Benchtop study of leakages across the Portex, TaperGuard, and Microcuff endotracheal tubes under simulated clinical conditions

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ABSTRACT

Objectives: To compare three endotracheal tubes for leakage across the cuff (microaspiration) under a comprehensive set of simulated clinical situations. These were the Mallinckrodt TaperGuard (Covidien, US) with a tapered polyvinyl chloride cuff; the KimVent Microcuff (Kimberly-Clark Health Care, US) with a cylindrical polyurethane cuff; and a conventional Portex (Smiths Medical International Ltd, UK) with a globular polyvinyl chloride cuff.

Design: A benchtop experimental study.

Setting and materials: A silicone cylinder serving as the model trachea was intubated with each of the three endotracheal tubes, one at a time. A total of 20 mL of water were added above the cuff and leakage measured every minute for 20 minutes under five simulated mechanical ventilation scenarios, including different positive end-expiratory pressure levels, and disconnection with and without spontaneous breathing efforts. Each scenario was studied under three cuff pressures of 10, 20 and 30 cm H_2O, and then repeated with the application of a continuous suction force of 200 cm H_2O, and leakage measured every minute for 3 minutes.

Results: The outcome of interest was the cumulative amount of leakage. The Microcuff endotracheal tubes with an ultrathin polyurethane cuff consistently provided the best protection against microaspiration under all simulated clinical situations, followed by TaperGuard with a tapered cuff, and lastly Portex with a globular polyvinyl chloride cuff. Clinical scenarios associated with the greatest leakage were mechanical ventilation with zero positive end-expiratory pressure, circuit disconnection with spontaneous breathing efforts, application of suction, and a low cuff pressure.

Conclusions: Microcuff endotracheal tubes outperformed TaperGuard and Portex endotracheal tubes in preventing microaspiration, which is one of the major mechanisms for ventilator-associated pneumonia.

Hong Kong Med J 2014;20:7–15
DOI: 10.12809/hkmj133930

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This article was published on 22 July 2013 at www.hkmj.org.

New knowledge added by this study

- Microcuff endotracheal tubes (ETTs) with an ultrathin polyurethane cylindrical cuff provided the best protection against microaspiration under diverse situations.
- TaperGuard ETT with a tapered polyvinyl chloride (PVC) cuff provided protection against microaspiration in simulated at-risk situations, given that the cuff pressure was maintained at the recommended 20 to 30 cm of H_2O.
- The most widely used Portex ETT with a globular PVC cuff did not protect against microaspiration under these at-risk simulated situations, even at recommended cuff pressures of 20 to 30 cm H_2O.

Implications for clinical practice or policy

- This study supports more widespread use of ETTs with an ultrathin polyurethane cuff (eg the Microcuff) to better prevent microaspiration, which is one of the major mechanisms of ventilator-associated pneumonia.
- Some scenarios appear more prone to microaspirations, eg zero positive end-expiratory pressure, total disconnection, and spontaneous breathing. The Microcuff ETT outperformed other ETTs, particularly in such scenarios.

Introduction

One of the major mechanisms of ventilator-associated pneumonia (VAP) is microaspiration of bacteria-colonised oropharyngeal secretions that collect above the inflated cuff of the endotracheal tube (ETT). In Hong Kong, for several decades, the cuff of the most commonly used ETT has been made of polyvinyl chloride (PVC) and has a globular shape. This type of cuff protects against microaspiration poorly, due to microchannels formed from infolding of redundant cuff material after inflation.[1] Novel designs of the ETT cuff attempt to overcome this problem by modifying the material from the thicker (50- to 80-micron) PVC to the ultrathin (10-micron)

模擬臨床環境下測試Portex、TaperGuard和Microcuff氣管內插管的滲漏情況

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目的：在模擬臨床環境下測試以下兩種新的氣管內插管：有錐形聚氯乙烯氣囊的Mallinckrodt TaperGuard（美國Covidien公司）以及有圓柱形聚氨酯氣囊的KimVent Microcuff（美國Kimberly-Clark公司），把它們與有球狀聚氯乙烯氣囊的Portex（英國Smiths Medical International Ltd）的傳統氣管內插管在氣囊處的滲漏情況（顯微吸入現象）進行比較。

設計：台式實驗研究。

安排和材料：利用矽膠圓柱作模型氣管，先後插入三款氣管內插管的其中一枝。把20毫升的水倒入氣囊之上，然後在五個模擬機械通氣的情況下每分鐘記錄滲漏量，整個過程維持20分鐘。測試中涉及不同呼氣末正壓水平以及把呼吸機管路脫開（部份情況有自主呼吸），再分別以10、20和30 cm H_2O三種氣囊壓力研究氣管內插管滲漏的情況。然後加入200 cm H_2O的連續抽吸力重複測試，每分鐘記錄滲漏量，整個過程維持3分鐘。

結果：結果記錄了不同情況下的累積滲漏量。有超薄聚氨酯氣囊的Microcuff氣管內插管在所有模擬情況下均能針對顯微吸入現象提供最好的保護，其次是有錐形氣囊的TaperGuard，最後為有球狀聚氯乙烯氣囊的Portex。最大滲漏量與下列臨床情況相關：呼氣末正壓為零的機械式通氣、在有呼吸的情況下把呼吸機管路脫開、使用抽吸力和低氣囊壓力。

結論：Microcuff氣管內插管在防止顯微吸入方面的表現比TaperGuard和Portex優勝；顯微吸入是呼吸機相關性肺炎的主要成因之一。

polyurethane (PU),[2] and the cuff shape from globular to tapered or cylindrical. In addition, a subglottic secretion drainage port for aspiration of secretions collected above the cuff is available in some ETTs. Although these novel ETTs have been available for many years,[3,4] they are not widely used locally. Reasons include inadequate cost-effectiveness data, even though most studies reported favourable efficacy in reducing VAP, though not necessarily mortality.[1]

Many previous benchtop studies have shown the benefits of these novel designs, but mostly under a limited number of conditions, or under a static condition without the dynamic effect of different levels of positive pressures from mechanical ventilation or negative pressures associated with spontaneous breathing and/or suction.[5,6] Moreover, they mostly reported the amount of leakage at a particular time point without showing continuous trends.[5] The aim of the present study was to compare these novel ETTs under a comprehensive set of simulated clinical conditions, and to find the best-performing tube in which downward leakage of fluid across the cuff was minimal.

Methods

The experimental setup is shown in Figure 1. The three types of ETTs under test were the Portex Endotracheal Tube (Smiths Medical International Ltd, UK) with a globular PVC cuff; the Mallinckrodt TaperGuard Endotracheal Tube (Covidien, US) with a tapered PVC cuff; and the KimVent Microcuff Endotracheal Tube (Kimberly-Clark Health Care, US) with a cylindrical PU cuff (Fig 2). A transparent, hollow silicone cylinder of length 20 cm and an internal diameter of 2 cm was used as the model trachea. An internal diameter of 2 cm was chosen because from autopsy studies, the mean diameters of male and female tracheas were 2.2 cm and 1.8 cm, respectively.[7] A flexible and extensible tube was added to the proximal end of the model trachea to prevent fluid from splashing out where significant upward leakage results from high positive ventilatory pressure.[5] The ETT under study was connected to a SERVO-i Adult ventilator (Maquet GmbH & Co. KG, Germany). The model trachea was inclined at 35 degrees to the horizontal to simulate the semi-recumbent position for VAP prevention. Cuff pressure (Pcuff) was maintained by an automated maintenance setup as devised and modified from a previous study.[8] In short, compressed air in the range of 2 to 3 L/min was used to inflate the cuff and the pressure was altered with a leakage port along the circuit, to maintain the desired Pcuff within a range of ± 1 cm H_2O at end-expiration. The PVC cuff was monitored continuously using a calibrated electronic pressure transducer (Model HCLA0050EU; Sensortechnics GmbH, Germany), with signals digitally transformed by an analogue-to-digital converter (NI USB-6212; National Instruments, US), so as to display on a computer using the LabVIEW

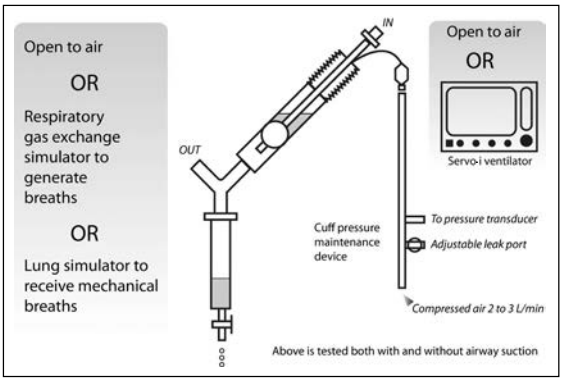

FIG 1. Graphical representation of the experimental setup
For the study of positive pressure mechanical ventilation, the distal end of the model trachea was connected to a lung simulator (SMS Lung Simulator, SMS Technologies, UK). For the study of spontaneous breathing, it was connected to a respiratory gas exchange simulator which generated breaths to mimic different metabolic rates. For the study of total disconnection, it was opened to atmospheric pressure

2010 software (National Instruments Corporation, US). The proximal end of a Y-piece was connected to the distal end of the model trachea. To the Y-piece's vertical end, a water trap made of a 20-mL syringe was connected. For the study of positive pressure mechanical ventilation, it was connected to a lung simulator (SMS Lung Simulator; SMS Technologies, UK) at its distal end. For the study of spontaneous breathing, it was connected to a Huszczuk-Whipp-Wasserman Gas Exchange System Validator (MedGraphics, US)[9] which generated breaths to mimic different metabolic rates; and for the study of total disconnection, it was opened to atmospheric pressure.

The scenarios simulated are shown in Table 1. Clear water (20 mL) was added above the ETT cuff. The whole process was recorded by a video recorder and leakage was measured as observed in the syringe for 20 minutes. Each scenario was studied under different Pcuffs of 10, 20, and 30 cm H_2O. For each scenario at each Pcuff, two tubes of the same ETT type were tested, and each tube was studied repeatedly for 4 times, therefore making a total of 8 measurements for each ETT type per scenario and Pcuff.

The same scenarios were then repeated under sustained tracheal suction by placing a suction catheter (12-Fr closed suction catheter) inside the ETT near the Murphy eye,[10] and a suction pressure of 200 cm H_2O was applied continuously for 3 minutes.

The primary measurement was the downward leakage across the cuff, defined as the amount of fluid collected in the syringe (the fluid trap) every minute during the observation period.

Statistical analysis

Between- and within-group analysis of variance (ANOVA) was used for analysis of the amount of downward leakage during the whole observation period, with the aim of comparing the difference in leakage between the three types of ETTs for each scenario. Each scenario at each Pcuff was analysed separately, in which between-group data were different types of ETTs and within-group data were the cumulative amount (in mL) of leakage over

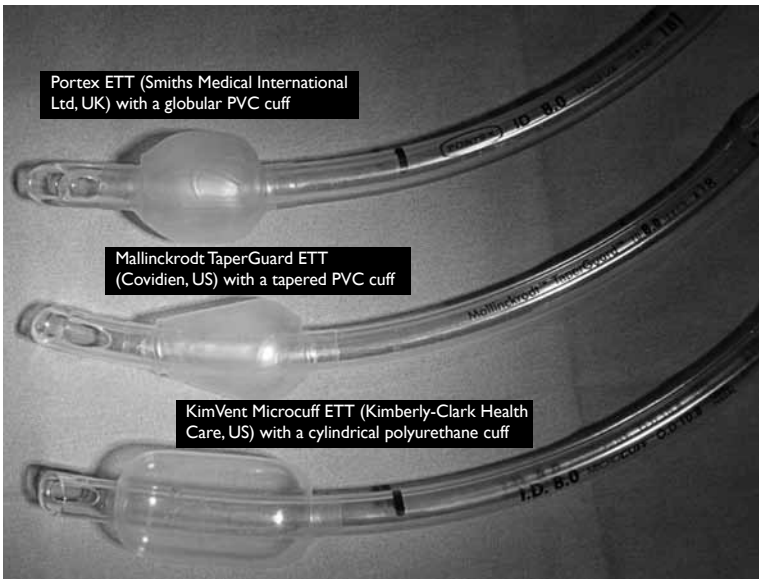

FIG 2. The three types of endotracheal tubes (ETTs) tested (8-mm internal diameter)
Abbreviation: PVC = polyvinyl chloride

TABLE 1. Simulated clinical scenarios tested under three different cuff pressures (10, 20, and 30 cm H_2O) using the three types of endotracheal tubes (ETTs)
Each scenario at each cuff pressure was repeated 8 times for each type of ETT, making a total of 72 (1 × 3 cuff pressures × 3 ETT types × 2 ETTs for each type × 4) experiments per scenario. Suction was applied with a sustained pressure of 200 cm H_2O for 3 minutes at the Murphy eye

Scenario		Simulated condition	Settings
Without suction	With suction		
1NS	1S	Mechanical ventilation strategy for acute severe asthma	PEEP = 0 cm H_2O PIP = 15 cm H_2O Frequency = 10/min I:E = 1:5 Breath cycle = 4 sec
2NS	2S	Mechanical ventilation strategy for normal lungs	PEEP = 5 cm H_2O PIP = 15 cm H_2O on top of PEEP (ie 20 cm H_2O) Frequency = 15/min I:E = 1:2.9 Breath cycle = 4 sec
3NS	3S	Mechanical ventilation strategy for acute respiratory distress syndrome	PEEP = 10 cm H_2O PIP = 20 cm H_2O on top of PEEP (ie 30 cm H_2O) Frequency = 20/min I:E = 1:1 Breath cycle = 3 sec
4NS	4S	Disconnection from ventilator with no spontaneous breathing effort	Distal end of Y-piece opened to atmospheric pressure
5NS	5S	Disconnection from ventilator with spontaneous breathing generated from the Gas Exchange System Validator	Frequency = 20/min Tidal volume = 1500 mL/breath

Abbreviations: PEEP = positive end-expiratory pressure; PIP = peak inspiratory pressure; I:E = inspiratory-to-expiratory ratio

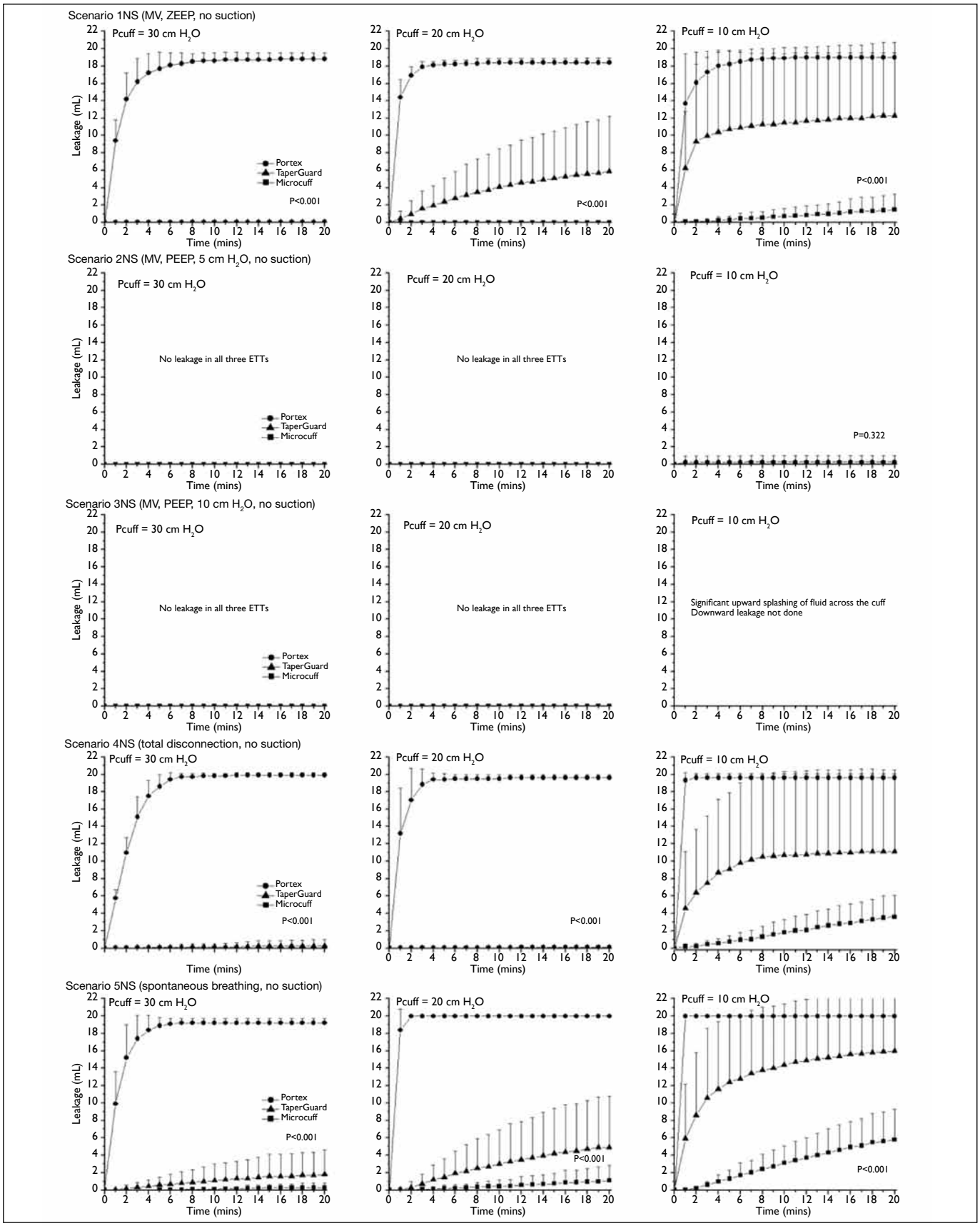

FIG 3. Downward leakage in the model trachea in the five scenarios without suction (1NS to 5NS)

Abbreviations: Pcuff = cuff pressure; MV = mechanical ventilation; ZEEP = zero end-expiratory pressure; PEEP = positive end-expiratory pressure; ETT endotracheal tube

Circles denote Portex, triangles TaperGuard, and squares Microcuff. Each point represents the mean and the vertical bars the standard deviations of eight samples of repeated measures (2 endotracheal tubes x 4). P values were obtained by analysis of variance over the whole 20-minute observation period

each observation period. Statistical analysis was performed using IBM SPSS software version 20 (SPSS, Inc, IBM, US).

Results

Results of the five scenarios without suction (1NS to 5NS) are shown in Figure 3. The P values represent analyses by ANOVA of the cumulative leakage over the whole 20-minute observation period. The cumulative leakages at the 20-minute time point are shown in Table 2. In summary, in scenario 1NS (positive end-expiratory pressure [PEEP] of 0 cm H_2O), the Microcuff outperformed the other two ETTs at all Pcuffs. At a Pcuff of 30 cm H_2O, only the Portex showed leakage, which was early and massive. At a Pcuff of 20 cm H_2O, only Microcuff did not leak. At a Pcuff of 10 cm H_2O, all three ETTs leaked, but the rate was fastest in Portex and lowest in Microcuff. In scenario 2NS (PEEP of 5 cm H_2O), at Pcuffs of 30 and 20 cm H_2O, all three ETTs showed no leakage, while at a Pcuff of 10 cm H_2O, only Portex showed minimal leakage. In scenario 3NS (PEEP of 10 cm H_2O), none leaked. In scenario 4NS (disconnection), significant leakage occurred only in Portex at Pcuffs of 30 and 20 cm H_2O. At a Pcuff of 10 cm H_2O, all leaked, but

TABLE 2. Cumulative leakage at the 20-minute time point for different scenarios

Scenario	PEEP (cm H_2O)	Pcuff (cm H_2O)	Observation / mean ± standard deviation leakage (mL)			
			Without suction (NS)	P value	With suction (S)	P value
1	0	30	PT: 18.8 ± 0.7 TG: 0.0 ± 0.1 MC: 0.0 ± 0.7	<0.001	PT: 19.7 ± 0.4 TG: 12.0 ± 6.2 MC: 0.0 ± 0.0	<0.001
		20	PT: 18.4 ± 0.5 TG: 5.9 ± 6.3 MC: 0.0 ± 0.0	<0.001	PT: 20.0 ± 0.1 TG: 11.1 ± 6.9 MC: 0.1 ± 0.2	<0.001
		10	PT: 19.0 ± 0.5 TG: 12.3 ± 8.4 MC: 1.5 ± 1.8	<0.001	PT: 20.0 ± 0.0 TG: 17.0 ± 3.9 MC: 1.8 ± 0.8	<0.001
2	5	30	No leakage for all three types	-	PT: 19.7 ± 0.4 TG: 0.0 ± 0.1 MC: 0.0 ± 0.0	<0.001
		20	No leakage for all three types	-	PT: 19.9 ± 0.4 TG: 7.4 ± 6.2 MC: 0.0 ± 0.0	<0.001
		10	PT: 0.3 ± 0.7 TG: 0.0 ± 0.0 MC: 0.0 ± 0.0	0.322	PT: 20.0 ± 0.0 TG: 12.7 ± 5.1 MC: 0.9 ± 0.8	<0.001
3	10	30	No leakage for all three types	-	No leakage for all three types	-
		20	No leakage for all three types	-	PT: 0.6 ± 1.1 TG: 0.0 ± 0.0 MC: 0.0 ± 0.0	0.405
		10	No leakage for all three types	-	Not done*	-
4	Disconnection	30	PT: 19.9 ± 0.3 TG: 0.3 ± 0.7 MC: 0.0 ± 0.1	<0.001	PT: 20.0 ± 0.0 TG: 0.2 ± 0.4 MC: 0.1 ± 0.1	<0.001
		20	PT: 19.6 ± 0.4 TG: 0.1 ± 0.1 MC: 0.1 ± 0.2	<0.001	PT: 20.0 ± 0.0 TG: 2.4 ± 2.4 MC: 0.0 ± 0.1	<0.001
		10	PT: 19.6 ± 0.5 TG: 11.1 ± 9.4 MC: 3.6 ± 2.5	<0.001	PT: 19.9 ± 0.4 TG: 13.9 ± 5.9 MC: 0.3 ± 0.4	<0.001
5	Spontaneous breathing	30	PT: 19.2 ± 0.5 TG: 1.8 ± 2.8 MC: 0.3 ± 0.5	<0.001	PT: 20.0 ± 0.0 TG: 0.0 ± 0.0 MC: 0.1 ± 0.1	<0.001
		20	PT: 20.0 ± 0.0 TG: 4.9 ± 5.9 MC: 1.1 ± 1.7	<0.001	PT: 20.0 ± 0.0 TG: 1.0 ± 1.9 MC: 0.0 ± 0.0	<0.001
		10	PT: 20.0 ± 0.0 TG: 16.0 ± 6.7 MC: 5.8 ± 3.5	<0.001	PT: 20.0 ± 0.0 TG: 20.0 ± 0.0 MC: 12.5 ± 4.3	<0.001

Abbreviations: PEEP = positive end-expiratory pressure; Pcuff = cuff pressure; PT = Portex; TG = TaperGuard; MC = Microcuff

* Significant upward splashing of fluid across the cuff; downward leakage not done

the rate was lowest with Microcuff. In scenario 5NS (spontaneous breathing), addition of spontaneous breathing led to leakage in all ETTs at Pcuffs of 10 and 20 cm H_2O, but the rate remained the lowest in Microcuff. At a Pcuff of 30 cm H_2O, only Microcuff showed minimal leakage.

Results of the five scenarios with suction (1S to 5S) are shown in Figure 4. The P values pertained to analyses by ANOVA of the whole 3-minute observation period. The cumulative leakages at the 3-minute time point are shown in Table 2. In summary, in scenario 1S (PEEP of 0 cm H_2O), at Pcuffs of 30 and 20 cm H_2O, only Microcuff was protective, while the other two leaked almost instantly. At a Pcuff of 10 cm H_2O, all three ETTs leaked, but Microcuff leaked very slowly. In scenario 2S (PEEP of 5 cm H_2O), at a Pcuff of 30 cm H_2O, leakage occurred instantly with Portex, in contrast to zero leakage in the corresponding scenario without suction. At a Pcuff of 20 cm H_2O, only Microcuff did not leak. At a Pcuff of 10 cm H_2O, all three ETTs leaked, but Microcuff leaked very slowly. In scenario 3S (PEEP of 10 cm H_2O), at a Pcuff of 30 cm H_2O, none leaked. At a Pcuff of 20 cm H_2O, minimal leakage occurred with Portex. In scenario 4S (disconnection), at a Pcuff of 30 cm H_2O, significant leakage was found in Portex. At a Pcuff of 20 cm H_2O, only Microcuff was protective whilst TaperGuard leaked slowly. At a Pcuff of 10 cm H_2O, Microcuff was still protective with minimal leakage at 3 minutes. In scenario 5S (spontaneous breathing), at a Pcuff of 30 cm H_2O, significant leakage was found in Portex. At a Pcuff of 20 cm H_2O, Portex leaked significantly, TaperGuard leaked very slowly, while Microcuff was protective. At a Pcuff of 10 cm H_2O, all three leaked.

Discussion

The present benchtop study showed that under the various simulated scenarios studied (positive pressure ventilation, disconnection, spontaneous breathing, with or without the application of suction), the Microcuff ETT consistently outperformed the others with the least downward leak and the lowest sealing pressure, whereas the TaperGuard ETT was in second place. The Portex ETT performed the worst, with significant leakage whenever there was a loss of positive airway pressure even at the recommended Pcuffs of 20 to 30 cm H_2O.

Among the limitations of the present study, many in-vivo factors were not or could not be fully simulated but might have affected the leakage rate. In-vivo leakage could be greater when there is a change in tracheal dimensions during inspiration and/or imperfect conformation of the circular cuff to the trachea (which could have different antero-posterior compared with transverse dimensions), and when there is a sudden change in airway pressure or the cuff position inside the trachea as the patient coughs or moves. Moreover, the seal between the cuff and the moist tracheal mucosa might actually be better, especially with the use of lubricant at the time of intubation.[4,11,12] The upward sweeping movement of the ciliated mucosa might also decrease aspiration. Furthermore, subglottic collections are more viscous than water, and their volume is not likely to be as high as 20 mL. This volume was chosen in the current experiment to better discriminate ETT performance and minimise measurement errors. Dynamic patient factors may also affect leakage. For example, leakage in the first scenario (zero PEEP) might be less if significant auto-PEEP develops in severe airflow obstruction, and the size of the cuff relative to the trachea might increase or decrease leakage. Nor did we test the effect of subglottic suction, which is extremely effective in removing fluid collected above the cuff. However, the effectiveness of subglottic suction might differ in vivo, depending on the viscosity of secretions and apposition of the posterior mucosal wall obstructing the suction lumen and interfering with such efforts.[13] According to guidelines on endotracheal suction for adults,[14] the lowest suction pressure that can effectively clear secretions should be used, which should not exceed 150 cm H_2O, and for not more than 15 seconds. We deliberately used sustained suction at 200 cm H_2O for 3 minutes to better discriminate the performance of each ETT. Notably though, in the present experiment it was observed that leakage occurred within the first second of suction. Although it can be argued that a 20-minute observation period may be too short, we found that prolonging this period led to excessive evaporation of the water above the cuff. We did not use coloured water because we measured water collected in the syringe, simulating the volume of fluid actually aspirated into the lower airway, and not the minute amounts that might just leak and stay around the cuff. Fluid more viscous than water was not used because firstly, human secretions can never be fully simulated, and secondly, should there be any leakage, fluid of a lower viscosity (like water) was considered more liable to leak. Furthermore, the need for thorough cleansing of viscous fluid by dismantling the connections of the apparatus after each set of experiments was another consideration. Such cleansing was regarded as not feasible, because each connection needed to be secured with glue and tapes to withstand the high positive airway pressure and this would take an unrealistic amount of time to do so repeatedly.

The present experiment clearly discriminated the performance characteristics of the three ETTs. Infolding of the excess and thick PVC material in the Portex ETT formed micro-channels through which leakage occurred. By modifying the cuff to a tapered shape, leakage in the TaperGuard ETT was

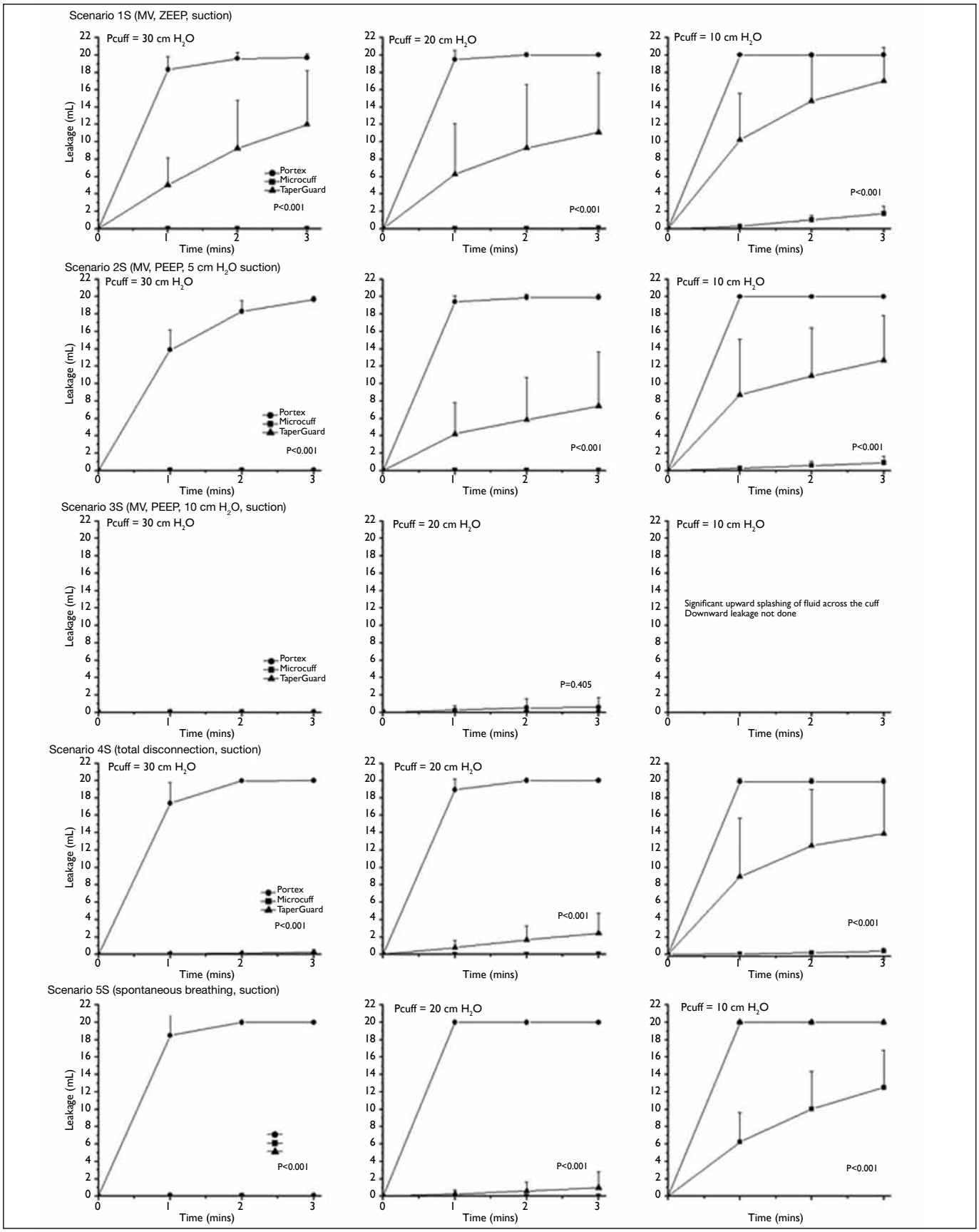

FIG 4. Downward leakage in the model trachea in the five scenarios after application of continuous suction of 200 cm H_2O for 3 minutes (1S to 5S)
Abbreviations: Pcuff = cuff pressure; MV = mechanical ventilation; ZEEP = zero end-expiratory pressure; PEEP = positive end-expiratory pressure; ETT endotracheal tube
Circles denote Portex, triangles TaperGuard, and squares Microcuff. Each point represents the mean and the vertical bars the standard deviation of eight samples of repeated measures (2 endotracheal tubes x 4). P values were obtained by analysis of variance of the whole 3-minute observation period

minimised, as there was a point along the length of the cuff where it fitted the trachea perfectly without the infolding of excess cuff material. In the Microcuff ETT, infolding of excess cuff material was still observed. However, micro-channels were not formed because of the much thinner PU material. Its cylindrical shape also provided a larger contact area between the cuff and tracheal wall, thus providing a better seal than the other two types of ETTs.

One of the clinical implications of our findings was that PEEP guards against downward leakage across cuffs, irrespective of the ETT type and Pcuff. In a previous study, it was shown that only the application of a 35 cm H_2O PEEP prior to cuff deflation at extubation was protective against aspiration, but not open or closed suction (that supposedly removes aspirated water).[15] This protective effect of a higher PEEP was independent of the peak inspiratory pressure (PIP) as leakage still occurred in scenario 1NS (with a PIP of 15 cm H_2O); such finding was in line with another study showing that only higher PEEP values and not higher inspiratory pressures were protective.[16] However, the protective effect of PEEP, especially with low pressures of around 5 cm of H_2O, was counteracted by the application of suction, as shown by the appearance of leakage when suction was applied to the Portex and TaperGuard ETTs as in scenario 2S. Another study showed that when suction at 200 or 300 mbar was applied via ETTs with a PVC cuff, leakage could only be reduced by transiently increasing Pcuff to 50 cm H_2O, and not at all by increasing the PEEP from 5 to 10 cm H_2O or the PIP from 15 to 25 cm H_2O.[17] This same study also showed that the PU cuff almost eliminated leakage under all suction pressures, and all PEEP or PIP values.[17] Therefore, to prevent leakage during suction, a Pcuff of 50 cm H_2O may be necessary unless a PU cuff is used, while the suction duration and force should be reduced to a minimum, and routine suction should always be avoided. Given that suctioning results in the loss of PEEP and recruitment manoeuvres are recommended thereafter,[14] it may be worth studying whether the application of high PEEP during suction can prevent both derecruitment and leakage across the cuff.

Similar to the effect of applying no PEEP during mechanical ventilation, disconnection from such ventilation results in significant leakage across the cuff, and should be avoided as far as possible. Harnessing the portability of an intensive care unit ventilator to avoid circuit disconnections should therefore be considered when patients are transported. When disconnection is necessary, its duration should be kept to a minimum with the maintenance of PEEP. For example, a PEEP valve from a bag-valve device may minimise leakage across the cuff. Spontaneous breathing during disconnection, which creates a negative intrathoracic pressure, further exacerbates downward leakage (scenario 5NS). Another study has also found that leakage increased with increasing inspiratory effort.[16] Therefore, during disconnection for spontaneous breathing trials, microaspiration is to be expected if the conventional globular PVC cuff is used. Even with the use of novel ETTs, a high patient inspiratory effort during a trial of spontaneous breathing is conducive to microaspiration and should be anticipated. Extrapolating these results, a high patient inspiratory effort while on mechanical ventilation may prove to be another scenario at high risk of microaspiration.

Under situations with a high risk of microaspiration, namely zero or low PEEP, circuit disconnection, in the presence of high patient inspiratory effort and application of a suction force, the type of ETT used will make a difference to the rate of downward leakage. The Microcuff ETT was shown to offer the best protection in these situations. The TaperGuard ETT was protective if a higher Pcuff could be maintained, and a Pcuff maintenance device (keeping it between 20 and 30 cm of H_2O) may be helpful. Notably, the most commonly used Portex ETT provided the least protection against microaspiration, and leakage occurred in these situations despite maintaining a Pcuff at the recommended 20 to 30 cm H_2O.

Based on the findings of the present study, further clinical trials on VAP prevention using novel ETTs less prone to microaspiration are needed. These should control for confounding factors including PEEP, airway suction, use of automated Pcuff maintenance devices, and airway disconnections. At the time of writing, the cost of a Microcuff ETT was around 6 times that of a Portex ETT (HK$68 vs HK$11), and a TaperGuard ETT was around double (HK$20). Although cost-effectiveness analysis is worthwhile as a basis for wider promotion of the novel ETTs, taking into account the small absolute cost difference, there may be a case for just switching ETTs to those with a lesser tendency to leak until evidence to the contrary appears.

Conclusions

The present benchtop study showed that a higher PEEP, avoidance of unnecessary circuit disconnections and suctioning, and maintenance of adequate Pcuff are important in minimising microaspiration. The Microcuff ETT was shown to be superior to TaperGuard and Portex ETTs in preventing leakage across the cuff. As microaspiration is one of the major mechanisms of VAP, more widespread use of ETTs with a PU cuff, combined with other prevention measures (eg bedhead elevation, oral hygiene) may help to reduce the frequency of associated pneumonias.

Declaration

No conflicts of interest were declared by the authors.

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