Section of Anæsthetics

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The Physiology of Respiration in Infants and Young Children

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IN the management of anæsthesia for the adult patient, the respiration is used as an important sign of the level of anæsthesia. In pædiatric practice the interpretation is more difficult owing to the changes in respiration occurring as the child grows. These variations in the anatomical and physiological development of the child's respiratory system form the subject of this paper.

Development of the lung.—The fœtal lung develops by a process of budding and elongation of the primary stem into the mesodermal mass, and after birth this process continues increasing the size of the lungs and the bronchial tree. The progress of this development has been studied by Engel (1947) in a series of examinations of post-mortem material and his results are summarized in Table I. The lung volume enlarges rapidly in the first year and then slows down till after the second year when the growth becomes roughly parallel to the increasing weight of the child. The internal development of the lung is more important and the estimates of the surface area show a higher rate of development, again more marked during the first two years. In contrast the air passages grow slowly and whereas the trachea takes two years to double its volume, the lung volume has reached this stage in twelve months.

TABLE I

Age	Lung volume c.c.	Surface area sq. cm.	Tracheal length cm.	Tracheal diameter mm.
Birth	100	16,000	4·0	6·0
3/12	150	—	3·8	6·8
6/12	230	57,000	4·2	7·2
12/12	400	—	4·3	7·8
18/12	470	111,000	4·5	8·8
2	500	184,000	5·0	9·5
3	550	236,000	5·3	—
4	600	—	5·4	11·0
5	700	—	5·6	—
6	800	—	5·7	—

The thoracic cage must grow to contain this increasing lung volume and its growth is therefore greatest in the first eighteen months, during which time its circumference increases by 50%. The shape is usually described as round in comparison to the adult chest, but even at birth there is a difference of 2 cm. between the antero-posterior and transverse diameters of the chest. This difference increases slowly at first during childhood, as a result of the different rate of growth in the two diameters, but after the age of 2 years, the ribs, which have been almost horizontal since birth, now start to slope downwards and this contributes to the increasing difference in the chest diameters. The main change in the shape of the chest, however, occurs during puberty when the difference in the two diameters of the chest alters from 6 cm. to 12 cm.

Respiration in the child.—The physiological investigation of respiration in the child has been confined principally to neonates and to school children, as between these ages it is impossible to obtain the co-operation of the subject. The results of Denning and Hienner (1936) and Cross (1949) on neonates agree very well, and their average results suggest 20 ml. as the tidal volume and 30 per minute as the rate. These are the resting values and are considerably exceeded when the child is active but the increase in ventilation demands a high energy expenditure and cannot be maintained for any length of time. When the respiration of school children has been investigated it has usually had a clinical bias to provide a standard for the assessment of the variations produced by disease. As a result there are a number of observations on such limiting factors as maximum ventilation rate and vital capacity but very few on normal quiet respiration. The results of two recent workers Piechaud (1951) and Ferris (Ferris *et al.*, 1952) are shown in Table II. The considerable difference in the results for vital capacity and the high value for the tidal volume are undoubtedly due to the difficulties of obtaining figures under constant basal conditions and suggested that the investigation of the respiration of children under anæsthesia would be of value.

TABLE II

	Piechaud		Ferris
Age	Tidal volume ml.	Vital capacity ml.	Vital capacity ml.
4	300	500	—
5	320	580	1,290
6	360	660	1,650
7	400	820	1,930
8	460	980	2,160
9	500	1,150	2,190
10	560	1,360	2,230
11	600	1,600	2,540
12	680	1,680	3,750
13	796	1,960	3,810

TABLE III

Age	Tidal volume ml.	Rate per minute	Minute volume ml.
6/12	64	55	3,500
12/12	79	45	3,700
18/12	131	33	4,300
2	143	30	4,400
3	156	31	4,900
4	180	30	5,500
5	192	28	5,400
6	199	27	6,000
7	204	30	6,300
8	228	25	6,200

Respiration under anæsthesia.—Such an investigation would reduce the variations due to the non-co-operation of the subject but naturally would add those of premedication and type of anæsthesia. To minimize these a large series of cases were studied and for convenience in the operating theatre the apparatus was kept small and portable. A small Krogh type spirometer was used, writing directly on the drum and connected to the patient by the usual anæsthetic tubing and face mask. The cases studied were principally "cold" operation cases of hernias, squints, and plastic repairs, of the age groups 3 months to 8 years. The measurements were made at the end of the operation just before the patient was returned to the ward. The dead space of this apparatus was large but its effect was minimized by keeping the time of recording short and repeating after a few breaths of air. 487 of the records were analysed and the results are shown in Table III. This shows a rapid increase in the tidal volume during the first two years, which then slows down, similar in pattern to that seen for the volume of the lung in Table I. The rate changes in an inverse manner, starting rapidly and slowing down during the first two years, then remaining steady. These two changes produce a more gradual increase in the minute volume. As the observations were made on children over the age of 3 months the variable pattern of respiration seen by Denning and Hienner (1936) in neonates was not seen and the respiration was always regular but not of adult pattern during the first two years. During this period the respiration is almost entirely abdominal in character as the ribs still maintain their original horizontal position. The thoracic cage can only enlarge slightly by means of the so-called "bucket-handle" movement of the ribs and respiration is maintained principally by diaphragmatic movement. Thus the tidal volume is limited and increased respiratory demands can only be met by an increase in rate. Interference with the free movement of the diaphragm by the presence of gas in the stomach or limitation of the abdominal movement either by surgical manipulations or the use of the prone position will reduce the tidal volume. When the ribs become more oblique after the age of 18 months the thoracic movements are increased for now the ribs can move up and down lifting the sternum and so enlarging the thorax. This allows the tidal volume to be increased to compensate for higher oxygen demands and the increase in rate is only used as a reserve mechanism.

The rapid respiratory rate of the infant under anæsthesia might be explained on the basis of carbon dioxide retention, and attempts were made to estimate the alveolar carbon dioxide in a number of small babies. No satisfactory result was obtained as the method, that of Rahn and Otis (1949), did not function well on their small tidal volumes and rapid respirations. Over the age of 3 the method was satisfactory, but the average alveolar carbon dioxide content was normal or a little below (4·3–4·5%). However, the suggestion that the rapid respirations might be due to carbon dioxide retention is supported by a consideration of the dead space of the child in relation to that of the adult. Anatomically the dead space may be defined as that part of the respiratory tract which does not allow respiratory exchange to take place and consists of the oronasopharynx, trachea, bronchi and bronchioles. At the end of expiration this space is filled with expired air; the next inspiration will draw in fresh air, which will be diluted by this volume of expired air and the resultant mixture reaching the alveoli will contain, therefore, less oxygen but more carbon dioxide than the atmospheric air. As the composition of the atmospheric air is constant, the concentrations of the gases reaching the alveoli during a given inspiration are in direct relationship to those removed during the previous expiration and therefore sudden changes in the blood gases are avoided. By measuring the concentration of a gas in the inspired, expired and alveolar air, and knowing the tidal volume, it is possible to calculate the volume of the diluting gas, or dead space, which can be defined physiologically as that volume of the inspired air which does not take part in respiratory exchange. Assuming that the adult relationship between the expired and alveolar carbon dioxide content remains true for infants, the dead space can be estimated as one-fifth of the tidal volume (Table IV).

TABLE IV

Age	Tidal volume ml.	Dead space ml.
6/12	64	12
12/12	79	16
18/12	131	26
2	143	29
3	156	31
4	180	36
5	192	38
6	199	40
7	204	42
8	228	46

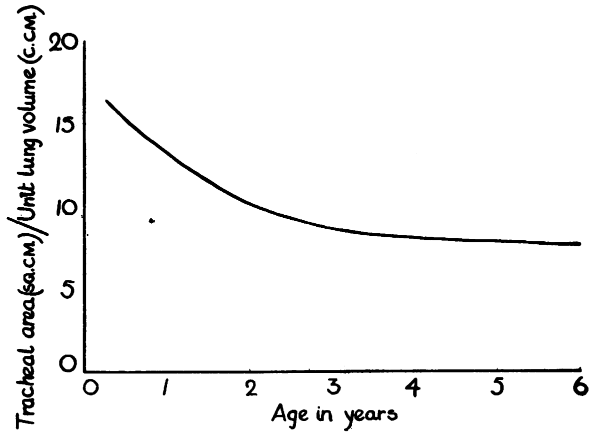

FIG. 1.

These figures indicate the magnitude of the dead space but do not show the relative changes. The cross-sectional area of the trachea is directly proportional to the dead space and this has been divided by the lung volume and plotted against age to obtain the graph, Fig. 1, which shows that the relative dead space decreases with age, and this would contribute to the high respiratory rate of the infant.

Effect of added dead space.—To evaluate these figures in terms of practical anæsthesia of children where the semi-closed method is commonly used the effect of the added dead space in the mask and connexions should be considered. The smallest mask generally used has a volume of roughly 50 ml. allowing for the volume taken up by the nose and face when it is in position, and can be used up to the age of 1 year. The natural dead space at this age is 16 ml. to which must now be added the mask volume of 50 ml., a total of 66 ml. As the tidal volume is only 79 ml. there is a theoretical alveolar ventilation of only 13 ml. with each respiratory cycle or 585 ml. per minute, or one-fifth of the normal alveolar ventilation. The next size of mask has a volume of 80 ml. and can be used up to the age of 4 years, when the child will have a tidal volume of 180 ml. and a natural dead space of 36 ml., and the corresponding figures will be 64 ml. per cycle and 1,920 ml. per minute, or half of the normal. To try and follow the changes due to this alteration of the dead space, the Rahn and Otis (1949) sampling attachment was placed between the anæsthetic face mask and the expiratory valve so that samples of the expired gas could be taken without interrupting the anæsthesia. Some dilution of the sample occurred as a reults of the high flow rate of anæsthetic gases used, 6 litres/min., and the results cannot be compared to normal expired air but they do enable the changes in a given case to be followed. The results of a typical case are seen in Table V and show that after the induction period the carbon dioxide level falls continuously.

TABLE V

Age 4 years. Pre-med.—Rectal Pentothal and Atropine
Anæsthesia—Gas, oxygen and ether

Time in minutes	0	15	25	35	45
% CO_2	2·54	3·00	2·30	2·25	2·15

Conclusion.—It has been shown that the respiratory system of the child develops most rapidly in the first two years and then more slowly during the rest of childhood. The addition of the dead space of anæsthetic apparatus to the relatively large dead space of the infant combined with the small tidal volume gives rise to a potential danger of carbon dioxide retention. The results of measurements on the expired carbon dioxide during anæsthesia suggest that this danger can be avoided, provided that the flow rate of gases is kept sufficiently high.

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The Complications of the Trendelenburg Position [*Summary*]

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Dr. Hewer reviewed the history of, and indications for the use of the Trendelenburg position for the patient during surgery, and discussed the physiological disturbances which accompany it.

In the cardiovascular system these include hydrostatic effects leading to a rise in cerebral arterial, venous and C.S.F. pressures. The speaker drew attention to the risk of levelling up the patient too rapidly at the end of the operation if there had been much hæmorrhage or when vasomotor tone was depressed.

In the respiratory system, the upward displacement of the diaphragm by the abdominal viscera appreciably reduces the vital capacity. Thus hypoxia and hypercarbia are likely to occur unless adequate ventilation is ensured. This respiratory embarrassment is often aggravated by a distended stomach, and the passage of a stomach tube is often worth while. Secretions which nevertheless collect in the most dependent part—the nasopharynx—should be removed by suction before levelling the table.

The risks of injury to the brachial plexus and to other parts of the body were discussed in relation to the methods employed for securing the patient in the Trendelenburg position. The usual methods of strapping the legs, or of using pelvic or shoulder rests all have disadvantages; these are obviated by a technique which utilizes the principle of skin friction, by means of a special corrugated rubber mattress with special bolsters under the neck, back and Achilles tendons (Fig. 1).

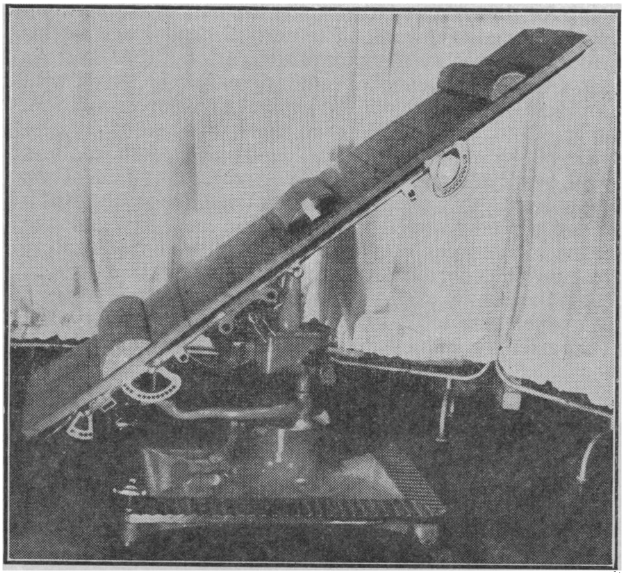

Fig. 1.—Corrugated rubber mattress hooked on to foot-end of tilted operating table. The three transverse ribbed bolsters fit respectively into the concavities of the patient's neck, lumbar region and Achilles tendons. The arms are secured on the central (lumbar) bolster, if desired.

Acknowledgment.—Fig. 1 from *Brit. med. J.*, 1955, ii, 127; by kind permission.

Dr. Hewer concluded with a description of the details and advantages of this method of fixation based on his experience with it over the past two years.