheal cartilage; (b) the length of the transverse muscle—that is, length of the tracheal membrane; (c) the total internal perimeter at the level of the mucosal basement membrane. The data on (a) and (b) were then used to calculate the ratio of the length of cartilage to length of muscle.

When the measurements were completed, the full clinical histories and the detailed pathological findings at necropsy were collated and the children were grouped as follows: (1) Those without congenital anomaly and with no postmortem changes indicative of pathology of the respiratory tract; this group comprised children dying by accident, poisoning, or acute illnesses not affecting the respiratory system—that is, apparently normal respiratory tracts in anatomically normal children. (2) Those with gross congenital anomalies—that is, congenital heart disease, myelomeningocele, multiple deformities, chromosomal abnormalities; some of these also had
Those dying unexpectedly in infancy—that is, cases of "cot death"—without any congenital deformity and with no reported history of symptoms suggesting disease of the respiratory tract. (4) Those with no gross deformities but with a history suggesting disease of the respiratory tract; some of these were hospital deaths and some cot deaths.

Of the original 1000 tracheas the measurements of the 392 from children classed as anatomically normal (group 1 above) are reported here. These comprised 70 stillborn babies (28–40 weeks' gestation), 207 liveborn babies (40 weeks' gestation to 1 year), and 115 children (1–15 years). The range of crown-rump length was 20–90 cm.

For the study of the general shape of the trachea a further 60 overtly normal tracheas from children conforming to category 1 were removed by the routine necropsy procedure and fixed in formaldehyde for four days. Twelve to 15 serial transverse blocks were taken throughout the length of the trachea, the thickness of the blocks varying with the length of the trachea. The blocks were sectioned, processed, and measured in the same way as in the standard block survey. The cases were then grouped according to the crown-rump length of the child. The number of children in each crown-rump-length group, measured in centimetres, was: 59–63, 8; 52–58, 6; 47–51, 4; 42–46, 4; 37–41, 5; 32–36, 14; 28–31, 10; 23–27, 9.

Results

ALTERATION IN FORM OF TRACHEA WITH AGE

The 60 tracheas that were sectioned throughout the entire length show how the parameters vary at different points along the length of the trachea, and how they may be affected by increasing size and age. The mean length of cartilage and muscle and internal perimeter were calculated for each point on the trachea for each group of children.

The method of presentation is as follows. A device for comparison of corresponding points of tracheas of children of different sizes is used. The length of the trachea is represented by the horizontal distance between the vertical broken lines from larynx to carina; each solid line represents the mean length of an element of tracheal tissue for a group of children of specified crown-rump length. The mean total internal perimeters for children of different sizes are shown in figure 1. The slope of the lines indicates the difference in size between the laryngeal and bronchial ends of the trachea. We see that the trachea is funnel shaped, the top being the larger end of the funnel. The trachea of the neonate with a crown-rump length of 25 cm shows the greatest difference between the upper and lower end, and there is a progressive diminution of this difference with increasing age; the trachea is thus more cylindrical in the older child. The difference in internal perimeter between the top and the bottom of the trachea in the smallest children is 1 mm, while it is only 0.1 mm in children with a crown-rump length of 60 cm.

This pattern of growth is repeated for the cartilage and the muscle. While there is a gradual increase in the length of cartilage at all points of the trachea throughout childhood, the cartilages at the upper end remain longer than those at the bottom. This difference is more pronounced in the smallest children: 1-6 mm in the smallest neonates and only 1-2 mm in children with a crown-rump length of 60 cm.

There is also a gradual increase in the length of muscle with age, and like the cartilage and internal perimeter the muscle is longer at the top than at the bottom. Unlike the internal perimeter and cartilage, however, the difference is greater in the older children, as the slopes on the lines indicate. The difference in the length of muscle between the top and bottom in the smallest children is 0-1 mm while in the oldest group it is 0-25 mm.

Despite the differential growth of the tracheal wall and the size of the tracheal lumen, the ratio of the length of cartilage to the length of muscle remains unchanged for each point on the trachea regardless of age.

GROWTH OF THE TRACHEA ASSESSED AT THE MID-POINT

From the measurements of the tracheal sections of the specimens of group 1, the growth pattern of the tracheal tissue is assessed in figures 2, 3, and 4.
There is a continuous increase of the internal perimeter with crown-rump length, but with three apparently different phases (fig 2). In phase one, as the crown-rump length increases from 20 to 35 cm the tracheal perimeter enlarges by 4 mm, a rate of 2-6 mm per 10-cm increase in crown-rump length. This corresponds to the final 12 weeks of intrauterine growth—that is, the 28th to the 40th week of gestation. In the second phase, as the crown-rump length increases from 35 cm to 75 cm the corresponding increase in the internal perimeter is 20 mm, averaging 5 mm per 10-cm increase in crown-rump length and almost double the rate of the intrauterine phase. In phase three, which corresponds to the postpubertal period, the average increase is 2-6 mm per 10-cm increase in crown-rump length, which is equal to that of the later intrauterine period.

In parallel with the increasing internal perimeter the cartilage and muscle both grow in the same way, in three phases. The appropriate rates for the increase in the length of cartilage per 10-cm increase in crown-rump length (fig 3) are: phase 1—2-6 mm; phase 2—4-5 mm; phase 3—2 mm. For the muscle (fig 4) the corresponding rates are: 0-7 mm, 1-25 mm, 0-7 mm. The relative lengths of cartilage and muscle remain the same throughout all periods of growth, as shown in figure 5.

**Discussion**

Our method of study of the trachea, like previous methods, has limitations. Of foremost concern in assessing postmortem material is the accurate estimation of the normal, since the material is always biased towards abnormality. While the grossly abnormal is easy to identify, children who are marginally abnormal present difficulty. About a third of the children had died unexpectedly after being apparently normal and healthy. Histological examination of certain tissues, however, notably the costochondral junction, thymus, and liver, showed changes suggesting that growth had not been normal for some time before death. Sinclair-Smith et al found that over 90% of children dying unexpectedly...
showed evidence of growth retardation at the costochondral junction, which may reflect a more generalised growth disturbance. How far this disturbance of growth affects tissues such as those of the trachea and the crown-rump length of children is not certain, but they are probably affected in a parallel way; and this is probably why our data for the trachea correlate better with crown-rump length than with body weight or age. Another problem is the question of how postmortem shape and configuration reflect shape during life. In general, postmortem autolysis produces laxity of soft tissues, whereas fixation causes contraction of these tissues. Any alteration in shape will be greater in hollow organs like the trachea and gut than in solid ones like the liver or spleen. There is no evidence that the effects of fixation are appreciably age dependent and thus we believe that our results are valid, at least on the basis of relative growth.

In brief, we find the trachea to be funnel shaped in the newborn, wider at the top than at the bottom, becoming marginally more cylindrical during the first five years after birth. During this period of differential growth, the ratio of cartilage to muscle remains constant, so that the rigidity of the wall is maintained. Others have found a funnel-shaped trachea in children, notably Donaldson and Tompsett and Butz. However, and Beneke and Endres thought that the trachea was spindle shaped. This difference could be accounted for by the different methods used in those studies, one of which relied on tracheal casts and the other on direct measurement of fresh postmortem material.

References