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PRESSURE–FLOW CHARACTERISTICS AND DEAD SPACES OF ENDOTRACHEAL TUBES USED IN INFANTS

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IN 1945, Cole[1,2] described a series of endotracheal tubes of non-uniform bore (fig. 1) devised especially for the intubation of infants and small children. These tubes consisted of a short segment (2.5 to 4.5 cm.) of small bore suitable for insertion into the trachea and a larger and longer segment (approximately 9 cm. long and with an internal diameter of 3.94 mm. in all cases) for attachment to resuscitative or anesthetic equipment. Because only the diameter of the short end was restricted by the size of the trachea, the principle advantage claimed for tubes of this design, compared to tubes of uniform bore, was a decrease in the resistance to the flow of air. A theoretical disadvantage, not noted by the author, was an increase in respiratory dead space. The present study on the pressure-flow characteristics and dead spaces of endotracheal tubes used in infants was undertaken, since apparently no previous measurements were available.

FIG. 1. Cole endotracheal tube.

METHOD

Flow rates through the endotracheal tubes were measured with a Krogh spirometer recording via a rotational transducer * and a direct writing oscillograph.† The paper speed was timed electrically. Pressures across the tubes were measured during different flow rates by a U-shaped water manometer for higher pressures and a pressure transducer † for pressures under 2 cm. of water. Endotracheal tubes of uniform bore ranging in internal diameter from 1.58 to 3.73 mm. were studied, as well as Cole endotracheal tubes whose smallest internal diameter varied from 1.09 to 3.30 mm.

RESULTS AND DISCUSSION

The results of the measurements of pressure-flow characteristics of the various endotracheal tubes are shown in figures 2 and 3. The dead spaces of the tubes are shown in table 1 together with the age and size of the patients for which these tubes are designed. For purposes of comparison, peak flow rates during quiet respiration and estimated total respiratory space for the infants and children of different sizes are given.

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* Manufactured by Doelcam Division of Minneapolis Honeywell, Brighton, Massachusetts.
† Manufactured by the Sanborn Company, Waltham, Massachusetts.

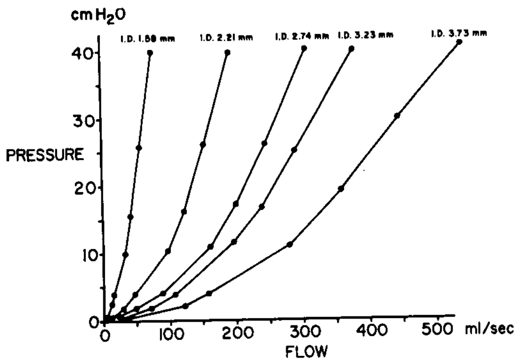

Fig. 2. Pressure-flow characteristics of endotracheal tubes of Uniform Bore (I.D. = internal diameter).

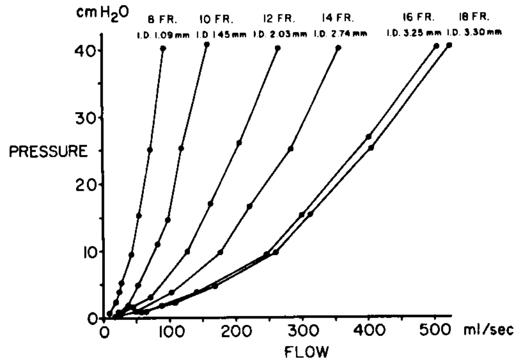

Fig. 3. Pressure-flow characteristics of Cole endotracheal tubes (I.D. = internal diameter).

Resistance (R) to linear flow is related to the radius (r) of a tube as well as its length (l) according to the following equation:

$$R = k \times \frac{l}{r^4}$$

When there is turbulent flow, R is more closely related to $1/r^5$. Because the narrower portion of the tube is limited in length in the Cole design, it would be expected that the resistance would be less. That this difference provides a significant advantage is shown by comparison of two tubes of approximately the same internal diameter (approximately 2.74 mm.) at their tracheal end. At the estimated peak flow rate of 60 ml./second, the Cole tube's resistance would be about 1.5 cm. of water, while that of the tube of uniform bore would be 2.5 cm. of water. At a higher flow rate of 180 ml./second, which might well occur during anesthesia, the absolute difference in resistance pressures is much greater, 5 versus 10 cm. of water. Although infants are able to produce 40 to 60 cm. of water pressure with their respiratory muscles,[6, 7] even 10 cm. of water pressure resistance would be taxing to an infant during spontaneous respiration. Hence for the same internal diameter of the endotracheal portion of the tube, the Cole design provides a lower resistance than the tube of uniform dimensions.

The volume of endotracheal tubes might contribute significantly to the total respiratory dead space of patients. Therefore this parameter was examined. The volume of the smaller Cole tubes was several times that of the comparable tubes of uniform bore (table 1). However, this added dead space was

TABLE 1

Estimated Respiratory Dead Space and Peak Flow Rates for Infants and Comparison of Uniform and Cole Endotracheal Tubes

Age	Patient Size[3], Weight (kg.)	Estimated Respiratory Dead Space[4] (ml.)	Estimated Peak Flow Rates-Quiet Resp.[5] (ml./second)	Appropriate Cole Tube			Appropriate Uniform Tube	
				(Fr.)	I.D. (mm.) (small end)	V_D (ml.)	I.D. (mm.)	V_D (ml.)
Premature	1.0	2	20	8	1.1	1.13		
Premature	1.5	3	30	10	1.5	1.16	1.6	.3
Newborn	2.0	4	40	12	2.0	1.23	2.2	.5
Newborn	3.0	6	60	14	2.7	1.33	2.8	.8
1–3 mos.	4.0	9–12	100	16	3.2	1.43	3.2	1.1
3–9 mos.	4.5–8	10–18	150	18	3.3	1.45	3.7	1.4

I.D. = internal diameter and V_D = dead space volume.

replacing the dead space of the nasopharynx and larynx. Since this bypassed space is approximately half of the total respiratory dead space, the total is not appreciably increased even with the Cole tubes, and in fact, in some instances may be reduced.

SUMMARY

The pressure-flow characteristics and contribution to total dead space of endotracheal tubes used for infants and children were examined. The Cole tube, with a short, narrow end for introduction into the trachea and a larger end for attachment to resuscitative or anesthetic equipment, was found to have a smaller flow resistance than the tubes of uniform bore. This difference should be advantageous to the patient. The difference in dead space contribution of the two types of tubes was not considered important to the patient.

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