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Incremental change in cross sectional area in small endotracheal tubes: A call for more size options

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ABSTRACT

Objective: To elucidate the relatively large incremental percent change (IPC) in cross sectional area (CSA) in currently available small endotracheal tubes (ETTs), and to make recommendation for lesser incremental change in CSA in these smaller ETTs, in order to minimize iatrogenic airway injury.
Methods: The CSAs of a commercially available line of ETTs were calculated, and the IPC of the CSA between consecutive size ETTs was calculated and graphed. The average IPC in CSA with large ETTs was applied to calculate identical IPC in the CSA for a theoretical, smaller ETT series, and the dimensions of a new theoretical series of proposed small ETTs were defined.
Results: The IPC of CSA in the larger (5.0–8.0 mm inner diameter (ID)) ETTs was 17.07%, and the IPC of CSA in the smaller ETTs (2.0–4.0 mm ID) is remarkably larger (38.08%). Applying the relatively smaller IPC of CSA from larger ETTs to a theoretical sequence of small ETTs, starting with the 2.5 mm ID ETT, suggests that intermediate sizes of small ETTs (ID 2.745 mm, 3.254 mm, and 3.859 mm) should exist.
Conclusion: We recommend manufacturers produce additional small ETT size options at the intuitive intermediate sizes of 2.75 mm, 3.25 mm, and 3.75 mm ID in order to improve airway management for infants and small children.

1. Introduction

In the management of tiny infants and small babies, pediatric intensivists are repeatedly faced with the task of trying to appropriately match a very limited number of endotracheal tube (ETT) sizes to a wide ranging continuum of pediatric airway shapes and lumen sizes.

While it is still widely held that cuffless ETTs are the most appropriate type of ETT for infants less than one year of age [1], the use of cuffed ETTs is also now well studied and is gaining wide acceptance in an increasing number of pediatric and neonatal applications [2–4]. Nonetheless, for both cuffed and uncuffed ETTs, a properly fitting ETT will allow for a leak around that tube or around its cuff at insufflation pressures of $\leq$20–25 cm H_2O, which corresponds to the capillary perfusion pressure of the tracheal mucosa [5].

It has been shown that the use of smaller, looser fitting ETTs is associated with a diminished incidence of acquired subglottic stenosis [6]. However, the selection of an ETT size is often a complex, multifactorial decision, which weighs the need to generate adequate flow and positive pressure in the lower airway against concerns about creating ischemic mucosal injury.

Remarkably, currently available ETTs have the same interval increase in inner diameter (0.5 mm) for large ETTs as for the smallest ETTs. This results in a much greater interval percent change (IPC) in the outer cross sectional area (CSA) between consecutive size small ETTs, than for larger ETTs (Fig. 1). We recommend the manufacture of more size options in small ETTs to improve airway management in these tiny patients.

2. Methods

The outer dimensions of a representative, commercially available cuffless endotracheal tube line (Hudson RCI, Sheridan uncuffed, Teleflex Medical, Research Triangle Park, North Carolina 27709, USA) were used to calculate the cross sectional areas of the ETTs across the product line, from the 2.0 mm ID ETT size, through the 7.0 mm ID ETT size. The outer dimensions of the Hudson RCI, Sheridan/HVT cuffed endotracheal tube series were utilized to calculate the cross-sectioned areas of the 7.5 mm and 8.0 mm ID ETTs. The interval percent change (IPC) of the cross sectional area (CSA) between each consecutive size ETT was calculated $\left(\frac{CSA\ larger\ tube - CSA\ smaller\ tube}{CSA\ smaller\ tube}\right) \cdot 100\% = IPC\ in\ CSA$ and graphed. The average IPC in CSA between consecutive sizes of larger ETTs (ID

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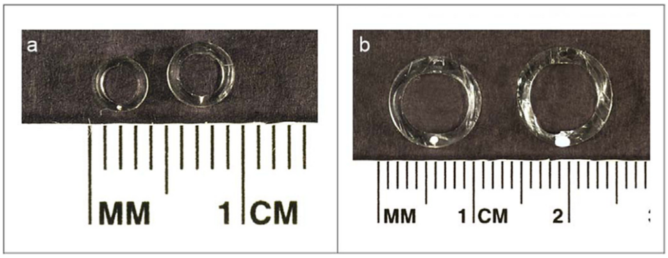

Fig. 1. Incremental change between current available consecutive endotracheal tubes. (a) 2.5 mm I.D. ETT and 3.0 mm I.D. ETT. (b) 7.0 mm I.D. ETT and 7.5 mm I.D. ETT.

5.0–8.0 mm) was calculated and compared to the IPC in CSA between the smallest ETTs. Then the average IPC in CSA present in the large endotracheal tubes (5.0–8.0 mm ID) was applied to calculate the identical interval percent increase in the CSA of a theoretical small endotracheal tube series, beginning with the dimensions of a standard 2.5 mm ID ETT. Finally, working from these calculated, theoretical outer cross sectional area values, the outer dimensions of a new series of proposed small ETTs was defined. Accounting for the increasing thickness of the endotracheal tube wall seen with increasing ETT size, we generated a series of proposed ETT dimensions for small size ETTs that increase in CSA similar to the interval percent change in CSA seen in larger endotracheal tubes.

Table 1
Interval percent change in cross sectional area between consecutive, currently available endotracheal tubes.

ID (mm)	OD (mm)	r (mm)	A = Pr2 (mm^2)	IPC CSA (%)	Consecutive Size (mm ID)
2.0	2.9	1.45	6.61		
2.5	3.6	1.8	10.18	54.10	2.0–2.5
3.0	4.2	2.1	13.85	36.05	2.5–3.0
3.5	4.9	2.45	18.86	36.17	3.0–3.5
4.0	5.5	2.75	23.76	25.98	3.5–4.0
4.5	6.2	3.1	30.19	27.06	4.0–4.5
5.0	6.8	3.4	36.32	20.30	4.5–5.0
5.5	7.5	3.75	44.18	21.64	5.0–5.5
6.0	8.2	4.1	52.81	19.53	5.5–6.0
6.5	8.9	4.45	62.21	17.80	6.0–6.5
7.0	9.6	4.8	72.38	16.35	6.5–7.0
7.5	10.2	5.1	81.72	12.90	7.0–7.5
8.0	10.9	5.45	93.31	14.18	7.5–8.0

ID: inner diameter, OD: outer diameter, r: radius, A: area, IPC: interval percent change, CSA: cross sectional area.

Table 2
Theoretical small endotracheal tube sizes as cross sectional area increases by 17 percent increments.

ID (mm)	OD (mm)	Cross Sectional Area (mm)	IPC in CSA	Recommended ETT Sizes (ID mm)
2.5 (current)	3.60	10.179		2.5
2.745	3.894	11.909	17%	2.75
3.009	4.212	13.934	17%	3.0
3.254	4.556	16.303	17%	3.25
3.523	4.928	19.074	17%	3.5
3.859	5.331	22.317	17%	3.75
4.19	5.766	26.110	17%	4.0
4.50 (current)	6.2	30.19	16%	4.5

3. Results

The dimensions and calculated interval percent change of the CSA of the studied ETTs is shown in Table 1. The IPC CSA value listed for any given ETT is the interval increase in cross sectional area between that tube and the cross sectional area of the preceding smaller endotracheal tube. Example: moving from a 3.0 mm ID ETT to a 3.5 mm ID ETT yields a 36.17% incremental increase in the CSA. The interval percent changes in CSA across the currently available product line of ETTs are graphed in Fig. 2. The average IPC of CSA of the larger ETTs (5.0–8.0 mm ID) is 17.07%, as shown in Fig. 2. The average IPC of CSA in the smaller ETTs (2.0–4.0 mm ID) is remarkably larger (38.08%).

The relatively low average IPC in CSA seen in the larger endotracheal tubes (17.07%) was used to calculate the dimensions of a theoretical series of small endotracheal tubes, working upward from the existing dimensions of a standard 2.5 mm ID ETT (Table 2). These calculations show that, in order to stay consistent in the incremental percent change of cross sectional area across the smaller ETT line, intermediate size ETTs, theoretically of 2.75, 3.25 and 3.86 mm ID, should exist (Fig. 3). Recommendation for the manufacture of additional size options of small endotracheal tubes (2.75 mm ID, 3.25 mm ID, and 3.75 mm ID ETTs) is made.

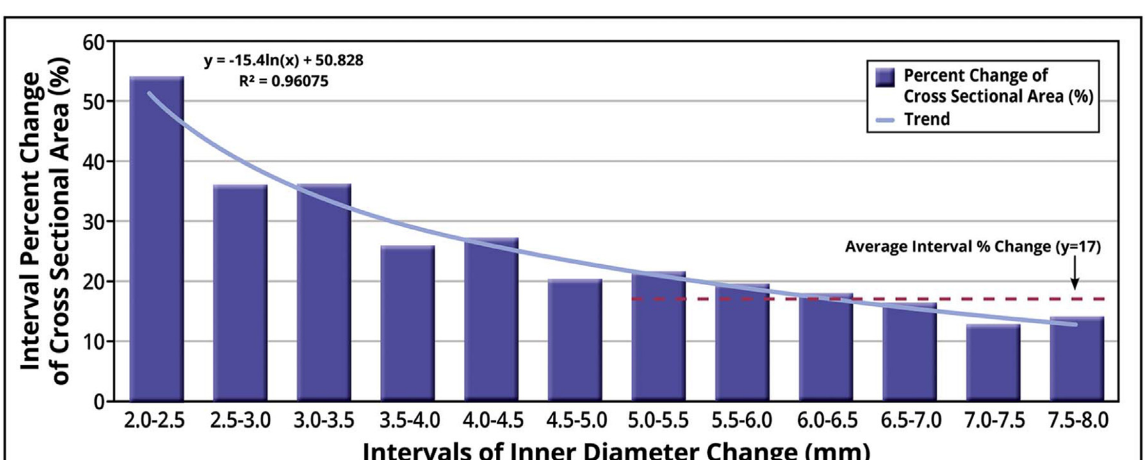

Fig. 2. The interval change in cross sectional area between current commercially available endotracheal tubes.