

# Improving Endotracheal Cuff Inflation Pressures: An Evidence-Based Project in a Military Medical Center

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Poor management of endotracheal tube cuff pressures occurs in more than 50% of all general anesthetics, leading to tracheal ischemia, tracheal rupture, sore throats, recurrent laryngeal nerve palsy, tracheal stenosis, microaspiration, and/or inadequate ventilation. General endotracheal anesthesia is common practice throughout the world. Endotracheal tube cuffs are filled with a fluid (gas or liquid) to a safe and adequate pressure of 20 to 30 cm H<sub>2</sub>O to protect the lung parenchyma from aspiration while also ensuring positive pressure can be generated to oxygenate/ventilate patients. An evidence-based project to improve anesthesia providers' management of endotracheal tube

cuff pressures was performed at a military medical center in the southwestern United States. The intervention consisted of an education presentation, availability of cuff manometers in all operating rooms, a charting reminder to document cuff pressures, and a visual prompt in the electronic anesthesia record. The intervention resulted in a statistically significant increase in safe cuff pressures ( $P = .0032$ ; odds ratio = 4.41, 95% CI = 1.71-11.3).

**Keywords:** Cuff manometer, endotracheal tube cuff, education intervention, general endotracheal anesthesia.

**M**ismanagement of endotracheal (ET) tube cuff pressure (CP), defined as a CP that falls outside the recommended range of 20 to 30 cm H<sub>2</sub>O, is a frequent occurrence during general anesthetics, with study findings ranging from 55% to 80%.<sup>1-4</sup> Endotracheal tube cuffs are typically filled with air to a safe and adequate pressure of 20 to 30 cm H<sub>2</sub>O to protect the lung parenchyma from aspiration while also allowing positive pressure to oxygenate/ventilate patients.<sup>1,5-9</sup> Mismanagement of ET tube CPs can lead to complications such as tracheal edema, tracheal ischemia, tracheal stenosis, tracheal rupture, sore throats, recurrent laryngeal nerve palsy, microaspiration, and inadequate ventilation.<sup>5-7,10-12</sup> A 2012 study found tracheal ischemic lesions present in 83% of intensive care unit patients 24 hours after extubation.<sup>7</sup> Tracheal stenosis is the narrowing of the trachea and can be a result of an overpressurized ET tube cuff.<sup>13</sup> The signs and symptoms of tracheal stenosis, which may be delayed 20 years, include hoarseness, inspiratory stridor, dyspnea, and complete obstruction.<sup>14,15</sup> Although the potential long-term sequelae are rarely seen by individual anesthesia providers, the literature has recurrent case reports of postintubation stenosis and granulomas, some with fatal consequences.<sup>13-17</sup> A common complaint after general ET anesthesia is a sore throat, with reported rates of 62% and overpressurized ET tube cuffs being a key variable.<sup>12</sup> Interventions such as aggressive suction-

ing, difficult intubation, or large ET tubes could also be contributors to potential ET tube morbidities and should not be ignored. However, maintaining an ET tube CP within the recommended range is an easy noninvasive intervention that would minimize the impact of this variable on negative patient outcomes. There is a wealth of literature supporting the objective measurement for ET tube CP, yet overpressurized ET tube cuffs remain a persistent problem. Many potential barriers may contribute to the persistence of this problem, including the cost and availability of cuff manometers, provider knowledge gaps regarding best practice, acceptance of minor complaints such as sore throats as normal, and the rarity and visibility of the major morbidities. Before implementation of this project, in the institution of the primary author (M.A.T.), 72.5% of ET tube CPs were outside the safe pressure of 20 to 30 cm H<sub>2</sub>O.

An evidence-based practice project was conducted at the primary author's institution to improve ET tube inflation pressure management by anesthesia providers. The intervention consisted of an evidence-based education intervention, cuff manometers available in all operating rooms (ORs), a documentation reminder, and a visual prompt in the electronic anesthesia record. The aims of the project were to remove barriers to the regular use of cuff manometry, resulting in the regular measurement and documentation of ET tube CPs within acceptable evidence-based limits.

## Review of the Literature

A review of the literature was conducted using the following databases: the National Library of Medicine's PubMed, Cumulative Index to Nursing & Allied Health Literature (CINAHL), Google Scholar, and Cochrane Reviews. Research regarding ET tube CPs is frequent in the literature with several recurrent themes. Among these themes, 20 to 30 cm H<sub>2</sub>O is frequently cited as the acceptable pressure range, and anesthesia providers by subjective measurements, such as the widely used palpation technique, are poor at estimating this pressure range. This review will focus on ET tube CP as it relates to the adult population.

• **Importance of Endotracheal Cuff Pressure Management.** Regarding ET tube CP, the literature focuses on 2 extremes: what morbidities occur when the CP is inflated above the threshold levels and what morbidities occur below the threshold levels. There is no set standard for CP from any of the major anesthesia professional bodies. The American Association of Nurse Anesthetists, the American Society of Anesthesiologists, and the major European anesthesia organizations do not identify a specific standard for CP management and decline to state recommended pressure ranges for CP. Despite the silence of these professional societies, there is a significant body of evidence supporting the regular use of objective measurements to determine safe ET tube CPs.<sup>5,6,8,9,11</sup> Therefore, it falls on the best evidence presented in the literature to recommend the best practice for managing CP by anesthesia providers.

An early landmark study corroborated the findings of earlier animal studies that CP altered tracheal blood flow, specifically that capillary blood flow was compromised at a CP greater than 30 cm H<sub>2</sub>O and was completely occluded at pressures greater than 50 cm H<sub>2</sub>O.<sup>18</sup> Ischemia caused by the overpressurization of ET tube cuffs can lead to tracheal lesions and subsequent granuloma development with concurrent narrowing of the trachea and potentially fatal outcomes; this ischemia can occur in 15 minutes.<sup>7,9</sup> This complication may not be seen for years; one case report stated that symptomatic tracheal stenosis developed 20 years after intubation in a patient.<sup>14</sup> This rare but tragic morbidity can be life-altering and result in recurrent endoscopic tracheal dilations or surgery to remove the stenosis.<sup>15,19</sup> Studies using manometers during surgery resulted in fewer complaints of sore throat and lesser severity of sore throat if present.<sup>10-12</sup> The potential severity of complications involving overpressurized ET tubes and the propensity of providers to overestimate CPs via subjective measures supports the need for tools of objective measurement.<sup>5,8,10,11</sup>

A CP less than 20 cm H<sub>2</sub>O has been cited as substantially increasing the risk of pneumonia development in intubated patients.<sup>20-22</sup> Many of these studies take place in intensive care units and are not directly related to

the timeframe in which anesthetists usually work with intubated patients; they do, however, highlight the importance of maintaining a minimum CP that minimizes the risk of aspiration and other morbidities, thus increasing patient safety. Ultrathin polyurethane ET tube cuffs may be one potential avenue to minimize the risk of low pressures in ET tubes, but the research is limited, and at present these tubes are not common in most practices.<sup>23</sup>

Other factors are present that may affect the CP during surgery and may be attenuated by use of a cuff manometer to ensure that the CP remains within an acceptable range. One factor is temperature, in that ambient air injected into an ET tube cuff may result in an increase in pressure as it warms to body temperature.<sup>5,24</sup> This effect may be amplified in hypothermic patients rewarmed to normal physiologic levels, such as patients undergoing coronary bypass.<sup>5,24</sup> Another factor is anesthetics that include the administration of nitrous oxide because it will diffuse in the ET tube cuff and result in greatly increased CPs over time.<sup>5,24</sup>

• **Methods to Determine Adequate Endotracheal Cuff Pressure.** The preponderance of the literature demonstrates the inadequacy of the widely used palpation method to determine CP. Currently the most reliable and accurate measure of CP is the cuff manometer. Studies examining the varieties of current methods used to determine adequate CP consistently illustrate the inadequacy of the palpation method while providing examples of more effective alternatives.

Stewart et al<sup>4</sup> investigated CP measurements comparing subjective estimated CPs vs objective CP measurements. The study participants included Certified Registered Nurse Anesthetists (CRNAs), student registered nurse anesthetists (SRNAs), and anesthesiologists. Forty providers were instructed to inflate cuffs in their usual manner; subsequently a cuff manometer was used to determine the actual pressure. The results demonstrated that less than one-third of the providers were able to estimate a CP in the predetermined range and 60% of the measured pressures were more than 40 cm H<sub>2</sub>O; these numbers are consistent throughout the literature. Additionally, no differences in estimation accuracy were found between the 3 types of anesthesia providers participating.<sup>4</sup>

A British study investigated how pilot balloon design affected estimation of CPs.<sup>25</sup> The researchers used 6 different styles of pilot balloons, and participants were asked to determine if pressures were acceptable or were below or above acceptable ranges. Participants determined accurate pressures 42.9% of the time; however, based on the study design, accurate pressures could have been determined by chance 33% of the time.<sup>25</sup> This study demonstrated a recurrent theme in the literature that anesthesia providers' estimates of CP are typically high and inconsistent.

As an alternative to the palpation technique, a 2017

randomized controlled trial compared a palpation technique with a technique using a loss-of-resistance syringe.<sup>26</sup> This study randomly divided patients into either the loss-of-resistance group or the palpation group. Nearly two-thirds of the patients in the loss-of-resistance group had CPs in the acceptable range, 20 to 30 cm H<sub>2</sub>O, whereas only 22.5% of cuffs in the palpation group were in the acceptable range. This study demonstrated that the loss-of-resistance syringe technique, although not as effective as a cuff manometer, does appear to be more accurate than palpation. As the authors point out, the loss-of-resistance syringe technique may offer benefits to countries and regions that cannot afford the expense of cuff manometers.

A multicenter study examined the effect that a lack of cuff manometers has on CPs.<sup>1</sup> The authors confirmed the widely published evidence that a lack of cuff manometers results in inadequate CPs, because only 27% of their measured CPs were in the accepted 20 to 30 cm H<sub>2</sub>O range. Additionally, these investigators measured the volume of air required to obtain a CP in the accepted range. Across the 3 institutions where the study was performed and across a range of ET tube sizes from 7.0 to 8.5 mm, the volume of air required to reach a pressure of 20 cm H<sub>2</sub>O was variable between patients but typically required less than 5 mL. Regression analysis revealed that 2 to 4 mL of air was typically enough volume to achieve a CP of 20 to 30 cm H<sub>2</sub>O.<sup>1</sup> Given that many providers automatically place a 10-mL syringe on the pilot balloon of ET tubes, this study provides credence that a change of practice from 10-mL syringes to 5-mL syringes may be in order to help mitigate the risk of severely overinflated ET tubes. Another study found that while changing to a 5-mL syringe did not result in reducing CPs to the ideal range, it did mitigate the degree to which the cuffs were overpressurized.<sup>27</sup>

Other techniques such as sealing CP or minimal occlusive volume, minimal leak test, and stethoscope-guided techniques are noted in the literature and demonstrate viable options regarding minimizing the overpressurization of ET tubes; however, they all remain subjective measures and do not address the risks associated with underpressurized ET tubes.<sup>8,28,29</sup> In locations where manometers may not be a viable option because of cost, these alternate techniques, including the loss-of-resistance technique discussed previously, may be the best option available compared with the palpation technique. The authors in all the aforementioned studies suggest that an objective measure of CP, such as the cuff manometer, should be used whenever they are available.<sup>1,4,8,25-29</sup>

• **Previous Education Programs Addressing Endotracheal Cuff Pressure.** There is minimal literature regarding CP management and education programs to address the recurrent issue of inadequate CP management. The 2 articles reviewed are the only articles the authors found that in-

corporate an education program and CP management. A potential barrier to wider implementation of quantitative monitoring could be knowledge gaps regarding best practice; thus, the need for the education component of this project with the aim of closing identified knowledge gaps. A 2015 study investigated whether an education program could improve the safety of the CP palpation technique.<sup>2</sup> The first finding from this study was that the experience of the provider had no impact on the ability of the provider to accurately determine a safe CP.<sup>2</sup> The second finding was that despite the education program, the palpation technique was a poor estimator of CP.

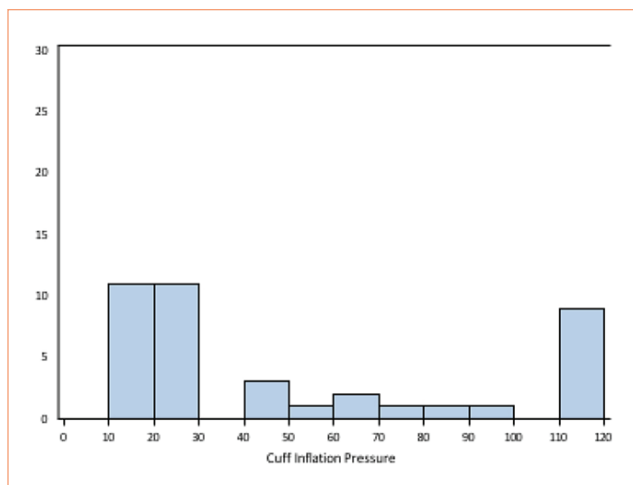
The only available study specifically investigating CP management in conjunction with an education program and the ready availability of cuff manometers was recently published in the *Journal of Military Medicine*.<sup>3</sup> The study included a mixed group of anesthesiologists and CRNAs and demonstrated an improvement in CPs after implementation of the education program in conjunction with the availability of cuff manometers. This study is apparently the first of its kind described in the literature. Although the intervention was successful in lowering overall CPs, it did not demonstrate dramatically statistically significant improvements.

Multiple serious morbidities are associated with inadequately controlled and measured ET tube CPs. The findings across the literature suggest that CP should be maintained in the range of 20 to 30 cm H<sub>2</sub>O to ameliorate the morbidities associated with underpressurized and overpressurized ET tube cuffs. The preponderance of the literature demonstrates the inadequacy of the widely used palpation method to determine CP. Currently the most reliable and accurate measure of CP is the cuff manometer.

## Methods

The setting for this scholarly work was a military treatment facility located in the southwestern United States serving more than 100,000 beneficiaries who receive care in the military health system. The anesthesia staff consisted of 35 CRNAs and 5 physician anesthesiologists, along with 6 SRNAs, who provide anesthesia services for approximately 800 surgeries per month.

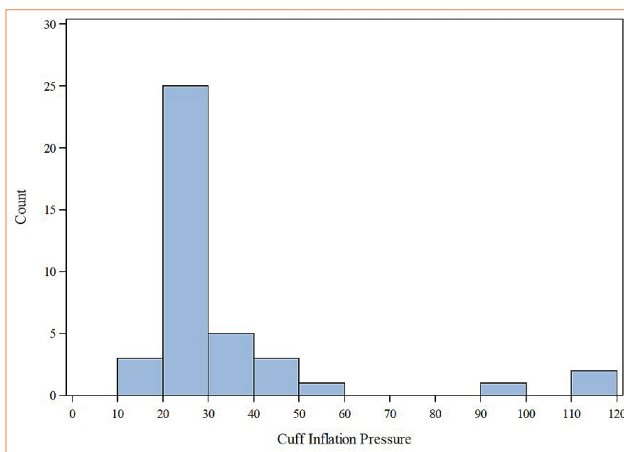
Institutional review board exemption was obtained as the project examined the impact of an educational intervention designed to produce an evidence-based modification of existing practice and no protected health information was collected or disclosed. The project was then completed in 3 phases. The first phase (preintervention) consisted of the following assessments: 1) staff practice modalities to assess for an appropriate ET tube cuff inflation pressure; 2) staff knowledge of best practices to accurately assess ET tube inflation pressures; and (3) random checks of current CP in patients undergoing general ET anesthesia at the treatment facility. The first 2 parts of phase 1 were assessed via a data collection tool.



**Figure 1.** Preimplementation Endotracheal Tube Cuff Pressures (cm H<sub>2</sub>O)

The data collection tool was used to determine preintervention clinician practice and baseline knowledge of best practice regarding CP in the anesthesia department. The data collection tool did cover areas outside the scope of this project to possibly help guide future projects, mainly pediatric intubation. Completed data were collected and evaluated to guide the education component of the intervention. Following the data collection, a convenience sample of 40 intubated patients had their CPs evaluated by the primary author of this project via a single cuff manometer (Posey Cufflator 8199, VBM Medizintechnik GmbH). The manometer used for the study was the personal manometer of the primary author, and it was believed that the familiarity with this manometer would provide the most consistent measurements and minimize error throughout the study. That brand of manometer is the one used by the department in this study. Given the size of the department and with consultation of the hospital statistician, it was decided that an n of 40 CPs would be sufficient data to detect a change in behavior.

The second phase (intervention) consisted of an education in-service and slide presentation (PowerPoint, Microsoft). This presentation was guided by the insight gained from the data collection tool regarding baseline knowledge of ET tube CPs, and it further educated the staff about morbidity related to inappropriate inflation pressures as well as best practices described in the literature. This education program was disseminated in the Department of Anesthesia. The methods of delivery were 3 separate presentations to the staff during morning meetings and informal teaching sessions to the staff about cuff manometry. Additionally, clinical tools to aid the clinicians in application of best practices were put in place. The tools consisted of the placement of ET cuff manometers (Posey Cufflator 8199) in all OR locations, charting reminders in the electronic anesthesia record, and visible labels on all anesthesia machines listing the



**Figure 2.** Postimplementation Endotracheal Tube Cuff Pressures (cm H<sub>2</sub>O)

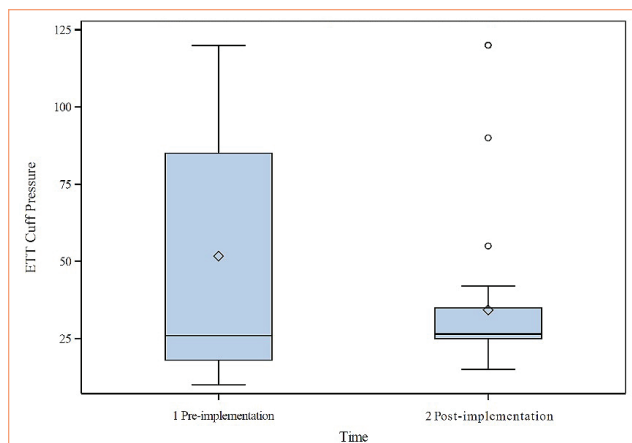
recommended CP range of 20 to 30 cm H<sub>2</sub>O.

The third and final phase was postimplementation data collection assessed by the same data collection tool used in phase 1. Phase 3 occurred approximately 60 days after the initial presentation. The subsequent data collection tool was distributed, and results were evaluated. An additional 40 intubated patients had their CPs evaluated by the same brand of cuff manometer used in the preimplementation sample. Last, a chart review was undertaken to determine whether CPs were being charted.

## Results

A total of 30 anesthesia providers completed and returned the data collection tool before the intervention, and 31 providers returned completed data tools after the intervention. Primary outcome measures improved substantially after the intervention. In a comparison of 40 ET tube CPs recorded before and after implementation, safe pressures of 20 to 30 cm H<sub>2</sub>O increased from 27.5% to 62.5% (11 vs 25,  $P = .0032$ ). The incidence of having “not normal cuff pressures” were 4.4 times more likely before implementation (odds ratio = 4.394; 95% CI = 1.709-11.295). Endotracheal tube CPs were brought closer to the safe pressure range after the intervention as evidenced by the preintervention and postintervention histograms in Figures 1 and 2 and the box plot in Figure 3. The percentage of anesthesia providers who used an appropriate measure to determine adequate ET tube CPs increased from 10% to 94% after implementation (3/30 vs 29/31,  $P < .0001$ ).

Additionally, the frequency of checking the CP during the case and the anesthesia provider knowledge was improved. The percentage of anesthesia providers who monitored CP at the beginning and every hour thereafter increased from 11% to 53% ( $P = .0007$ ). Anesthesia providers’ knowledge of an accurate CP (20-30 cm H<sub>2</sub>O) increased from 35% to 87% (30 vs 27/31,  $P < .0001$ ). In the preimplementation data, 25 (83%) of 30 respondents



**Figure 3.** Preimplementation vs Postimplementation Endotracheal (ET) Tube Cuff Pressures (cm H<sub>2</sub>O)<sup>a</sup>

<sup>a</sup>Diamonds indicate mean; open circles, outliers.

would use a 10-mL syringe to fill their ET tube cuffs, with the remaining 5 respondents (17%) using a 5-mL syringe. The postimplementation data resulted in 20 (63%) of 32 responses demonstrating a change of practice to regularly using a 5-mL syringe to inflate their ET tube cuffs ( $P = .0001$ ).

Last, a chart review was undertaken to review 40 anesthetic charts 30 to 60 days after implementation. The chart review demonstrated that 30 (75%) of 40 general ET anesthetics had ET tube CP documented, and all pressures were within the range of 20 to 30 cm H<sub>2</sub>O. The preimplementation data tool had a self-reported incidence of 6 (19%) of 31 regularly documenting CPs. Seven of the 10 charts without CP documentation were from 3 providers. These 3 providers were questioned as to why they chose not to document CPs. Two stated that they had begun to regularly check pressures but declined to document their pressures. The third provider believed his or her palpation technique provided the best measure of CP and that the documentation of palpation was unnecessary. The providers of the 3 remaining undocumented charts reported regularly checking and documenting CPs but simply forgetting to document them in this instance.

## Discussion

The substantially increased likelihood of a patient at this military treatment facility undergoing general ET anesthesia having an ET tube CP in the recommended range of 20 to 30 cm H<sub>2</sub>O after implementation is clearly demonstrated by the results of the statistical analysis. This improvement in practice, if sustained, should result in the potential for fewer complications resulting from poor management of CPs.

The overall staff knowledge of ET tube CPs improved demonstrably as evidenced by results of the postimplementation data collection tool. The availability of cuff manometers in all anesthetic locations led to a more than

9-fold increase in their use during general ET anesthesia. These changes coincided with the overall improvement in CP management.

The volume of air injected into an ET tube cuff can be directly affected by the size of the syringe used to inflate the cuff, with larger syringes resulting in higher CPs.<sup>1,27</sup> With the literature demonstrating that a syringe size less than 5 mL will often result in an ET tube CP in the 20 to 30 cm H<sub>2</sub>O range, this change to best practice should result in less initial overpressurization of ET tubes.<sup>1,27</sup>

Additionally, this group of anesthesia providers dramatically changed their documentation practice regarding ET tube CPs. Whether this was a result of the documentation reminder in the electronic record or a result of an increased cognizance of ET tube CPs is perhaps an area of further inquiry. Another potential area of further study is whether the improvement in CP management will continue past the postimplementation evaluation phase.

## Conclusion

The current evidence in the literature is clear that 20 to 30 cm H<sub>2</sub>O pressure in an ET tube cuff is the range that provides the safest pressure margin to patients undergoing general ET anesthesia. Moreover, anesthesia providers are inconsistent in subjective measures, such as the palpation technique, in determining optimal ET tube CP and the current best objective measurement is the cuff manometer. Additionally, changing practice by attaching a 5-mL syringe to the pilot balloon instead of the more common 10-mL syringe may result in fewer initially overpressurized ET tubes.

By removing barriers to widespread use of cuff manometers in this facility, the shift in the clinical data obtained from before to after implementation highlights a knowledge shift and the implementation of evidenced-based practice into widespread use in this anesthesia department. The dramatic decrease in overpressurized ET tube cuffs in this institution should not only result in a reduction of common intubation morbidities such as sore throat but also should minimize the risk of higher morbidity events such as tracheal stenosis or rupture. This project was well received by participants and demonstrates a successful example of translating the available research and the implementation of evidence-based practice into daily clinical routine.

## REFERENCES

1. 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. doi:10.1186/1471-2253-4-8
2. Seyed Siamdoust SA, Mohseni M, Memarian A. Endotracheal tube cuff pressure assessment: education may improve but not guarantee the safety of palpation technique. *Anesthesiol Pain Med.* 2015;5(3):e16163. doi:10.5812/aapm.5(3)2015.16163
3. Stevens GJ, Warfel JW, Aden JK, Blackwell SD. Intraoperative endotracheal cuff pressure study: how education and availability of manom-

- eters help guide safer pressures. *Mil Med.* 2018;183(9-10):e416-e419. doi:10.1093/milmed/usx127
4. Stewart SL, Secrest JA, Norwood BR, Zachary R. A comparison of endotracheal tube cuff pressures using estimation techniques and direct intracuff measurement. *AANA J.* 2003;71(6):443-447.
  5. Grant T. Do current methods for endotracheal tube cuff inflation create pressures above the recommended range? A review of the evidence. *J Perioper Pract.* 2013;23(12):292-295. doi:10.1177/175045891302301205
  6. Hockey CA, van Zundert AA, Paratz JD. Does objective measurement of tracheal tube cuff pressures minimise adverse effects and maintain accurate cuff pressures? A systematic review and meta-analysis. *Surv Anesthesiol.* 2017;61(1):6. doi:10.1097/01.sa.0000513228.54664.47
  7. Touat L, Fournier C, Ramon P, Salleron J, Durocher A, Nseir S. Intubation-related tracheal ischemic lesions: incidence, risk factors, and outcome. *Intensive Care Med.* 2013;39(4):575-582. doi:10.1007/s00134-012-2750-6
  8. Feng TR, Ye Y, Doyle DJ. Critical importance of tracheal tube cuff pressure management. *World J Anesth.* 2015;4(2):10-12. doi:10.5313/wja.v4.i2.10
  9. Rokamp KZ, Secher NH, Møller AM, Nielsen HB. Tracheal tube and laryngeal mask cuff pressure during anaesthesia—mandatory monitoring is in need. *BMC Anesthesiol.* 2010;10(1):20. doi:10.1186/1471-2253-10-20
  10. Liu J, Zhang X, Gong W, et al. Correlations between controlled endotracheal tube cuff pressure and postprocedural complications: a multicenter study. *Anesth Analg.* 2010;111(5):1133-1137. doi:10.1213/ANE.0b013e3181f2ecc7.
  11. Sultan P, Carvalho B, Rose BO, Cregg R. Endotracheal tube cuff pressure monitoring: a review of the evidence. *J Perioper Pract.* 2011;21(11):379-386. doi:10.1177/175045891102101103
  12. El-Boghdadly K, Bailey CR, Wiles MD. Postoperative sore throat: a systematic review. *Anaesthesia.* 2016;71(6):706-717. doi:10.1111/anae.13438
  13. Wain JC. Postintubation tracheal stenosis. *Chest Surg Clin.* 2003;13(2):231-246. doi:10.1016/S1052-3359(03)00034-6
  14. Dikkers FG. Tracheal stenosis can occur 20 years after intubation. *BMJ.* 2001;322(7282):362-362.
  15. Gaspar MTDC, Maximiano LF, Minamoto H, Otoch JP. Tracheal stenosis due to endotracheal tube cuff hyperinflation: a preventable complication. *Autopsy Case Rep.* 2019;9(1):e2018072. doi:10.4322/acr.2018.072
  16. Park S-Y, Choi HS, Yoon J-Y, et al. Fatal vocal cord granuloma after orthognathic surgery. *J Dent Anesth Pain Med.* 2018;18(6):375-378. doi:10.17245/jdapm.2018.18.6.375
  17. Altun D, Yilmaz E, Basaran B, Camci E. Surgical excision of postintubation granuloma under jet ventilation. *Turk J Anaesthesiol Reanim.* 2014;42(4):220-222.
  18. 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(6422):965-968. doi:10.1136/bmj.288.6422.965
  19. Elsayed H, Mostafa AM, Soliman S, Shoukry T, El-Nori AA, El-Bawab HY. First-line tracheal resection and primary anastomosis for postintubation tracheal stenosis. *Ann R Coll Surg Engl.* 2016;98(6):425-430. doi:10.1308/rcsann.2016.0162
  20. Rello J, Sonora R, Jubert P, Artigas A, Rué M, Vallés J. Pneumonia in intubated patients: role of respiratory airway care. *Am J Respir Crit Care Med.* 1996;154(1):111-115. doi:10.1164/ajrccm.154.1.8680665
  21. Lorente L, Blot S, Rello J. Evidence on measures for the prevention of ventilator-associated pneumonia. *Eur Respir J.* 2007;30(6):1193-1207. doi:10.1183/09031936.00048507
  22. Sole ML, Su X, Talbert S, et al. Evaluation of an intervention to maintain endotracheal tube cuff pressure within therapeutic range. *Am J Crit Care.* 2011;29(2):109-118. doi:10.4037/ajcc2011661
  23. Blot SI, Rello J, Koulenti D. The value of polyurethane-cuffed endotracheal tubes to reduce microaspiration and intubation-related pneumonia: a systematic review of laboratory and clinical studies. *Crit Care Lond Engl.* 2016;20(1):203-203. doi:10.1186/s13054-016-1380-8
  24. Atlas GM. A mathematical model of differential tracheal tube cuff pressure: effects of diffusion and temperature. *J Clin Monit Comput.* 2005;19(6):415-425. doi:10.1007/s10877-005-1626-5
  25. Janossy KM, Pullen J., Young D, Bell G. The effect of pilot balloon design on estimation of safe tracheal tube cuff pressure. *Anaesthesia.* 2010;65(8):785-791. doi:10.1111/j.1365-2044.2010.06413.x
  26. Bulamba F, Kintu A, Ayupo N, et al. Achieving the recommended endotracheal tube cuff pressure: a randomized control study comparing loss of resistance syringe to pilot balloon palpation. *Anesthesiol Res Pract.* 2017;2017:2032748. doi:10.1155/2017/2032748
  27. Williams GW II, Arttime CA, Mancillas OL, et al. Subglottic perioperative airway-tube inflation via randomized evaluation with variable syringe size (Spair-Tire) study. *Clin Respir J.* 2019;13(1):66-69. doi:10.1111/crj.12984
  28. Borhazowal R, Harde M, Bhadade R, Dave S, Aswar SG. Comparison between two endotracheal tube cuff inflation methods; just-seal vs. stethoscope-guided. *J Clin Diagn Res.* 2017;11(6):UC01-UC03. doi:10.7860/JCDR/2017/26301.10017
  29. Al-metwalli RR, Al-Ghamdi AA, Mowafi HA, Sadek S, Abdulshafi M, Mousa WF. Is sealing cuff pressure, easy, reliable and safe technique for endotracheal tube cuff inflation?: a comparative study. *Saudi J Anaesth.* 2011;5(2):185-189. doi:10.4103/1658-354X.82795

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## ACKNOWLEDGMENTS

The authors gratefully acknowledge the support from the leadership and staff in the Department of Anesthesia at William Beaumont Army Medical Center