



Dimensional compatibility and limitations of tracheal intubation through supraglottic airway devices: a mannequin-based *in vitro* study

Compatibilité dimensionnelle et limitations de l'intubation trachéale avec des dispositifs supraglottiques : une étude *in vitro* sur mannequin

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Abstract

Background Flexible bronchoscope-guided tracheal intubation through supraglottic airway devices (SGAs) is a well-established element of difficult intubation algorithms. Success can be limited by dimensional incompatibilities between tracheal tubes (TTs) and SGAs.

Methods In this *in vitro* study, we tested the feasibility of TT passage through SGAs, removal of SGAs over TTs, and the ability to guide the flexible bronchoscope with 13 TT brands (internal diameter, 6.5–8.0 mm) and ten different SGAs (#4 and #5) in an intubation mannequin.

Results We tested 1,040 combinations of SGAs and TTs. Tracheal tube passage failed in 155 (30%) combinations of the five tested first-generation SGAs (117 [46%] with SGA

#4, 38 [15%] with SGA #5) and in three (0.6%) combinations of the five tested second-generation SGAs (two [0.8%] with SGA #4 and one [0.4%] with SGA #5). The reason for failed passage of a TT through a first-generation SGA consistently was a too-narrow SGA connector. Removal of the SGA over the TT in the 882 remaining combinations was impossible for all sizes of reinforced TTs, except the Parker Reinforced TT, and was possible for all non-reinforced TTs. Only one combination with SGA #4 and 84 combinations with SGA #5 were not ideal to adequately guide the flexible bronchoscope.

Conclusion Clinically relevant combinations of adult-size TTs and SGAs can be incompatible, rendering flexible bronchoscope-guided tracheal intubation through an SGA impossible. Additional limitations exist regarding removal of the SGA and maneuverability of the flexible bronchoscope.

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Résumé

Contexte L'intubation endotrachéale guidée par bronchoscope flexible via un dispositif supraglottique (DSG) est un élément établi des algorithmes utilisés pour les intubations difficiles. La réussite de l'intubation peut être limitée par des incompatibilités dimensionnelles entre les tubes endotrachéaux (TET) et les DSG.

Méthode Dans cette étude *in vitro*, nous avons testé la faisabilité de faire passer un TET par un DSG, le retrait du DSG par-dessus le TET et la possibilité de guider un bronchoscope flexible avec 13 marques de TET (diamètre interne, 6,5-8,0 mm) et dix DSG différents (#4 et #5) sur un mannequin d'intubation.

Résultats Nous avons testé 1040 combinaisons de DSG et de TET. Le passage du tube endotrachéal a échoué dans 155 (30 %) combinaisons avec les cinq DSG de première génération testés (117 [46 %] avec DSG #4, 38 [15 %] avec DSG #5) et dans trois (0,6 %) combinaisons avec les cinq DSG de deuxième génération testés (deux [0,8 %] avec DSG #4 et une [0,4 %] avec DSG #5). La raison de l'échec du passage d'un TET à travers un DSG de première génération était systématiquement liée à un connecteur de DSG trop étroit. Dans les 882 combinaisons restantes, le retrait du DSG par-dessus le TET s'est avéré impossible avec toutes les tailles de TET armés, à l'exception du TET armé Parker, et était possible avec tous les TET non armés. Une seule combinaison avec le DSG #4 et 84 combinaisons avec le DSG #5 n'étaient pas idéales pour guider le bronchoscope flexible de manière adéquate.

Conclusion Les combinaisons cliniquement pertinentes de TET et de DSG de tailles adultes peuvent être incompatibles, rendant impossible l'intubation endotrachéale guidée par bronchoscope flexible via un DSG. D'autres limites existent en ce qui concerne le retrait du DSG et la maniabilité du bronchoscope flexible.

Keywords supraglottic airway device · tracheal tube · flexible bronchoscope · intubation · tracheal

Tracheal intubation through supraglottic airway devices (SGA) is a well-established element of algorithms for the management of the unanticipated difficult airway.¹⁻⁴ Algorithms emphasize the importance of flexible bronchoscope guidance, since blind intubation through SGAs is associated with low success rates.⁵ Flexible bronchoscope-guided intubation through an SGA is a procedure that is easy to learn and perform with high success rates and is therefore the recommended technique.⁵⁻⁷

Tracheal intubation through an SGA may be hampered by dimensional incompatibilities, such as a mismatch of the internal diameter (ID) of the SGA in relation to the outer diameter (OD) of the tracheal tube (TT) or its cuff balloon, or limited freedom to manually maneuver the flexible bronchoscope with the TT mounted above the SGA.⁸⁻¹² A structured overview of dimensional compatibilities is essential for the success and safety of flexible bronchoscope-guided intubation through SGAs and impacts the selection of equipment, which is particularly important in emergency situations. Several studies have investigated the feasibility of the technique and differences between different SGAs as conduits for flexible bronchoscope-guided intubation with regard to success and intubation times.^{7,13-16}

The most recent summary of dimensional limitations was reported ten years ago and was limited to a number of first-generation SGAs.¹⁷ Since then, several new disposable first- and second-generation SGAs have been introduced to the market. Newer comprehensive studies reporting dimensional limitations of SGAs as conduits for tracheal intubation exist only for children, and data for adults are missing.^{8,12}

The aim of this study was to investigate dimensional compatibilities and limitations of different brands and sizes of TTs used in adults for flexible bronchoscope-guided tracheal intubation through different brands and sizes of disposable SGAs.

Methods

This was a laboratory-based *in vitro* study dedicated to the testing of various TT-SGA combinations for intubation in a bench-based approach, and the testing of various TT-SGA combinations for intubation in a mannequin, namely the Laerdal Airway Management Trainer (Laerdal Medical, AS, Stavanger, Norway).

Thirteen brands of TTs with IDs of 6.5–8.0 mm (four different sizes) as well as five first-generation and five second-generation disposable SGAs #4 and #5 were ordered in 2019 and used for this study (Table 1). Selection was based on commonly used and locally available types of SGA and TT. The maximal ID of the TTs that fit through a specific SGA, as indicated by the manufacturer (product brochures, internet information), are summarized in Table 2. For the SGA air-Q® Blocker (Cookgas®, Saint Louis, MO, USA), sizes #3.5 and #4.5 were used as they best correspond to sizes #4 and #5 of other SGA models. For the SGA iLTS-D® (VBM Medizintechnik GmbH, Sulz a. N., Germany), size #4.5 was used, corresponding to size #4 and size #5 of other SGA models. Outer diameters of 13 brands and four TT sizes as provided by the manufacturer are summarized in the Appendix. The lengths of all included brands and the sizes of TTs were measured without connector.

For *in vitro* dimensional feasibility testing of tracheal intubation through SGAs, a single-use flexible bronchoscope (aScope™ 4 Broncho Regular endoscope; OD, 5.0/5.4 mm; length, 600 mm; working channel width, 2.2 mm; Ambu A/S, Ballerup, Denmark) and an intubation mannequin (Laerdal Airway Management Trainer, Adult; Laerdal Medical, AS, Stavanger, Norway) were used.

Tracheal tubes and SGAs were assessed in the following three *in vitro* experimental setups:

TABLE 1 Supraglottic airway devices and tracheal tubes used in this study

SGA brand name	Study name	Generation	Reference number	Manufacturer, location, country
air-Q® Blocker	air-Q	1 st	3045	Cookgas®, Saint Louis, MO, USA
Ambu® Aura-i™	Aura-i	1 st	329500000	Ambu A/S, Ballerup, Denmark
Ambu® Aura Once™	AuraOnce	1 st	321500000	Ambu A/S, Ballerup, Denmark
LMA® Unique™	Unique	1 st	125050	Teleflex Medical, Athlone, Ireland
Portex® Soft Seal	Portex	1 st	100/220/500	Smith Medical, Kent, United Kingdom
Ambu® AuraGain™	AuraGain	2 nd	408500000	Ambu A/S, Ballerup, Denmark
i-gel®	i-gel	2 nd	8205000	Intersurgical GmbH, Sankt Augustin, Germany
iLTS-D®	iLTS	2 nd	32-08-045-1	VBM Medizintechnik GmbH, Sulz a. N., Germany
LarySeal™ Pro	LarySeal	2 nd	038-94-850	Flexicare Irvine, CA, USA
LMA® Protector™	Protector	2 nd	192050	Teleflex Medical, Athlone, Ireland
TT brand name	Study name	Reference number	Manufacturer, location, country	
Covidien Mallinckrodt™ Hi-Contour	Mallinckrodt	107-80	Covidien, Athlone, Ireland	
Covidien Mallinckrodt™ Safetyflex™	Mallinckrodt Reinforced	118-80 M	Covidien, Athlone, Ireland	
Intersurgical InTube™	Intersurgical	8040080	Intersurgical Ltd, Wokingham, Berkshire, UK	
Intersurgical InTube™ reinforced	Intersurgical reinforced	8060080	Intersurgical Ltd, Wokingham, Berkshire, UK	
Parker Flex-Tip® tracheal tube	Parker	I-PFHV-80	Parker Medical, Highlands Ranch, CO, USA	
Parker Flex-Tip® Reinforced Tracheal Tube	Parker Reinforced	I-PFRC-80	Parker Medical, Highlands Ranch, CO, USA	
Rueschelit® SuperSafety Clear	Ruesch	112482-80	Teleflex Medical, Athlone, Ireland	
Rueschflex	Ruesch reinforced	104202-80	Teleflex Medical, Athlone, Ireland	
Portex® tracheal tube	Portex	100/150/080	Smith Medical, Kent, UK	
Portex® tracheal tube reinforced	Portex reinforced	100/110/080	Smith Medical, Kent, UK	
Unomedical HiLo	Unomedical	UM61110080	ConvaTec, Deeside, Flintshire, UK	
Unomedical UnoFlex™	Unomedical reinforced	UM61214080	ConvaTec, Deeside, Flintshire, UK	
Microcuff®	Microcuff	35216	Halyard, Zaventem, Belgium	

Disposable first- and second-generation SGAs size #4 and #5 as well as TTs with a sized internal diameter of 6.5–8.0 mm included in the study. SGA reference number is given for #5 and TT reference number is given for size ID 8.0 mm

SGA = supraglottic airway device; TT = tracheal tube

Experimental setup 1: TT passage through the SGA

Feasibility and ease of full insertion of the TT through the SGA with a 15-mm connector were assessed. The only SGA whose connector could easily be removed for flexible bronchoscope-guided intubation, as indicated by the manufacturer, was the air-Q. In the air-Q, the SGA connector is designed to be removed for tracheal intubation through the SGA, while in the other SGAs, the connector is firmly inserted and can only be removed with difficulty, if at all.

Outcome parameters were as follows: easy passage, passage with resistance but possible, or passage not possible. In the case of resistance or failure to advance the TT, the maximal position of the TT tip in the lumen of the SGA was noted as follows: proximal SGA inlet, in the SGA lumen, or distal SGA outlet.

Experimental setup 2: SGA removal over the TT

We evaluated the feasibility of SGA removal over the TT by pushing the TT through the SGA with a stabilizing rod (air-Q® “removal stylet” size 1 for adults; Cookgas®, Saint Louis, MO, USA). Outcome parameters were successful or unsuccessful SGA removal over the TT.

Experimental setup 3: free distance to manually operate the flexible bronchoscope between the TT tip mounted on the flexible bronchoscope and the SGA connector

We assessed the free distance for manual operation of the Ambu aScope with the TT mounted on it (Electronic Supplementary Material [ESM], eFig. 1). The flexible bronchoscope loaded with the TT was inserted through the SGA until the tip of the flexible bronchoscope was level with the vocal cords. Thereafter, the distance between the

TABLE 2 Internal diameter of SGAs and TTs recommended by their manufacturers and measured length of SGA

SGA brand	SGA #4 (3.5 for air-Q)				SGA #5 (4.5 for air-Q)			
	ID of SGA (mm)	Max. ID of TT (mm)	Recommended for BW or BL	Length of SGA (mm)	ID of SGA (mm)	Max. ID of TT (mm)	Recommended for BW or BL	Length of SGA (mm)
air-Q	14	7.5	50–70 kg	172.8 (0.6)	15	8.5	70–100 kg	186.8 (1.3)
Aura-i	12.4	7.5	50–70 kg	173.4 (1.1)	12.7	8	70–100 kg	187.4 (2.2)
Aura Once	9.6	n.a.	50–70 kg	182.4 (1.4)	10.6	n.a.	70–100 kg	206.5 (1.5)
Unique	n.a.	n.a.	50–70 kg	201.1 (0.5)	n.a.	n.a.	70–100 kg	221.7 (0.8)
Portex	11	n.a.	50–70 kg	214.3 (2.1)	12	n.a.	70–100 kg	228.9 (1.6)
AuraGain	12.7	7.5	50–70 kg	170.2 (2.9)	12.9	8	70–100 kg	182.7 (1.8)
i-gel	12.3	7	50–90 kg	175.1 (1.3)	13.2	8	> 90 kg	184.8 (2.9)
iLTS	n.a.	8	> 155cm	191.2 (0.9)	n.a.	8	> 155 cm	191.2 (3.2)
LarySeal	n.a.	8	50–70 kg	156.8 (1.1)	n.a.	8	70–100 kg	164.2 (1.4)
Protector	13	7.5	50–70 kg	180.0 (3.1)	13	7.5	70–100 kg	194.7 (2.4)

Internal diameter of SGA, maximal ID of TT recommended for potential insertion through a specific brand and size of SGA, and patient body weight or body length for selection of SGA size #4 and #5 as provided by the manufacturers. In addition to these data provided by the manufacturers, the mean (standard deviation) SGA length is measured in mm on the short side of the SGA tube including the connector (except for the connector from the air-Q, which was removed, as recommended by the manufacturer). BL = body length; BW = body weight; ID = internal diameter; n.a.= no information available; SGA = supraglottic airway device; TT = tracheal tube

*air-Q #3.5 corresponds to SGA #4 and air-Q #4.5 corresponds to SGA #5

TT tip and the upper border of the SGA connector was measured using an electronic sliding caliper (Sliding Calliper, Serie 500 – ABSOLUTE AOS Digimatic; Brütsch/Rüegger Werkzeuge AG, Urdorf, Switzerland). We considered a free distance of at least 20 mm desirable for good clinical performance. Accordingly, TT-SGA combinations being less than 20 mm or those showing negative values were assessed. Negative distances mean that the tip of the TT mounted on the flexible bronchoscope reached the SGA connector before the tip of the flexible bronchoscope entered the vocal cords.

For all experimental setups, the external surface of the TTs, the flexible bronchoscope, as well as the internal surface of the SGAs were lubricated with medical silicone spray prior to testing (Ruesch Silikonspray; Willy Ruesch GmbH, Kernlen-Rommelhausen, Germany). This was consistent with daily practice of using extensive lubrication to reduce surface frictions between the different pieces of equipment to a minimum. In our setting, lubrication was essential for differentiation of resistances and obstructions caused by dimensional incompatibility of the airway devices from those resistances caused by surface frictions between different synthetic materials. In experimental setup 1, 13 brands and four different sizes of TT were investigated in SGAs of ten different brands and two sizes (Table 1). Two TTs and SGAs (A/B) were tested for each brand and size (total, 104

TTs and 40 SGAs; 1,040 combinations). A TT with an ID of 8.0 mm was first passed through each SGA #5. The same experiment was repeated while downsizing TTs by half a number until reaching size ID 6.5 mm. Thereafter, the experiments were repeated in SGAs #4 in the same way. Experimental setups 2 and 3 included all combinations of SGAs and TTs with possible passage of the TT through the SGA as tested in Experimental setup 1.

All measurements of SGA and TT lengths and the assessments in experimental setups 1–3 were repeated twice by two different anesthesiologists and in randomized order for TT brands and SGA brands and for each run (www.random.org). Data were recorded in Microsoft Excel (Microsoft Office Professional Plus 2013, Redmond, WA, USA). Measured and calculated distances are presented as mean (standard deviation [SD]) for tables and as mean for graphical presentation.

Results

Experimental setup 1 (n = 1,040 TT-SGA combinations)

We made a total of 4,160 attempts to advance a specific TT through an SGA (13 TT brands x 4 IDs = 52 tubes x 10 SAD brands x 2 sizes = 20 = 1,040 combinations, two

TABLE 3 Possible combinations for intubation of TTs through SGAs

	Size (ID)	Size (OD)	air-Q		Aura-i		AuraOnce		Unique		Portex		AuraGain		igel		iLTS-D		LarySeal		Protector	
			3.5*	4.5*	4	5	4	5	4	5	4	5	4	5	4	5	4	5	4	5	4	5
Mallinckrodt	6.5	8.8							A		A											
	7.0	9.6					A		A		A											
	7.5	10.2					A		A		A	A			X							
	8.0	10.9	X		X		A	A	A		A	A	X		X						X/B	X/B
Mallinckrodt Reinforced	6.5	8.9					A		A		A											
	7.0	9.7					A		A		A											
	7.5	10.3					A		A		A	A			X						B	B
	8.0	11.0	X		X		A	A	A	B	A	A	X		X						X/B	X/B
Intersurgical	6.5	8.7							A		A											
	7.0	9.3					A	A	A		A											
	7.5	10.0					A	A	A		A	A			X						B	
	8.0	10.7	X		X		A	A	A	C	A	A	X		X			A			X/B	X/B
Intersurgical reinforced	6.5	8.8							C		A											
	7.0	9.5					A		A		A											
	7.5	10.0					A	A	A	A	A				X						B	B
	8.0	10.7	X		X		A	A	A	A	A	A	X		X/A			A	A		X/B	X/B
Parker	6.5	8.8					A				A	A										
	7.0	9.6					A		A		A	A										
	7.5	10.2					A		A		A				X							
	8.0	10.9	X		X		A	A	A	B	A	A	X		X						X/B	X/B
Parker Reinforced	6.5	9.0					A		C		A	A										
	7.0	9.6					A		A		A	A										
	7.5	10.2					A		A	A	A				X						B	B
	8.0	10.8	X		X		A	A	A	A	A	A	X		X						X/B	X/B
Ruesch	6.5	8.7					A				A											
	7.0	9.3					A		A		A											
	7.5	10.0					A		A		A	A			X						B	
	8.0	10.7	X		X		A	A	A	A	A	A	X		X						X/B	X/B
Ruesch reinforced	6.5	9.0					A		A		A	A										
	7.0	9.6					A		A		A	A										
	7.5	10.2					A	A	A	A	A				X						B	
	8.0	10.8					A	A	A	A	A	A	X		X						X/B	X/B
Portex	6.5	8.5									A											
	7.0	9.2					A				A				X							
	7.5	10.0					A		A		A	A										
	8.0	10.7	X		X		A	A	A		A	A	X		X						X	X
Portex reinforced	6.5	9.8					A		A		A	A										
	7.0	10.4					A		A		A	C										
	7.5	11.1					A	A	A	A	A	A			X						B	B
	8.0	11.9	X		X		A	A	A	A	A	A			X/A			A	A		X/B	X/B
Unomedical	6.5	8.8									A	A										
	7.0	9.6					A		A		A	A										
	7.5	10.2					A		A		A	A			X							
	8.0	10.9	X		X		A	A	A	A	A	A	X		X						X	X
Unomedical reinforced	6.5	9.0					A				A	A										
	7.0	9.6					A		A		A	A										
	7.5	10.2					A	A	A		A	A			X						B	
	8.0	10.8	X		X		A	A	A	A	A	A	X		X/A			A	A		X/B	X/B
Microcuff	6.5	8.7									A											
	7.0	9.3									A											
	7.5	10.2									A	A			X							
	8.0	10.8	X		X		A		A		A	A	X		X						X	X

TABLE 3 continued

*air-Q #3.5 corresponds to SGA #4 and air-Q #4.5 corresponds to SGA #5

Feasibility and ease of insertion of 13 different TT brands, sizes (ID) 6.5, 7.0, 7.5, and 8.0 mm and (OD), through SGAs size #4 and #5 of different brands. TT passage through SGAs is classified as follows: green squares = easy passage; yellow squares = passage with resistance but possible; and red squares = passage not possible. Locations of resistance are classified as A for proximal SGA inlet, B for SGA tube, and C for distal SGA outlet. Squares marked with thicker lines and "X" indicate a combination of TT size and SGA not recommended by the manufacturer. ID = internal diameter; OD = outer diameter; SGA = supraglottic airway device; TT = tracheal tube

attempts per anesthesiologist, two anesthesiologists). Results for the four attempts performed were consistent among the two investigators for all combinations tested. Failure to pass a TT through the five first-generation SGAs tested occurred in 155 (30%) of 520 combinations. These included 117 (46%) combinations with SGA #4 and 38 (15%) combinations with SGA #5. Failure to pass a TT through the five second-generation SGAs occurred in another three (0.6%) of 500 combinations: two (0.8%) combinations with SGA #4 and one (0.4%) combination with SGA #5 (Table 2). The reason for failed TT passage through a first-generation SGA was consistently a too-narrow SGA connector (Table 3). The Portex SGA #4 connector, for example, has a cone-shaped form with a measured minimal ID of 8.20 mm, making passage of all TTs included in this study impossible (ESM, eFig. 2).

Experimental setup 2 (n = 882 TT-SGA combinations [1,040 combinations-158 failed combinations])

Removal of the SGA over the TT was assessed in the remaining 882 combinations. Results for all four attempts performed were consistent among the two assessors for all combinations tested. Because the adapter was fixed to some TTs, its removal was not possible in all sizes of reinforced TTs except in one brand, the Parker Reinforced TT (Parker Medical, Highlands Ranch, CO, USA). For all other TTs, the SGA could be removed over the TT using the stabilizing rod (Table 4).

Experimental setup 3 (n = 882 TT-SGA combinations)

Measured lengths of SGAs and TTs are summarized in Table 2 and Table 5, respectively. The free distance for manual guidance of the flexible bronchoscope between TT tip and SGA connector ranged from 18.5 to 102.0 mm in SGAs #4 (n = 401), with just one TT-SGA combination showing a free distance of less than 20 mm. The free distance in SGAs #5 ranged from -30.5 to 84.0 mm (n = 481), with 84 (18%) TT-SGA combinations being less than 20 mm and 23 (5%) showing negative values (Fig. 1). The latter were particularly observed in three of five brands of

reinforced TTs, namely the Mallinckrodt Reinforced TT (Covidien, Athlone, Ireland), the Parker Reinforced TT (Parker Medical, Highlands Ranch, CO, USA), and the Ruesch Reinforced TT (Teleflex Medical, Athlone, Ireland). These reinforced TTs are about 20 mm longer than other similarly sized TTs tested (Table 5).

Discussion

This *in vitro* study investigated dimensional compatibilities and limitations of several currently available brands of TT and SGA for tracheal intubation by any technique (blind, flexible bronchoscope-guided, light-guided, use of the airway exchanger catheter) using an intubation mannequin. The main findings were that failure to pass the TT through the SGA occurred mainly with first-generation SGAs, where the TT tip became wedged mainly in the SGA connector. Removal of the SGA over the TT was generally feasible, except in four of five brands of wire-reinforced TTs because of the non-detachable TT connectors. Finally, in many combinations with SGA #5, there was no free distance for guidance of the flexible bronchoscope between TT tip and SGA connector.

Tracheal tube passage through the SGA

Our findings concerning TT sizes for possible passage through the SGA were not in full agreement with recommendations given by the manufacturers, as seen in Table 3, shown by the white squares with an X. We found that some combinations were possible with easy passage of a TT with a larger ID (8.0 mm and 7.5 mm) than recommended by the manufacturer, in two first-generation SGAs #4 and another two second-generation SGAs. The first-generation SGAs Portex (Smith Medical, Kent, UK), Aura Once (Ambu A/S, Ballerup, Denmark), and Unique (Teleflex Medical, Athlone, Ireland) are associated with a high rate of failed TT passage through the SGA, except for some in combination with a TT size ID 6.5. This is in accordance with previous clinical reports using these first-generation devices with either TTs size ID 6.0 or an

TABLE 4 Feasibility of removal of different TTs through different SGAs

Size #	Size (ID)		Air-Q*		Aura-i		AuraOnce		Unique		Portex		AuraGain		i-gel		iLTS-D		LarySeal		Protector	
	3.5	4.5	4	5	4	5	4	5	4	5	4	5	4	5	4	5	4.5	4	5	4	5	
Mallinckrodt	6.5																					
	7.0																					
	7.5																					
	8.0																					
Mallinckrodt Reinforced	6.5																					
	7.0																					
	7.5																					
	8.0																					
InTube	6.5																					
	7.0																					
	7.5																					
	8.0																					
InTube Reinforced	6.5																					
	7.0																					
	7.5																					
	8.0																					
Parker Flex	6.5																					
	7.0																					
	7.5																					
	8.0																					
Parker Flex Reinforced	6.5																					
	7.0																					
	7.5																					
	8.0																					
Ruesch	6.5																					
	7.0																					
	7.5																					
Ruesch Reinforced	6.5																					
	7.0																					
	7.5																					
	8.0																					
Portex	6.5																					
	7.0																					
	7.5																					
	8.0																					
Portex Reinforced	6.5																					
	7.0																					
	7.5																					
	8.0																					
Unomedical	6.5																					
	7.0																					
	7.5																					
	8.0																					
Unomedical Reinforced	6.5																					
	7.0																					
	7.5																					
	8.0																					
Microcuff	6.5																					
	7.0																					
	7.5																					
	8.0																					

TABLE 4 continued

Summarized are the results for SGAs size #4 and #5 of ten different brands over TTs of 13 different brands, sizes (ID) 6.5, 7.0, 7.5 and 8.0 mm, by pushing the TT with a stabilizing rod. Black squares: assessment excluded because passage of TT through SGA was not possible in Experimental setup 1; white squares = SGA removal over the TT possible; grey squares = TT adapter not able to be removed from the TT. *air-Q #3.5 corresponds to SGA #4 and air-Q® #4.5 corresponds to SGA #5. ID = internal diameter; SGA = supraglottic airway device; TT = tracheal tube

TABLE 5 Lengths of TTs studied

	Length of TT ID 6.5 mm	Length of TT ID 7.0 mm	Length of TT ID 7.5 mm	Length of TT ID 8.0 mm
Mallinckrodt	295.5 (0.5)	306.8 (0.2)	316.5 (0.1)	331.4 (0.2)
Mallinckrodt Reinforced	321.3 (0.3)	328.1 (0.5)	347.7 (0.3)	346.2 (0.3)
Intersurgical	312.9 (0.3)	326.1 (0.2)	336.0 (0.3)	336.0 (0.2)
Intersurgical reinforced	330.1 (0.2)	331.8 (0.2)	332.3 (0.2)	338.4 (0.1)
Parker	295.3 (0.1)	313.4 (0.4)	315.3 (0.1)	330.5 (0.2)
Parker Reinforced	314.7 (0.1)	325.0 (0.3)	341.8 (0.1)	350.0 (0.1)
Ruesch	301.7 (0.3)	317.9 (0.2)	333.2 (0.2)	343.3 (0.1)
Ruesch reinforced	335.7 (0.2)	347.3 (0.2)	353.5 (0.2)	357.8 (0.1)
Portex	302.7 (0.1)	306.4 (0.3)	311.9 (0.2)	328.2 (0.1)
Portex reinforced	301.8 (0.4)	313.4 (0.3)	324.2 (0.4)	333.5 (0.3)
Unomedical	299.3 (0.4)	311.7 (0.2)	318.0 (0.3)	331.1 (0.2)
Unomedical reinforced	300.2 (0.2)	307.6 (0.3)	315.2 (0.2)	336.9 (0.1)
Microcuff	292.4 (0.2)	303.9 (0.2)	313.9 (0.4)	324.3 (0.1)

Measured lengths without connector of the 13 brands and four sizes of TT. Lengths are mean (standard deviation) and given in mm. ID = internal diameter; TT = tracheal tube

Aintree exchange catheter for intubation (COOK MEDICAL LLC, Bloomington, IN, USA).^{18,19} Others have also pointed out that limitations exist for these SGAs regarding TT ID and TT length.^{17,20} Apart from the ID and the length of the airway tube of these SGAs, the angulation and the bars at the SGA opening were also reported to hinder intubation.¹⁹ As the design of most of the older first-generation SGAs is similar to the one of the LMA® Classic™ Airway (LMA; Teleflex Medical, Athlone, Ireland) that was designed for ventilation and not for intubation, this finding was not surprising.

Accordingly, no information is available from the manufacturer with regard to TT size able to fit through the SGA. The higher failure rate for reinforced TTs can likely be explained by their larger OD in some brands and sizes (Appendix). In contrast, the two first-generation SGAs, air-Q and Aura-i (Ambu A/S, Ballerup, Denmark), especially designed for flexible bronchoscope tracheal intubation through the SGA, feature an increased ID of the SGA lumen and shortened length of the SGA tube, resulting in improved compatibilities.

Of note, almost all combinations with second-generation devices permitted passage of the TT through the SGA, although they include an additional gastric channel. Our findings show that they have in general an increased ID of the SGA lumen and are generally shorter than first-generation devices (Table 2). Following the recommendations of current difficult airway guidelines that recommend using second-generation instead of first-generation SGAs (DAS, ASA), the risk posed by incompatible combinations of SGA and TT would significantly reduce.^{1,2} Nevertheless, despite the guidelines, first-generation SGAs are still widely used. This stands in contrast to children, where dimensional incompatibilities persist even with second-generation SGAs.⁸ The small IDs of pediatric SGAs mean that many combinations of SGA and TT were incompatible, particularly in the small SGA sizes combined with cuffed TTs.⁸

Supraglottic airway device removal over the TT

In general, it has been shown that SGAs do not need to be removed for shorter operations when a TT is placed over an SGA, which does not increase throat soreness or hoarseness.^{13–15} In children, there even exists a clear recommendation to leave the SGA in place when challenged with a difficult airway.²¹ Another option is to insert a tube exchanger into the trachea over the SGA and then remove the SGA over the inserted tube exchanger and subsequently advance the TT over the airway exchanger.^{22,23}

Removal of the SGA may, however, become necessary in the case of oro-maxillary interventions as well as when transferring the patient to the intensive care unit for postoperative ventilation. To remove the SGA over the TT, the TT connector needs to be removed, which is not always possible with reinforced TTs often used for flexible bronchoscope-guided intubation because of their easy passage and the possibility to follow the curves of the bronchoscope. In contrast to cuffed pediatric TTs, in which the cuff pilot balloon was shown to be bigger than the ID of pediatric SGAs (particularly sizes 1 and 1.5), thus making it impossible to remove the SGA over the TT,⁷ the pilot balloon was not a reason for failed passage in the tested adult sizes. The major factor inhibiting removal of the TTs in the present study was the TT connector that is firmly attached to most reinforced TTs.

Free distance for manual guidance of the flexible bronchoscope between TT tip and SGA connector

In our clinical judgement, a minimal distance of 20 mm between the TT tip and the connector of the SGA seems to

be required for manual handling/guidance of the flexible bronchoscope, at least to or through the level of the vocal cords (ESM, eFig. 1). In 85 combinations of TT and SGA, there was no free space, and in many more combinations less than 20 mm were available. This was mainly related to longer tubes (in particular reinforced TTs) and to SGAs #5. Reduced free space for manipulation of the flexible bronchoscope above the SGA connector hampers rotation and forward-backward guidance of the flexible bronchoscope. Since flexible bronchoscopes are rarely longer than 600 mm, the TT may be inserted into the SGA without protruding from the distal SGA lumen tube and the flexible bronchoscope can then be manipulated from above the TT connector.²⁴ The difficulty caused by not having enough space in which to guide the flexible bronchoscope will be increased with greater SGA length, mostly from first-generation SGAs, as seen in Table 2. Finally, a “perfect” SGA-TT combination for flexible bronchoscope intubation is a balance of optimal TT length and SGA length, since, on the one hand, longer TTs include the risk of reduced maneuverability of the flexible bronchoscope above the SGA connector and, on the other hand, shorter TTs entail the risk of the cuff being placed in the subglottic region or even between the vocal cords.²⁴ It is important to remember that the original technique described by the manufacturer for flexible bronchoscope-guided intubation through the LMA® Fastrach™ (Teleflex Medical, Athlone, Ireland) was by placing the TT through the tube of the SGA until the tip of the TT was near the exiting aperture of the SGD.²⁵ The TT subsequently was inserted into the trachea under flexible bronchoscopic control. If the minimal distance between the TT tip and the connector of the SGA is less than 20 mm, this could be a possible solution.

The implications of our findings are that specific lists or tables for the selection of dimensionally compatible equipment for possible flexible bronchoscope-guided or “blind” intubation through SGAs or even sets with compatible equipment should be available wherever patients are anesthetized. This is of particular importance in emergency situations, where time for adequate planning and for choosing compatible equipment is limited. Special caution must be given to wire-enforced TTs, which may fail to pass through the SGA, may fail SGA removal and may fail to allow a free distance for manipulation of the flexible bronchoscope above the SGA connector, particularly in SGA#5. Wire-enforced tubes are therefore not the first choice of TT for intubation through SGAs. Alternatively, a special set could be prepared institutionally or developed in collaboration with the manufacturer, as was previously the case with the intubating laryngeal mask airway including a special TT with long cuff inflation line, stabilizing rod, and an SGA with sufficient ID.^{26,27} Currently, this is only

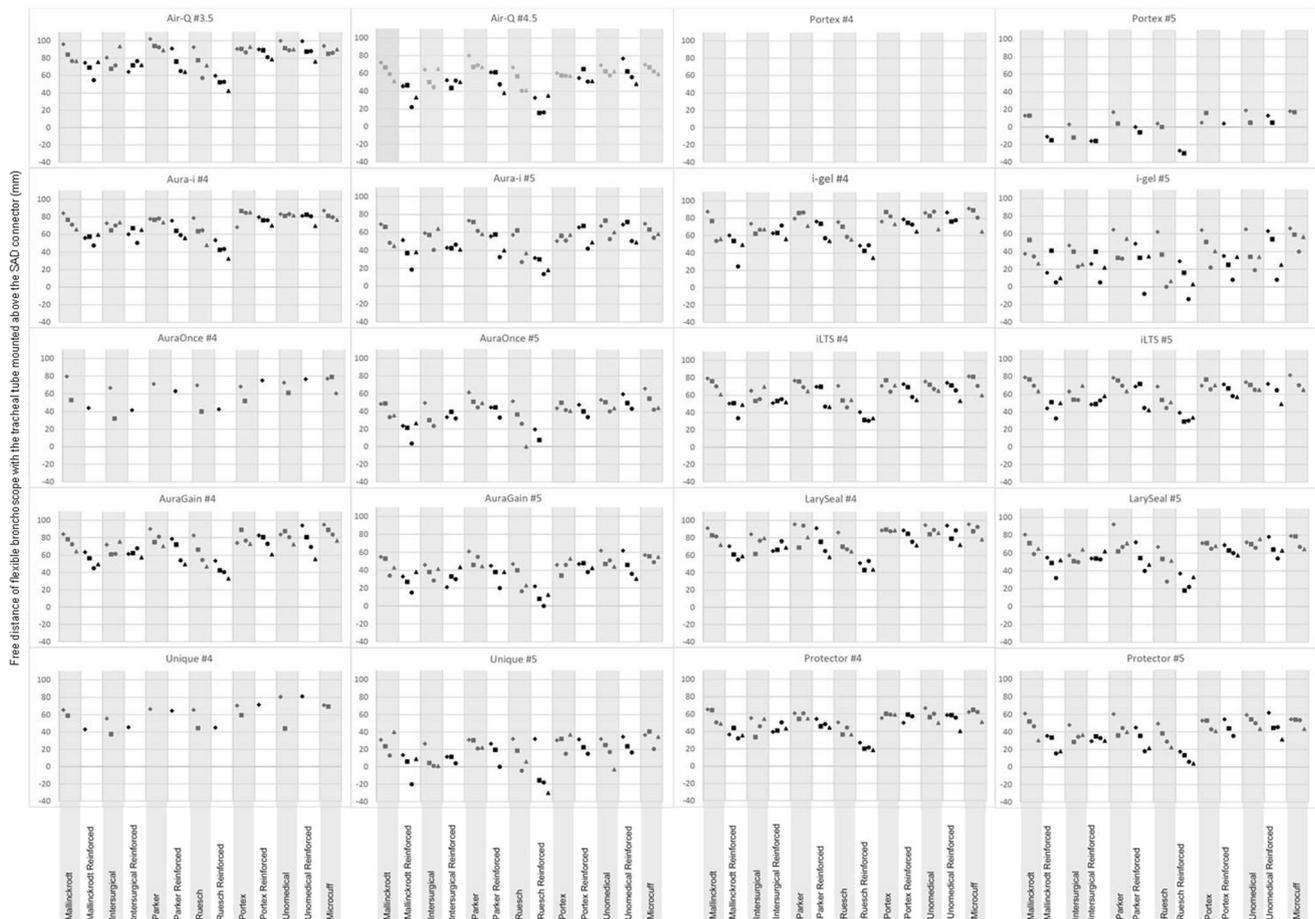


Fig. 1 Free distances above the SGA connector for manual guidance of the Ambu aScope flexible bronchoscope (length, 600 mm) with the TT mounted and the tip of the flexible bronchoscope placed level with the vocal cords using 13 TT brands, ID sizes 6.5 (●), 7.0 (■), 7.5 (◄) and 8.0 mm (▲) through SGAs of ten different brands, size #4 and #5.

provided in the newly marketed air-Q SGA with a considerably shortened SGA tube, removable SGA adapter, and different sizes of pushing rods.

For the current study, the following limitations are to be considered. The data are from an *in vitro* assessment. This might not fully reflect the situation in human patients *in vivo*. It does, however, provide similar and therefore comparable conditions for all TT and SGA combinations tested. While assessment of passage and removal is not affected by the *in vitro* design of this study, the position of the SGA within the mannequin may differ from that in individual patients. Nevertheless, in contrast to human studies with anatomical differences between patients, it can be assumed that the position of the SGA in a mannequin is largely the same. Therefore, assessment of the free distance

Negative values indicate a TT tip placed within the SGA connector or even deeper in the SGA lumen. Missing values indicate combinations with no possible TT passage through a specific SGA. Values are means. ID = internal diameter; SGA = supraglottic airway device; TT = tracheal tube

for manipulating the flexible bronchoscope allows combinations to be identified that are critical to the free distance available for manipulating the flexible bronchoscope. Finally, while this study included a comprehensive selection of commonly used SGAs and TTs, we acknowledge there might be other combinations with good compatibility or dimensional limitations that we have not investigated.

In conclusion, the current comprehensive update on *in vitro* dimensional compatibilities between a selection of SGAs and TTs shows that for adult sizes too, there exist many incompatible combinations, rendering tracheal intubation through these SGAs impossible. This was particularly the case with several first-generation SGAs and with wire-reinforced TTs.

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Appendix: Outer diameter of TT as indicated by the manufacturer (mm) for TT ID)

	OD of TT ID 6.5 mm	OD off TT ID 7.0 mm	OD of TT ID 7.5 mm	OD off TT ID 8.0 mm
Mallinckrodt	8.8	9.6	10.2	10.9
Mallinckrodt Reinforced	8.8	9.6	10.2	11.0
Intersurgical	8.7	9.3	10.0	10.7
Intersurgical reinforced	8.8	9.5	10.0	10.7
Parker	8.8	9.6	10.2	10.9
Parker Reinforced	9.0	9.6	10.2	10.8
Ruesch	8.7	9.3	10.0	10.7
Ruesch reinforced	9.0	9.6	10.2	10.8
Portex	8.5	9.2	10	10.7
Portex reinforced	9.8	10.4	11.1	11.9
Unomedical	8.7	9.3	10.0	10.7
Unomedical reinforced	8.9	9.7	10.3	10.8
Microcuff	8.7	9.3	10.2	10.8

ID = internal diameter; OD = outer diameter; TT = tracheal tubes

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