Patency of paediatric endotracheal tubes for airway instrumentation

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Conflict of interests
None of the authors has a conflict of interest to declare

Submitted 6 October 2016; accepted 7 October 2016; submission 18 May 2016.

Citation
Elfgen J, Buehler PK, Thomas J, Kemper M, Imach S, Weiss M. Patency of paediatric endotracheal tubes for airway instrumentation. Acta Anaesthesiologica Scandinavica 2017

doi: 10.1111/aas.12828

Background: Airway exchange catheters (AEC) and fiberoptic bronchoscopes (FOB) for tracheal intubation are selected so that there is only a minimal gap between their outer and inner diameter of endotracheal tube (ETT) to minimize the risk of impingement during airway instrumentation. This study aimed to test the ease of passage of FOBs and AECs through paediatric ETT of different sizes and from different manufacturers when using current recommendations for dimensional equipment compatibility taken from text books and manufacturers information.

Methods: Twelve different brands of cuffed and uncuffed ETT sized ID 2.5 to 5.0 mm were evaluated in an in vitro set-up. Ease of device passage as well as the locations of an impaired passage within the ETT were assessed. Redundant samples were used for same sized ETT and all measurements were triple-checked in randomized order.

Results: In total, 51 paired samples of uncuffed as well as cuffed paediatric ETT were tested. There were substantial differences in the ease of ETT passage concordantly for FOBs and AECs among different manufacturers, but also among the product lines from the same manufacturer for a given ID size. Restriction to passage most frequently was found near the endotracheal tube tip or as a gradually increasing resistance along the ETT shaft.

Conclusions: Current recommendations for dimensional equipment compatibility AECs and FOBs with ETTs do not appear to be completely accurate for all ETT brands available. We recommend that specific equipment combinations always must be tested carefully together before attempting to use them in a patient.

Editorial Comment:
This study tested the ease of passage of paediatric fiberoptic bronchoscopes and airway exchange catheters through a range of sizes of paediatric endotracheal tubes. The authors observed that bronchoscopes and exchange catheters that were advertized as specific for certain tube sizes did not always pass easily. These observations support the idea that compatibility should be checked before using.

The internal diameter (ID) states a normed characteristic of endotracheal tubes (ETT), whereas the outer diameter (OD) can vary according to the manufacturer's specifications.[1,2] In clinical practice, ETTs are selected based on their ID for different age and gender groups. Airway equipment used for instrumentation through endotracheal tubes, such as fiberoptic bronchoscopes

Acta Anaesthesiologica Scandinavica
AN INTERNATIONAL JOURNAL OF ANAESTHESIOLOGY AND INTENSIVE CARE, PAIN AND EMERGENCY MEDICINE

Table 1 The brands of the paediatric cuffed and uncuffed endotracheal tubes tested. (ID,internal diameter).

Endotracheal tube brand	Manufacturer	Size ID (mm)	Reference Number
Rüschelit Safety Clear Magill nasal/oral – uncuffed	Teleflex Medical Europe Ltd, Athlone, Ireland	2.5–5.0	100380
Rüschelit Safety Clear Murphy nasal/oral – uncuffed	Teleflex Medical Europe Ltd, Athlone, Ireland	2.5–5.0	100382
Rüschelit Super Safety Clear Magill - cuffed	Teleflex Medical Europe Ltd, Athlone, Ireland	2.5–7.0	112480
Rüschelit Super Safety Clear Murphy – cuffed	Teleflex Medical Europe Ltd, Athlone, Ireland	2.5–7.0	112482
Hudson RCI Sheridan/CF cuffed tracheal tube Magill type oral/nasal	Teleflex Medical Europe Ltd, Athlone, Ireland	3.0–7.0*	5-10214
Hudson RCI Sheridan/CF cuffed tracheal tube Murphy eye oral/nasal	Teleflex Medical Europe Ltd, Athlone, Ireland	3.0–7.0	5-10114
KimVent Microcuff endotracheal tube for paediatrics Magill oral/nasal	Kimberly-Clark Global Sales, LLC, Roswell, USA	3.0–7.0	35119
Portex tracheal tubes Magill - uncuffed (blue line)	Smith Medical International Ltd, Hythe, Kent, UK	2.5–5.0	100/111
Portex tracheal tubes Murphey - uncuffed (blue line)	Smith Medical International Ltd, Hythe, Kent, UK	2.5–5.0	100/141
Mallinckrodt Hi-Contour oral/nasal tracheal tube cuffed Murphey eye	Covidien, Mallinckrodt, Athlone, Ireland	3.0–7.0	107
Mallinckrodt oral/nasal tracheal tube Murphy eye cuffless	Covidien, Mallinckrodt, Athlone, Ireland	2.5–5.0	111
Curity endotracheal tube low pressure cuff Murphey eye	Covidien, Mallinckrodt, Athlone, Ireland	3.0–7.0*	94

*Only sizes ID 3.0; 4.0; 5.0; 6.0; 6.5; 7.0 mm available.

(FOB) and airway exchange catheters (AEC), is selected according to its outer diameter (OD) in relation to the internal diameter of the intended endotracheal tube.

The aim of this study was to test the ease of passage of current bronchoscopes and exchange catheters through currently available paediatric endotracheal tubes of different sizes and from different manufacturers when using current recommendation for size selection.

Methods

Twelve different brands of cuffed and uncuffed tracheal tubes sized ID 2.5 to 5.0 mm from four different manufacturers were ordered from the local distributors for this in vitro assessment (Table 1). Fiberoptic bronchoscopes were taken from the departmental airway equipment inventory (Table 2). The fiberoptic bronchoscopes were all without structural changes such as folds and bevels. New sets of airway exchange catheters (Airway Exchange Catheters, Cook Medical, Bloomington, Indiana, USA) from our hospital's stock, as listed in Table 2, were used for testing tracheal tube for ease of insertion and advancement.

The outer diameters of bronchoscopes and AECs in relation to tube's ID were chosen in accordance with standard textbooks recommendations and AEC sizes were based on manufacturer recommendations (Table 2).[3–5] The 7 Fr AEC (Mettro® Mizus Endotracheal Tube Replacement Obturator – Cook Medical) used in our study is not mentioned on the manufacturer website but is supplied by the local distributor.

Two ETT samples (A/B) of each brand and size from the same production line were tested in three chronologically separate runs each. During each run we sequentially evaluated the passage of one fiberoptic bronchoscope and two identically sized samples of airway exchange catheters according to Table 2. The sequence of ETT samples was created through www.random.org using list randomization.

Before each run, the inner surface of the endotracheal tube sample was lubricated with a short burst of silicone spray (Ruesch-Silikospray, Teleflex Medical Europe Ltd, Athlone, Irland) to minimize surface friction during the test. Ease of insertion and advancement of FOBs and AECs from the press-fitted 15 mm ETT connector until leaving the distal tube tip was judged as well as during withdrawal of the device. The findings were translated into a four-point ordinal scale: (1) without resistance; (2) with slight resistance; (3) with strong but surmountable resistance; and (4) passage not

Table 2 Technical data of fiberoptic bronchoscopes and airway exchange catheters used as well as intended tracheal tube sizes for airway instrumentation[4,5,6]. (OD, outer diameter, ID, internal diameter).

Fiberoptic Bronchoscope					
Manufacturer/Type	Proximal OD	Distal OD (mm)	Working Channel ID (mm)	Length (cm)	Intended Tube Size ID (mm)
Olympus BF-N20	2.2	1.8	–	55	≥ ID 2.5
Pentax FI-7BS	2.4	2.2	–	60	≥ ID 3.0
Olympus BF-XP40	2.8	2.8	1.20 mm	60	≥ ID 3.5
Pentax FI-10BS	3.5	3.0	1.31 mm	60	≥ ID 4.0
Pentax FI-13BS	4.2	3.8	1.72 mm	60	≥ ID 5.0
Airway Exchange Catheter					
Manufacturer	OD (Fr)	OD (mm)	Reference Number	Length (cm)	Intended Tube Size ID (mm)
Cook Medical	7	2.3	G05170	70	≥ ID 2.5
Cook Medical	8	2.7	G07833	45	≥ ID 3.0
Cook Medical	11	3.7	G06732	83	≥ ID 4.0
Cook Medical	14	4.7	G07873	83	≥ ID 5.0
Cook Medical	19	6.3	G05880	83	≥ ID 5.0

possible. Further, the location of resistance was noted as (1) proximal tube (proximal orifice); (2) central tube part; (3) Murphy eye area (distal ETT with hole on the tube wall side); (4) tube tip (distal orifice); and (5) gradually increasing resistance along length of tube.

The experiments and ratings were performed for all tube brands and sizes by two different teams, consisting of staff paediatric anesthetists and a staff intensivist. The median values of perceived resistance (1–4) were calculated for each tube brand and size for the insertion of FOBs (6 attempts) and AECs (12 attempts) and are presented as a colour-graded table.

Results

Fifty-one paired samples of uncuffed as well as cuffed paediatric tracheal tubes sized ID 2.5 to 5.0 mm were tested (Tables 3 and 4). A total of 906 insertion manoeuvres were performed of which 306 with FOB's and 600 with AECs. Incidence of insertion difficulties was more common with the AECs than with the FOBs (63.6% vs. 23.2%) (Tables 3and 4).

Ease of passage for FOBs and AECs is presented for each ETT size and brand tested in Table 4. Highest incidence of impossible AEC passage was found in uncuffed Rüschelit Safety Clear ETTs (3 of 4 ETT sizes tested) and in the KimVent Microcuff ETT (all ETT sizes tested). Similarly, the same ETT brands size ID 3.0 mm revealed impossible passage of an OD 2.4 mm FOB (Table 4).

The patency of ETTs were most often restricted at the ETT tip when tested with FOBs (49/306 tests). An increasing resistance along the ETT shaft was most commonly detected problem with AECs (169/600 tests) (Tables 3 and 5).

Differences in findings between the samples (A and B) of an ETT pair were observed for FOBs in 4 of 51 pairs and for AECs in 2 of 50 pairs tested. There was only one tube in which resistance was detected during retrieval but not during advancement of a fiberoptic bronchoscope.

Discussion

This in vitro trial demonstrates substantial differences in tube patency between different ETT manufacturers but also among the product lines of the same manufacturer. Particularly in Kim-Vent Microcuff and uncuffed Rüschelit Safety Clear ETTs, there was a failure of passage

Table 3 Distribution (%) of ease of passage and location of resistances (FOB, Fiberoptic Bronchoscope; AEC, Airway Exchange Catheter). (Figures for multiple selection choices for locations of resistance are presented).

Ease of passage	(1) Without resistance	(2) Slight resistance	(3) strong resistance	(4) passage not possible		
with AEC	36.3%	22.8%	19.3%	21.5%		
with FOB	71.1%	9.5%	4.9%	8.5%		
Location of resistance	(0) No resistance	(1) proximal tube	(2) central tube	(3) Murphy eye area	(4) Tube tip	(5) Increasing along the tube
Symbol	–	>==	===	=O>	==>	+++
with AEC	34.6%	0.3%	15.2%	0.6%	21.1%	28.1%
with FOB	74.7%	0.3%	7.0%	0.3%	16.1%	1.6%

Table 4 Ease of passage for different sized tested fiberoptic bronchoscopes and airway exchange catheters through different sized tracheal tubes (ID, internal diameter; OD, outer diameter; Fr, French; AEC, Airway Exchange Catheter; FOB, Fiberoptic Bronchoscope; n.a., endotracheal tube size not available since not provided by the manufacturer). Values are median.

AEC					
Endotracheal tube size (ID; mm)	2.5	3.0	4.0	5.0	7.0
Airway Exchange Catheter (OD; Fr)	7	8	11	14	19
Airway Exchange Catheter (OD; mm)	2.3	2.7	3.7	4.7	6.3
Gap OD/ID	0.2	0.3	0.3	0.3	0.7
Rüschelit Safety Clear Magill nasal/oral - uncuffed	3.5	4	4	2.5	n.a.
Rüschelit Safety Clear Murphy nasal/oral - uncuffed	4	4	4	1.5	n.a.
Rüschelit Super Safety Clear Magill - cuffed	3	1.5	2	1.5	1
Rüschelit Super Safety Clear Murphy- cuffed	3	2	1	3	1
Hudson RCI Sheridan/CF cuffed tracheal tube Magill type oral/nasal	n.a.	4	3	4	1
Hudson RCI Sheridan/CF cuffed tracheal tube Murphy eye oral/nasal	n.a.	2.5	3	3	1
KimVent Microcuff endotracheal tube for pediatrics Magill oral/nasal	n.a.	4	4	4	4
Portex tracheal tubes Magill - uncuffed (blue line)	2	1	1.5	1	n.a.
Portex tracheal tubes Murphey - uncuffed (blue line)	2.5	1	1	1	n.a.
Mallinckrodt Hi-Contour oral/nasal tracheal tube cuffed Murphey eye	n.a.	1	1	1.5	1
Mallinckrodt oral/nasal tracheal tube Murphy eye cuffless	2.5	1	2	1	n.a.
Curity endotracheal tube low pressure cuff Murphey eye	n.a.	3	1.5	2.5	1

FOB					
Endotracheal tube size (ID; mm)	2.5	3.0	3.5	4.5	5.0
Fiberoptic Bronchoscope (distal OD; mm)	1.8	2.2	2.8	3	3.8
Fiberoptic Bronchoscope (proximal OD; mm)	2.2	2.4	2.8	3.5	4.2
Gap OD/ID	0.7	0.6	0.7	1.5	1.2
Rüschelit Safety Clear Magill nasal/oral - uncuffed	1	4	1	1	2
Rüschelit Safety Clear Murphy nasal/oral - uncuffed	1	4	1	1	1
Rüschelit Super Safety Clear Magill - cuffed	1	1	1	3.5	1
Rüschelit Super Safety Clear Murphy- cuffed	1	1	1	1	1
Hudson RCI Sheridan/CF cuffed tracheal tube Magill type oral/nasal	n.a.	4	n.a.	n.a.	1
Hudson RCI Sheridan/CF cuffed tracheal tube Murphy eye oral/nasal	n.a.	2	1	1	1.5
KimVent Microcuff endotracheal tube for pediatrics Magill oral/nasal	n.a.	4	3.5	1	2
Portex tracheal tubes Magill - uncuffed (blue line)	1	1	1	1	1
Portex tracheal tubes Murphey - uncuffed (blue line)	1	1	1	1	1
Mallinckrodt Hi-Contour oral/nasal tracheal tube cuffed Murphey eye	n.a.	1	1	1	1
Mallinckrodt oral/nasal tracheal tube Murphy eye cuffless	1	1	1	1	1
Curity endotracheal tube low pressure cuff Murphey eye	n.a.	1	n.a.	n.a.	1

Passage without resistance		Passage with slight resistance		Passage with stronger esistance		Passage not possible
1	1.5	2	2.5	3	3.5	4

Table 5 Site of resistance to passage of different sized tested fiberoptic bronchoscopes and airway exchange catheters through different sized tracheal tubes. Values are most frequent sites (ID, internal diameter; OD, outer diameter; Fr, French; AEC, Airway Exchange Catheter; FOB, Fiberoptic Bronchoscope; n.a., endotracheal tube size not available since not provided by the manufacturer).

AEC					
Endotrachealtube size(ID;mm)	2.5	3.0	4.0	5.0	7.0
AirwayExchange Catheter (OD;Fr)	7	8	11	14	19
AirwayExchangeCatheter (OD;mm)	2.3	2.7	3.7	4.7	6.3
RüschelitSafetyClearMagillnasal/oral - uncuffed	+++	==>	==>	+++	n.a.
RüschelitSafetyClearMurphynasal/oral - uncuffed	=== +++	==>	==>	===	n.a.
RüschelitSuperSafetyClearMagill - cuffed	+++	+++	+++	+++	===
RüschelitSuperSafetyClearMurphy - cuffed	+++	==>	>== +++	===	–
HudsonRCISheridan/CFcuffedtrachealtubeMagilltypeoral/nasal	n.a.	==> +++	==>	===	===
HudsonRCISheridan/CF cuffedtrachealtubeMurphyeyeoral/nasal	n.a.	==>	==>	+++	===
KimVentMicrocuffendotrachealtubeforpediatricsMagilloral/nasal	n.a.	=== ==>	==>	===	===
PortextrachealtubesMagill - uncuffed(blueline)	+++	+++	+++	–	n.a.
Portex trachealtubesMurphey - uncuffed(blueline)	+++	+++	===	–	n.a.
MallinckrodtHi -Contouroral/nasaltrachealtubecuffedMurpheyeye	n.a.	–	–	===	===
Mallinckrodtoral/nasaltrachealtubeMurphyeyecuffless	+++	+++	==> +++	=== ==>	n.a.
Curity endotrachealtubelowpressurecuffMurpheyeye	n.a.	+++	+++	==>	–

FOB					
Endotrachealtube size(ID;mm)	2.5	3.0	3.5	4.5	5.0
FiberopticBronchoscope (distalOD;mm)	1.8	2.2	2.8	3	3.8
FiberopticBronchoscope (proximalOD;mm)	2.2	2.4	2.8	3.5	4.2
RüschelitSafetyClearMagillnasal/oral - uncuffed	–	==>	–	–	==>
RüschelitSafetyClearMurphynasal/oral - uncuffed	–	==>	–	–	–
RüschelitSuperSafetyClearMagill - cuffed	–	–	==>	==>	==>
Rüschelit SuperSafetyClearMurphy - cuffed	–	==>	–	==>	==>
HudsonRCISheridan/CFcuffedtrachealtubeMagilltypeoral/nasal	n.a.	===	n.a.	n.a.	===
HudsonRCISheridan/CFcuffedtrachealtubeMurphyeyeoral/nasal	n.a.	==>	=== +++	–	===
KimVent MicrocuffendotrachealtubeforpediatricsMagilloral/nasal	n.a.	=== ==>	==>	–	===
PortextrachealtubesMagill - uncuffed(blueline)	–	–	–	–	–
PortextrachealtubesMurphey - uncuffed(blueline)	–	–	–	–	–
MallinckrodtHi -Contour oral/nasaltrachealtubecuffedMurpheyeye	n.a.	–	–	–	–
Mallinckrodtoral/nasaltrachealtubeMurphyeyecuffless	==>	–	–	–	–
CurityendotrachealtubelowpressurecuffMurpheyeye	n.a.	==>	n.a.	n.a.	==>

–	>==	===	=O>	==>	+++
No resistance	Proximal tube	Central tube	Murphy eye area	Tube tip	Increasing along tube

concordantly with standard FOB and AEC sizes, which otherwise demonstrated free passage through cuffed Mallinckrodt Hi-Contour oral/nasal tracheal tubes.

Airway exchange catheters for tube exchange and fiberoptic bronchoscopes for tracheal intubation are usually selected so that there is only a minimal gap between their outer diameter and inner ETT diameter.[6] This minimizes the risk of impingement of the ETT tip on the aryepiglottic folds or vocal cords during ETT advancement over the AEC or FOB through the larynx.[7–9] This is in contrast to *diagnostic* bronchoscopy, when much smaller fiberoptic bronchoscopes are chosen for a given ETT size, to allow sustained ventilation during the procedure.[10] The same concept applies to reversible extubation or bridging extubation, where an airway exchange catheter is left in the patient's trachea after tracheal extubation to allow for sufficient spontaneous breathing.[11]

Our findings revealed that standard bronchoscopes for neonatal tubes such as the 2.4 mm OD Pentax fiberoptic bronchoscope seems not suitable for size ID 3.0 mm KimVent Microcuff tubes, uncuffed Rüschelit Safety Clear and cuffed Magill type Sheridan ETTs. These ETT brands require the use of an ultrathin, high-sophisticated and very expensive 2.2 mm OD Olympus fiberoptic bronchoscope.

Similarly, manufacturer's size recommendations for the use of AECs (Cook Medical) do not work in all paediatric ETTs. Compared to FOBs there was a higher incidence and increased severity of restricted ETT passage with the AECs. This can be explained by the much smaller gap between the AEC's OD and the ETT's ID when compared with FOBs (Table 3). AECs are used in clinical practice when the tube is already inserted in the patient, which means that if there is moderate or severe resistance, the patient's airway is at risk for inadvertent extubation. In contrast, tracheal tubes for fiberoptic intubation are mounted on the FOB first and a dimensional incompatibility is detected before approaching the patient. Based on the study results, size recommendations for AECs should be adapted or avoided or restricted to be used with caution. The most important clinical implication is that combinations of equipment such as AECs, ETTs and FOBs must always be tested outside the patient before clinical use.

This is the first systematic evaluation reporting on in vitro dimensional compatibility of paediatric ETTs with airway exchange catheters and fiberoptic bronchoscopes. To our knowledge, there is no systematic clinical or in vitro data on the patency of paediatric endotracheal tubes for airway instrumentation or related problems. A search revealed only one report on a suction catheter impacted within a tracheal tube.[12]

The tests performed in this study were carried out under quite benign in-vitro conditions. We used new and properly lubricated ETTs and AECs, as well as FOBs in good condition. In clinical practice, a complex array of ill-defined factors might further exacerbate friction and surface stickiness between the ETT and the inserted device. The fact that only two samples per AEC size from the same lot number and only one sample of a FOB per size was used and that the chosen paediatric fiberoptic bronchoscopes from our departmental resources were not brand-new may be regarded as a limitation of this study. Thus, the results are valid only for the two FOB brands and one AEC brand used in the comparison. However, since FOBs and AECs showed concordant non-compatibility patterns, the problem is rather related to the ETT than to equipment inserted. The 7 Fr AEC revealed an acceptable passage through most of the ID 2.5 mm sized uncuffed tracheal tubes, except in the Rüschelit tubes. Alternatively, a 6 Fr angiographic catheter could be used instead. The teams performing the tests were not blinded for the tested brands of the ETTs and AECs. This may be considered as another limitation of this study. However, the fact that two different teams each performed six test runs per ETT in randomized order make a bias very unlikely.

In summary, dimensional compatibility of AECs and FOBs with ETTs depends on tube brands. Current recommendations for AEC and FOB size selection cannot be applied to all ETT brands. We recommend that specific equipment combinations always must *always* be tested carefully together before attempting to use them in a patient.

Acknowledgement

Departmental funding only.

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