



# Airway injury from the presence of endotracheal tubes and the association with subglottic secretion drainage: a prospective observational study

## Lésion des voies aériennes due à la présence de sondes endotrachéales et association avec le drainage des sécrétions sous-glottiques : une étude observationnelle prospective

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### Abstract

**Purpose** Laryngeal and tracheal injuries are known complications of endotracheal intubation. Endotracheal tubes (ETTs) with subglottic suction devices (SSDs) are commonly used in the critical care setting. There is

concern that herniation of tissue into the suction port of these devices may lead to tracheal injury resulting in serious clinical consequences such as tracheal stenosis. We aimed to describe the type and location of tracheal injuries seen in intubated critically ill patients and assess injuries at the suction port as well as in-hospital complications associated with those injuries.

**Methods** We conducted a prospective observational study of 57 critically ill patients admitted to a level 3 intensive care unit who were endotracheally intubated and underwent percutaneous tracheostomy. Investigators performed bronchoscopy and photographic evaluation of the airway during the percutaneous tracheostomy procedure to evaluate tracheal and laryngeal injury.

**Results** Forty-one (72%) patients intubated with ETT with SSD and sixteen (28%) patients with standard ETT were included in the study. Forty-seven (83%) patients had a documented airway injury ranging from hyperemia to deep ulceration of the mucosa. A common tracheal injury was at the site of the tracheal cuff. Injury at the site of the subglottic suction device was seen in 5/41 (12%) patients. There were no in-hospital complications.

**Conclusions** Airway injury was common in critically ill patients following endotracheal intubation, and tracheal injury commonly occurred at the site of the endotracheal

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*cuff. Injury occurred at the site of the subglottic suction port in some patients although the clinical consequences of these injuries remain unclear.*

## Résumé

**Objectif** *Les lésions laryngées et trachéales sont des complications connues de l'intubation endotrachéale. Les sondes endotrachéales (SET) avec dispositifs d'aspiration sous-glottiques (DASG) sont couramment utilisées aux soins intensifs. On craint qu'une hernie tissulaire dans l'orifice d'aspiration de ces dispositifs n'entraîne des lésions trachéales, résultant en de graves conséquences cliniques telles qu'une sténose trachéale. Nous avons cherché à décrire le type et l'emplacement des lésions trachéales observées chez les patients gravement malades intubés et à évaluer les lésions au port d'aspiration ainsi que les complications hospitalières associées à ces lésions.*

**Méthode** *Nous avons mené une étude observationnelle prospective auprès de 57 patients gravement malades admis dans une unité de soins intensifs de niveau 3 qui ont été intubés par voie endotrachéale et ont subi une trachéostomie percutanée. Les chercheurs ont réalisé une bronchoscopie et une évaluation photographique des voies aériennes au cours de la trachéostomie percutanée afin d'évaluer les lésions trachéales et laryngées.*

**Résultats** *Quarante et un (72 %) intubés par SET avec DASG et seize (28 %) patients avec SET standard ont été inclus dans l'étude. Quarante-sept (83 %) patients ont présenté une lésion documentée des voies aériennes allant de l'hyperémie à l'ulcération profonde de la muqueuse. Une lésion trachéale commune était localisée sur le site du ballonnet trachéal. Une lésion au site du dispositif d'aspiration sous-glottique a été observée chez 5/41 (12 %) patients. Il n'y a pas eu de complications à l'hôpital.*

**Conclusion** *Les lésions des voies aériennes étaient fréquentes chez les patients gravement malades après une intubation endotrachéale, et les lésions trachéales se produisaient généralement au site du ballonnet endotrachéal. Des lésions se sont produites au site de l'orifice d'aspiration sous-glottique chez certains patients, bien que les conséquences cliniques de ces lésions restent incertaines.*

**Keywords** endotracheal intubation · tracheal injury · subglottic suction

Patients in the intensive care unit (ICU) often require endotracheal intubation for the provision of mechanical ventilation (MV) during a critical illness. This is a life-saving intervention for patients with respiratory failure but

is associated with an increased risk of ventilator-associated pneumonia (VAP). Ventilator-associated pneumonia is associated with prolonged duration of MV, ICU length of stay, and hospital stay, and increased healthcare costs.<sup>1,2</sup> Ventilator-associated pneumonia results from the aspiration of oropharyngeal secretions and regurgitated gastric contents (which are microbiologically colonized with pathogens) into the lungs causing inflammation and infection.<sup>3</sup> Endotracheal tubes (ETT) compromise the natural barrier of the oropharynx and larynx allowing secretions to pool above the cuff. Although the cuffs on ETTs protect against large volume aspiration, they allow the passage of contaminated secretions into the lower respiratory tract in the channels that form when large volume/low-pressure cuffs are inflated.<sup>4</sup> Endotracheal tubes with subglottic suction devices (SSDs) are designed to decrease the volume of secretions entering the lungs by aspirating secretions through a port in the tube above the cuff where suction is applied. This intervention has been shown to decrease the incidence of VAP, number of days of MV, and ICU length of stay.<sup>5–7</sup>

Laryngeal injuries are well recognized in critically ill patients who have been intubated and can result in hoarseness, throat clearing, dysphonia, and breathing difficulty.<sup>8,9</sup> An additional potential complication arising from the use of ETTs is *tracheal injury*, which can lead to complications such as tracheal stenosis.<sup>10</sup> It is unknown what predisposes some patients to develop this dreaded complication, while the majority do not. A potential etiology for tracheal injury that was investigated after the development of ETTs with SSD was suction-related injury at the site of the SSD port, which can cause herniation of tracheal tissue into the suction port.<sup>11</sup> Animal studies have shown this pattern of injury at the site of the suction port when it is subjected to continuous suction.<sup>12</sup> As a result of the initial animal studies, the configuration of ETTs was changed and tubes were modified with an increased evidence of safety. Nevertheless, the potential association of SSD, tracheal injury, and tracheal stenosis has never been fully refuted. The primary aim of this study was to describe the incidence and location of tracheal injury in critically ill patients undergoing percutaneous tracheostomy intubated with a SSD ETT vs a standard ETT. Our secondary aim was to assess the type and severity of tracheal injury at the suction port site in patients intubated with a SSD ETT, other airway injuries associated with endotracheal intubation, and factors that potentially contribute to worsening airway injury.

## Methods

We conducted a prospective observational study conducted in a level 3 medical/surgical ICU in Kingston, ON, Canada

(approx. 1,300 admissions/yr). The Queen's University Health Sciences Research Ethics Board (Kingston, ON, Canada) approved this study. Patients were accrued over 12 months. All participants or their substitute decision makers provided written consent prior to enrolment. Consent was obtained for the first eight patients enrolled in the study (including consent for photography and publication); however, an amendment for consent was approved after the eighth patient was recruited. The photographs in this manuscript are from a patient who consented to image acquisition and publication.

Patients  $\geq 18$  yr of age who were intubated with either a standard ETT without an SSD or a Mallinckrodt™ TaperGuard Evac™ (Medtronic/Covidien LLC, Mansfield, MA, USA) SSD ETT and who were scheduled to undergo percutaneous tracheostomy were screened for enrolment in the study. The indication for tracheostomy was determined by the attending physician, and the study did not influence the selection of patients for the procedure. Once the patient or their substitute decision maker had agreed to the tracheostomy, they were approached for inclusion in the study. Patients were excluded if their tracheostomies were not to be performed at the bedside by the intensive care physician (i.e., surgical tracheotomies) because of difficulties coordinating with the operating theatre.

Patients were intubated with a standard ETT or SSD ETT at the discretion of the provider performing the intubation. Patients who were intubated in the prehospital setting or operating theatre were typically intubated with a standard ETT, and patients with an anticipated intubation of  $> 72$  hr were intubated with a SSD ETT. As per protocol in our ICU, patients with an SSD ETT had continuous suction at  $-20$  to  $-30$  mm Hg applied to the suction port. Respiratory therapists checked endotracheal cuff pressures twice a day as part of their routine safety checks and maintained cuff pressures of 20–30 cm H<sub>2</sub>O.<sup>13,14</sup> At the time of percutaneous tracheostomy, patients underwent bronchoscopy as standard procedure. The percutaneous tracheostomy was done with the Ciaglia Blue Rhino® Advanced Percutaneous Tracheostomy Introducer Set or the Ciaglia Blue Dolphin® Percutaneous Dilational Tracheostomy Device (both, Cook Medical, Bloomington, IN, USA) according to the manufacturers' direction.<sup>15</sup> During the tracheostomy procedure, the endotracheal tube was withdrawn until its tip was above the first ring of the trachea. The tracheostomy was then performed, but the ETT was left in place post procedure to allow for visualization of the sub-glottic area. The ETT was then withdrawn over the bronchoscope to allow for visualization of the vocal cords, larynx, and epiglottis. Tracheal and laryngeal injury was graded and documented by the attending physician performing the tracheostomy,

and photographs were taken. Senior respiratory/critical care physicians with extensive experience in bronchoscopy and airway injury reviewed all photographs after the procedures.

Airway injury was defined using a similar classification for laryngeal injuries after intubation.<sup>16</sup> Early nonspecific changes were mild erythema. Edema was defined as swelling of the mucosa. Granulation was defined as abnormal tissue that formed at sites of irritation and ulceration. Ulceration was defined as superficial or deep erosions in the mucosa. Miscellaneous injuries included laceration, hematoma, damage to intrinsic muscles, and perforation.

Baseline characteristics and factors potentially contributing to tracheal injury such as agitation (defined as a Richmond Agitation Sedation Scale score  $\geq 2$ ), duration of intubation, number of intubation attempts, difficulty of intubation, ETT size, intubation location, and level of experience of the person performing the intubation were recorded on standardized data collection forms. The primary outcome was the presence, severity, and location of tracheal injury and was documented manually using a standardized form and photographically. Patients were followed to discharge from hospital, and complications and otolaryngology consultations were documented.

#### Statistical analysis

Baseline characteristics were summarized as means and standard deviations for continuous variables and proportions for binary and categorical variables. A chi-square test was used to compare risk of airway injury between the standard ETT and the SSD ETT. Relative risks and confidence intervals are reported. *P* values are two-sided. No imputations were performed for missing data. Statistical analysis was performed using SAS software, version 9.4 (SAS Institute Inc., Cary, NC, USA).

#### Results

Fifty-seven patients were enrolled in the study. The characteristics of the cohort are described in Table 1. The majority of patients were intubated in the ICU (54%) with a 7.5 or larger ETT (75%). Sixty-four percent of patients had agitation described as a Richmond Agitation-Sedation Scale score  $> 2$  within the 24 hr leading up to their tracheostomy. The average time from intubation to tracheostomy was 10.2 days. Five patients had been intubated within the past year and three had injuries; one had mild erythema at the site of the suction port and cuff, one had ulceration at the cuff, and one had granulation tissue at the cuff. Twenty-four patients had failed

**Table 1** Cohort characteristics

Male sex, <i>n</i> /total <i>N</i> (%)	28/57 (49%)
Age (yr), mean (SD)	60.7 (16.3)
BMI (kg·m <sup>-2</sup> ), mean (SD)	30.4 (9.7)
APACHE II score, mean (SD)	23.5 (8.2)
<i>Diagnosis, n</i> /total <i>N</i> (%)	
Neurologic	19/57 (33%)
COPDE/respiratory failure	5/57 (9%)
Pneumonia	6/57 (11%)
Abdominal	10/57 (18%)
Cardiac	2/57 (4%)
Trauma	9/57 (16%)
Cardiac arrest	2/57 (4%)
Other	4/57 (7%)
C-spine collar, <i>n</i> /total <i>N</i> (%)	12/57 (22%)
<i>Type of ETT, n</i> /total <i>N</i> (%)	
SSD	41/57 (72%)
non-SSD	16/57 (28%)
Prior intubations, <i>n</i> /total <i>N</i> (%)	5/57 (9%)
<i>Number of intubations this hospitalization, n</i> /total <i>N</i> (%)	
1	33/57 (58%)
2	16/57 (28%)
3	8/57 (14%)
<i>Location of intubation, n</i> /total <i>N</i> (%)	
ICU	31/57 (54)
OR	8/57 (14)
Out of hospital	12/57 (21)
ER	5/57 (9)
Other/unknown	1/57 (2)
<i>Person performing intubation, n</i> /total <i>N</i> (%)	
Attending physician	17/57 (30%)
Resident physician	17/57 (30%)
Other/unknown	23/57 (40%)
<i>Difficulty of intubation, n</i> /total <i>N</i> (%)	
None	21/57 (37%)
Some difficulty (as reported by practitioner performing intubation)	8/57 (14%)
Unknown	28/57 (49%)
<i>Size of ETT, n</i> /total <i>N</i> (%)	
6.5	1/57 (2%)
7.0	13/57 (23%)
7.5	25/57 (44%)
8.0	17/57 (30%)
8.5	1/57 (2%)
Duration of intubation (days), mean (SD)	10.2 (5.8)
Agitation in 24 hr prior to tracheostomy, <i>n</i> /total <i>N</i> (%)	35/57 (64%)
<i>Airway injury location, n</i> /total <i>N</i> (%)	
Any	47/57 (83%)
<i>Laryngeal</i>	

**Table 1** continued

Male sex, <i>n</i> /total <i>N</i> (%)	28/57 (49%)
Epiglottic	27/57 (59%)
Vocal cords	33/57 (69%)
Subglottic	19/57 (36%)
<i>Tracheal</i>	
Cuff	28/57 (53%)
Suction port	5/57 (10%)
<i>Airway injury type</i>	
Early nonspecific changes	4
Edema	33
Granulation	11
Ulceration	20
Miscellaneous injuries	0

APACHE II = Acute Physiology and Chronic Health Evaluation II, BMI = body mass index, COPDE = chronic obstructive pulmonary disease exacerbation, ER = emergency room, ETT = endotracheal tube, ICU = intensive care unit, OR = operating room, SD = standard deviation, SSD = subglottic suction device

extubations and were reintubated at least once during their current admission. Tracheal injury was seen in 13 reintubated patients (54%). The most common diagnosis was a neurologic diagnosis. Forty-one patients were intubated with a SSD ETT, and 16 patients were intubated with a standard ETT. A 7.5 endotracheal tube (both standard and SSD) was the most commonly used.

Airway injury was common and found in 83% of patients in the study. Tracheal injury overall was more commonly observed in females than in males (59% vs 43%), and three of the five injuries at the site of the subglottic suction device were observed in females. Thirty-three patients had injuries at multiple locations. Four patients had injury described as mild hyperemia or erythema. Thirty-three patients had moderate to severe airway edema. Eleven patients had granulation tissue. Twenty patients had ulceration noted on bronchoscopy.

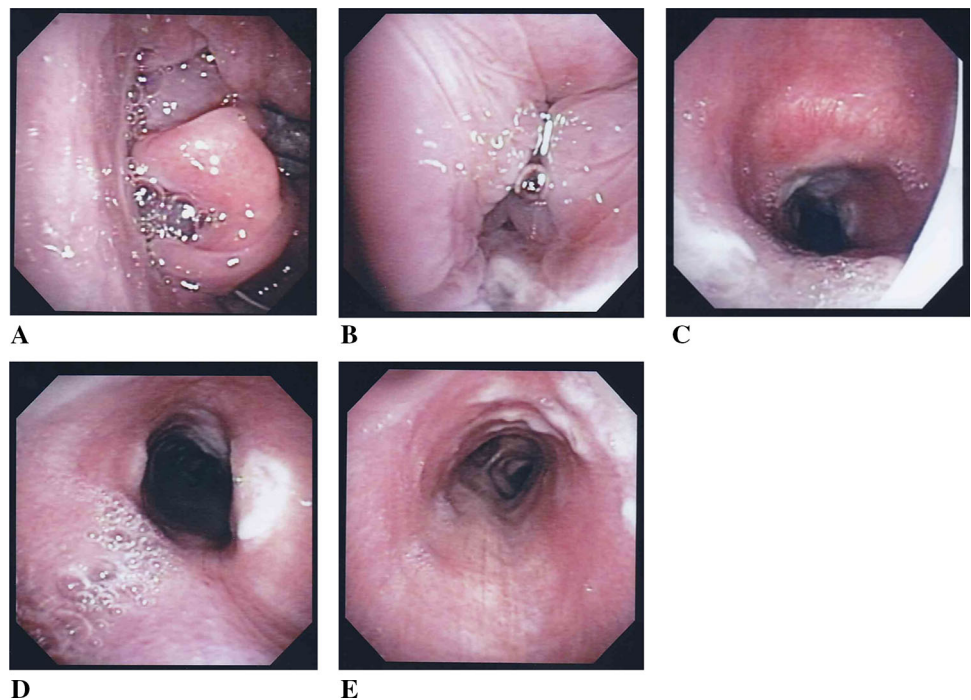
The specific location of airway injury is outlined in Table 2. There was no overall difference between the standard ETT and the SSD ETT in terms of airway injury ( $P = 0.88$ ). The study was underpowered to determine if there were differences in injuries at the specific epiglottic, vocal cord, subglottic, or tracheal locations. Of those patients with tracheal injury, a common location was the endotracheal cuff. Five patients had an injury visualized at the suction port site; one patient had mild erythema, three patients had superficial ulceration, and one patient had a deep ulceration. All patients with injury at the site of the suction port also had discrete injuries at the site of the endotracheal cuff. Four patients with visualized injury at

**Table 2** Airway injuries

	Standard ETT ( <i>n</i> /total <i>N</i> )	SSD-ETT ( <i>n</i> /total <i>N</i> )	Relative Risk (95% CI)	<i>P</i> value
Any injury	13/16	34/41	0.98 (0.62 to 1.26)	0.88
Epiglottic	6/16	21/41		
Vocal cord	8/16	25/41		
Subglottic	4/16	15/41		
Tracheal	10/16	22/41		
Cuff	8/16	20/41		
Suction port	-	5/41		

CI = confidence interval, ETT = endotracheal tube, SSD = subglottic suction device

**Figure** Airway injury photographs taken during the tracheostomy procedure: *A*) edema of the epiglottis, *B*) edema of the vocal cords, *C*) erythema of the subglottic trachea, *D*) ulceration at the site of the subglottic suction device port, and *E*) ulceration at the site of the endotracheal tube cuff



the suction port site were decannulated and had no complications at the time of hospital discharge. One patient died prior to decannulation because of a nonrelated process. Three patients received otolaryngology consults while in the hospital with a question of subglottic stenosis, including one patient with mild erythema at the suction port site who had stridor after the first extubation attempt. No subglottic stenosis was seen in any of these patients. Photographs taken during the tracheostomy procedure can be seen in [Figure](#).

## Discussion

This descriptive observational study is the largest study in an intensive care setting to evaluate tracheal injury between

patients intubated with standard ETTs and SSD ETTs with. Patients who undergo intubation, regardless of the ETT used, are at high risk for airway injury. The majority of patients in this study were noted to have some degree of airway injury ranging from mild erythema to severe edema and ulceration. Of the 41 patients intubated with an ETT with SSD, five had evidence of edema and ulceration at the level of the suction port; however, this did not result in any in-hospital complications.

Laryngeal and tracheal injury are well-known complications of endotracheal intubation, and several risk factors for the development of this injury have been identified such as intubation technique, duration of intubation, reintubation, and patient factors such as comorbidities.<sup>17</sup> Additionally, tube constitution and size are potential risk factors for airway injury, and it should be

noted that ETTs with SSD have a larger external diameter for any given internal diameter than the equivalent standard ETT. These injuries are usually self-limited,<sup>16</sup> however, tracheal injury from intubation can lead to infections, tracheal stenosis, and tracheomalacia, which are associated with an increased costs and prolonged hospital admissions.<sup>18,19</sup> Patients with iatrogenic tracheal injury are more likely to have tracheomalacia and long-term tracheostomy dependence.<sup>20</sup>

The concern for increased tracheal injuries from ETTs with SSD first arose from an animal study by Berra *et al.* showing a specific pattern of tracheal injury at the site of the suction port.<sup>12</sup> In this study, sheep were intubated using a standard ETT or a Hi-Lo Evac Mallinckrodt ETT with continuous suction of subglottic secretions for 72 hr. The 14 sheep intubated with the suction device all developed mucosal injuries of varying degrees of severity at the level of the suction port compared with the seven sheep intubated with standard ETT in which there were no airway lesions.<sup>12</sup>

There has been limited study of the potential for ETT with SSD to cause tracheal injury in humans. Seguin *et al.* performed a randomized trial where patients had continuous suctioning at  $-20$  mm Hg or intermittent suctioning at  $-100$  mm Hg for 15 sec and no suctioning for eight seconds. Bronchoscopy was performed at the time of intubation and prior to extubation.<sup>21</sup> There was a similar pattern and rate of injury between the two groups, with injury found in approximately 20% of all patients studied. Suys *et al.* studied the effect of intermittent suction on tracheal mucosa using high-resolution computerized tomography (CT) in six patients.<sup>22</sup> In all enrolled patients, prolapse of the tracheal mucosa into the suction port was shown on the CT scan. In three patients who underwent bronchoscopy, evaluation of tracheal mucosa revealed tracheal mucosal lesions, including maceration, erythema, linear erosions, and ulceration adjacent to the suction port.<sup>22</sup> Caroff *et al.* performed a systematic review and meta-analysis that showed no difference in postextubation stridor or reintubation between SSD and control groups.<sup>23</sup> There was no associated increase in the duration of MV, ICU length of stay, or in-hospital mortality.<sup>23</sup>

Given the impact VAP has on critically ill patients and on healthcare resources, there has been an extensive amount of research on the development of effective preventive strategies. Subglottic secretion drainage as a method to prevent VAP was first reported in 1992.<sup>24</sup> It has been extensively studied and has been consistently shown to reduce the occurrence of VAP and may be associated with a mortality benefit.<sup>25,26</sup> It is being increasingly advocated for routine use in all patients intubated in the ICU although it has not been adopted by all.<sup>27</sup> Though there is evidence of injury at the site of the SSD in a small percentage of patients, the benefit of reducing the risk of

VAP may outweigh the risk of complications from these injuries.

### Limitations

This single-centre study was observational in nature, and the degree and classification of injury may have been dependent on the expertise and experience of the operator performing the bronchoscopy. It may have been difficult to determine if the tracheal injury came from the cuff or from the suction port as the tube may have migrated or been repositioned. To mitigate this, all observations were recorded by attending physicians. Only patients who underwent percutaneous tracheostomy were included, so the findings here may not be generalizable to patients who do not require tracheostomy or to those who required tracheostomy by otolaryngology in the operating theatre. Patients who had been intubated in the past year were included in this study, so the airway injuries visualized could have been caused by previous intubations. Patients were also included if they had more than one intubation during their present admission. Tracheostomy is often performed after a failed attempt or accidental extubation and would require a second intubation to facilitate respiratory support and tracheostomy. It is possible some of the injuries visualized resulted from the first intubation period or subsequent intubation attempts. The sample size was small, and only 16 patients were intubated with standard ETT, which limited power to detect a statistically significant difference in airway injury at specific anatomic locations. Data on presence and duration of shock and vasopressor use were not collected for this study, though hypoperfusion could contribute to worsening airway injury. Patients were followed to hospital discharge, but no long-term follow-up was performed for patients who developed tracheal injury, limiting the ability to draw conclusions about long-term complications.

### Conclusion

Tracheal injuries are common in intubated patients and range from mild erythema to deep ulceration. There is evidence of injury at the site of the subglottic suction port, though no in-hospital complications were reported as a result of these injuries. These findings should be considered hypothesis generating, and further research is required to replicate these results and to investigate the modifications of ETTs to determine if changes in design could prevent airway injury at the site of the suction port. Larger and longer-term studies should be performed to ascertain if the benefit of reduced risk of VAP from use of SSD outweighs the potential risk of airway injury and incidence of long-term complications.

**Author contributions** John Muscedere and Stacy Ridi conceived and designed the study, obtained ethics approval, and supervised the conduct of the study. Stephanie Sibley performed the statistical analysis and drafted the manuscript with substantial input from John Muscedere. Ian Ball, Christine D'Arsigny, John Drover, Jason Erb, Imelda Galvin, Daniel Howes, Roy Ilan, David Messenger, Susan Moffatt, Christopher Parker, Stacy Ridi, and John Muscedere recruited patients, performed bronchoscopy and photography, and reviewed/edited the final manuscript. Stephanie Sibley and John Muscedere take responsibility for the paper as a whole.

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**Data availability statement** The data used in the current study are not publicly available because of identifying patient information but can be de-identified and obtained from the corresponding author on reasonable request.

## References

- Safdar N, Dezfulian C, Collard HR, Saint S. Clinical and economic consequences of ventilator-associated pneumonia: a systematic review. *Crit Care Med* 2005; 33: 2184–93. <https://doi.org/10.1097/01.ccm.0000181731.53912.d9>
- Muscedere JG, Martin CM, Heyland DK. The impact of ventilator-associated pneumonia on the Canadian health care system. *J Crit Care* 2008; 23: 5–10. <https://doi.org/10.1016/j.jcrc.2007.11.012>
- Chastre J, Fagon JY. Ventilator-associated pneumonia. *Am J Respir Crit Care Med* 2002; 165: 867–903. <https://doi.org/10.1164/ajrccm.165.7.2105078>
- Hamilton VA, Grap MJ. The role of the endotracheal tube cuff in microaspiration. *Heart Lung* 2012; 41: 167–72. <https://doi.org/10.1016/j.hrtlng.2011.09.001>
- Dezfulian C, Shojania K, Collard HR, Kim HM, Matthay MA, Saint S. Subglottic secretion drainage for preventing ventilator-associated pneumonia: a meta-analysis. *Am J Med* 2005; 118: 11–8. <https://doi.org/10.1016/j.amjmed.2004.07.051>
- Muscedere J, Rewa O, McKechnie K, Jiang X, Laporta D, Heyland DK. Subglottic secretion drainage for the prevention of ventilator-associated pneumonia: a systematic review and meta-analysis. *Crit Care Med* 2011; 39: 1985–91. <https://doi.org/10.1097/ccm.0b013e318218a4d9>
- Mao Z, Gao L, Wang G, et al. Subglottic secretion suction for preventing ventilator-associated pneumonia: an updated meta-analysis and trial sequential analysis. *Crit Care* 2016; 20: 353. <https://doi.org/10.1186/s13054-016-1527-7>
- Brodsky MB, Levy MJ, Jedlanek E, et al. Laryngeal injury and upper airway symptoms after oral endotracheal intubation with mechanical ventilation during critical care: a systematic review. *Crit Care Med* 2018; 46: 2010–7. <https://doi.org/10.1097/ccm.0000000000003368>
- Shinn JR, Kimura KS, Campbell BR, et al. Incidence and outcomes of acute laryngeal injury after prolonged mechanical ventilation. *Crit Care Med* 2019; 47: 1699–706. <https://doi.org/10.1097/ccm.0000000000004015>
- Pearson FG, Goldberg M, da Silva AJ. Tracheal stenosis complicating tracheostomy with cuffed tubes. Clinical experience and observations from a prospective study. *Arch Surg* 1968; 97: 380–94. <https://doi.org/10.1001/archsurg.1968.01340030040002>
- Dragoumanis CK, Vretzakis GI, Papaioannou VE, Didilis VN, Vogiatzaki TD, Pneumatikos IA. Investigating the failure to aspirate subglottic secretions with the Evac endotracheal tube. *Anesth Analg* 2007; 105: 1083–5. <https://doi.org/10.1213/01.ane.0000278155.19911.67>
- Berra L, De Marchi L, Panigada M, Yu ZX, Baccarelli A, Kolobov T. Evaluation of continuous aspiration of subglottic secretion in an in vivo study. *Crit Care Med* 2004; 32: 2071–8. <https://doi.org/10.1097/01.ccm.0000142575.86468.9b>
- Seegobin RD, van Hasselt GL. Endotracheal cuff pressure and tracheal mucosal blood flow: endoscopic study of effects of four large volume cuffs. *Br Med J (Clin Res Ed)* 1984; 288: 965–8. <https://doi.org/10.1136/bmj.288.6422.965>
- Sengupta P, Sessler DI, Maglinger P, et al. Endotracheal tube cuff pressure in three hospitals, and the volume required to produce an appropriate cuff pressure. *BMC Anesthesiol* 2004; 4: 8. <https://doi.org/10.1186/1471-2253-4-8>
- Cook Medical. Blue Rhino® G2-multi percutaneous tracheostomy introducer sets and trays, 2022. Available from URL: <https://www.cookmedical.com/products/a10321c1-93db-469a-9b3b-6c139143cb49/> (accessed June 2022).
- Benjamin B. Prolonged intubation injuries of the larynx: endoscopic diagnosis, classification, and treatment. *Ann Otol Rhinol Laryngol Suppl* 1993; 160: 1–15. <https://doi.org/10.1177/00034894931020s401>
- Volpi D, Lin PT, Kuriloff DB, Kimmelman CP. Risk factors for intubation injury of the larynx. *Ann Otol Rhinol Laryngol* 1987; 96: 684–6. <https://doi.org/10.1177/000348948709600614>
- Stauffer JL, Olson DE, Petty TL. Complications and consequences of endotracheal intubation and tracheotomy. A prospective study of 150 critically ill adult patients. *Am J Med* 1981; 70: 65–76. [https://doi.org/10.1016/0002-9343\(81\)90413-7](https://doi.org/10.1016/0002-9343(81)90413-7)
- Weymuller EA Jr. Laryngeal injury from prolonged endotracheal intubation. *Laryngoscope* 1988; 98: 1–15. <https://doi.org/10.1288/00005537-198808001-00001>
- Gelbard A, Francis DO, Sandulache VC, Simmons JC, Donovan DT, Ongkasuwan J. Causes and consequences of adult laryngotracheal stenosis. *Laryngoscope* 2015; 125: 1137–43. <https://doi.org/10.1002/lary.24956>
- Seguin P, Perrichet H, Le Pabic E, et al. Effect of continuous versus intermittent subglottic suctioning on tracheal mucosa by the mallinckrodt taperguard evac oral tracheal tube in intensive care unit ventilated patients: a prospective randomized study. *Indian J Crit Care Med* 2018; 22: 1–4. [https://doi.org/10.4103/ijccm.ijccm\\_350\\_17](https://doi.org/10.4103/ijccm.ijccm_350_17)
- Suys E, Nieboer K, Stiers W, De Regt J, Huyghens L, Spapen H. Intermittent subglottic secretion drainage may cause tracheal damage in patients with few oropharyngeal secretions. *Intensive Crit Care Nurs* 2013; 29: 317–20. <https://doi.org/10.1016/j.iccn.2013.02.007>
- Caroff DA, Li L, Muscedere J, Klompas M. Subglottic secretion drainage and objective outcomes: a systematic review and meta-analysis. *Crit Care Med* 2016; 44: 830–40. <https://doi.org/10.1097/ccm.0000000000001414>
- Mahul P, Auboyer C, Jospe R, et al. Prevention of nosocomial pneumonia in intubated patients: respective role of mechanical subglottic secretions drainage and stress ulcer prophylaxis.

- Intensive Care Med 1992; 18: 20–5. <https://doi.org/10.1007/bf01706421>
25. Pozuelo-Carrascosa DP, Herráiz-Adillo A, Alvarez-Bueno C, Añón JM, Martínez-Vizcaíno V, Cavero-Redondo I. Subglottic secretion drainage for preventing ventilator-associated pneumonia: an overview of systematic reviews and an updated meta-analysis. *Eur Respir Rev* 2020; 29: 190107. <https://doi.org/10.1183/16000617.0107-2019>
26. Hubbard JL, Veneman WL, Dirks RC, Davis JW, Kaups KL. Use of endotracheal tubes with subglottic secretion drainage reduces ventilator-associated pneumonia in trauma patients. *J Trauma Acute Care Surg* 2016; 80: 218–22. <https://doi.org/10.1097/ta.0000000000000927>
27. Baldwin F, Gray R, Chequers M, Dyos J. Audit of UK ventilator care bundles and discussion of subglottic secretion drainage. *Nurs Crit Care* 2016; 21: 265–70. <https://doi.org/10.1111/nicc.12146>

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