



# EVALUATION OF AN INTERVENTION TO MAINTAIN ENDOTRACHEAL TUBE CUFF PRESSURE WITHIN THERAPEUTIC RANGE

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**CE** 1.0 Hour

## Notice to CE enrollees:

A closed-book, multiple-choice examination following this article tests your understanding of the following objectives:

1. Review the physiological significance of endotracheal tube (ETT) pressure.
2. Compare continuous ETT cuff pressure monitoring with intermittent manual monitoring techniques.
3. Discuss adjustments required to maintain optimal ETT cuff pressures.

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**Background** Endotracheal tube cuff pressure must be kept within an optimal range that ensures ventilation and prevents aspiration while maintaining tracheal perfusion.

**Objectives** To test the effect of an intervention (adding or removing air) on the proportion of time that cuff pressure was between 20 and 30 cm H<sub>2</sub>O and to evaluate changes in cuff pressure over time.

**Methods** A repeated-measure crossover design was used to study 32 orally intubated patients receiving mechanical ventilation for two 12-hour shifts (randomized control and intervention conditions). Continuous cuff pressure monitoring was initiated, and the pressure was adjusted to a minimum of 22 cm H<sub>2</sub>O. Caregivers were blinded to cuff pressure data, and usual care was provided during the control condition. During the intervention condition, cuff pressure alarm or clinical triggers guided the intervention.

**Results** Most patients were men (mean age, 61.6 years). During the control condition, 51.7% of cuff pressure values were out of range compared with 11.1% during the intervention condition ( $P < .001$ ). During the intervention, a mean of 8 adjustments were required, mostly to add air to the endotracheal tube cuff (mean 0.28 [SD, 0.13] mL). During the control condition, cuff pressure decreased over time ( $P < .001$ ).

**Conclusions** The intervention was effective in maintaining cuff pressure within an optimal range, and cuff pressure decreased over time without intervention. The effect of the intervention on outcomes such as ventilator-associated pneumonia and tracheal damage requires further study. (*American Journal of Critical Care*. 2011;20:109-118)

Critically ill patients often require intubation with an endotracheal tube (ETT) to provide an artificial airway for mechanical ventilation. Management of the artificial airway is an important part of care rendered by nurses and respiratory therapists. One aspect of airway management is maintenance of an adequate pressure in the ETT cuff. The cuff is inflated to seal the airway to deliver mechanical ventilation. A cuff pressure between 20 and 30 cm H<sub>2</sub>O is recommended to provide an adequate seal and reduce the risk of complications.<sup>1-4</sup> Survey results<sup>5-7</sup> indicate that cuff pressure is usually monitored and adjusted every 8 to 12 hours.

ETT cuff pressure varies and may be out of range during the interval between intermittent measurements, increasing the risk for complications. In this study, we tested the effectiveness of an intervention, management of the ETT cuff pressure via continuous monitoring and alarm or clinical triggers, versus intermittent pressure measurement. The objective was to maintain the ETT cuff pressure within a range of 20 to 30 cm H<sub>2</sub>O. The study also provided an opportunity to describe the natural history of ETT cuff pressure over time.

### Background and Significance— Ideal Cuff Pressure

The ETT cuff pressure must be in a range that ensures delivery of the prescribed mechanical ventilation tidal volume, reduces the risk for aspiration of secretions that accumulate above

the cuff, and does not compromise tracheal perfusion. A minimal pressure of 20 cm H<sub>2</sub>O is recommended to prevent aspiration and ventilator-associated pneumonia (VAP).<sup>8,9</sup> In a study of 83 subjects, Rello and colleagues<sup>2</sup> found a 4-fold risk for VAP when the ETT cuff pressure was below 20 cm H<sub>2</sub>O. The amount of air needed to achieve a pressure of 20 cm H<sub>2</sub>O is small, ranging from 2.6 mL for a 7.0-mm ETT to 3.3 mL for an 8.5-mm tube.<sup>10</sup>

### About the Authors

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The pressure needed to seal the airway has not been extensively studied. In a study of 50 adolescents intubated with a 7.0-mm ETT, the mean cuff pressure required for an adequate seal was 19.1 cm during pressure control ventilation, set at a peak inspiratory pressure of 20 cm H<sub>2</sub>O, 15 breaths per minute, and 5 cm H<sub>2</sub>O of positive end-expiratory pressure (PEEP).<sup>11</sup> Some newer ETTs are made with a thin-walled polyurethane cuff, which may seal at a pressure as low as 9.5 cm H<sub>2</sub>O.<sup>11,12</sup>

The ETT cuff pressure associated with impaired tracheal capillary perfusion ranges between 30 and 50 cm H<sub>2</sub>O.<sup>13</sup> Sustained overinflation of the ETT cuff increases the risk for tracheal damage: subglottic stenosis or scarring,<sup>14,15</sup> hoarseness,<sup>16,17</sup> nerve damage,<sup>18</sup> fistula,<sup>19</sup> and damage of the tracheal wall.<sup>20</sup>

### Challenges in Maintaining the Cuff Pressure

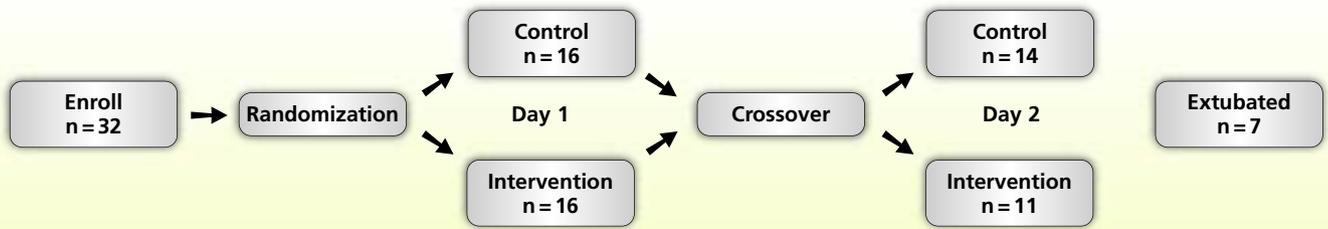
Maintaining the ETT pressure within an optimal range is challenging because many factors influence the pressure, such as the patient's position and certain anesthetic agents.<sup>21-24</sup> In observational studies that used continuous monitoring of ETT cuff pressure, only 54% to 75% of measurements were between 15 and 30 cm H<sub>2</sub>O.<sup>21,23,24</sup>

Nseir and colleagues<sup>22</sup> studied cuff pressure in 101 patients. The cuff pressure was adjusted to 25 cm H<sub>2</sub>O and continuous monitoring was started, yielding 808 hours of data. Underinflation (pressure < 20 cm H<sub>2</sub>O) was noted in 54% of patients, and overinflation (pressure > 30 cm H<sub>2</sub>O) occurred in 73% of patients. One-third of the patients sustained underinflation or overinflation for more than 30 minutes. Underinflation was associated with absence of sedation and longer duration of intubation. No specific risk factors or adverse outcomes for overinflation were reported.<sup>22</sup>

### Devices to Maintain Cuff Pressure

Different devices and specialized endotracheal tubes have been developed to maintain ETT cuff pressure.<sup>21,23,25-29</sup> These devices and tubes maintain

A cuff pressure of 20-30 cm H<sub>2</sub>O is recommended for adequate seal and to reduce complications.



**Figure 1** Study design.

the cuff pressure better than intermittent adjustment; however, a reduction in complications has not yet been shown.<sup>27,30</sup>

In a crossover study, Duguet and colleagues<sup>21</sup> tested a pneumatic (air-controlled) device in 9 patients receiving mechanical ventilation. During the control day, cuff pressure was monitored and adjusted twice a day to maintain an ETT cuff pressure between 22 and 28 cm H<sub>2</sub>O. During the intervention day, the pressure was regulated with the pneumatic device. The pneumatic device maintained the cuff pressure in the desired range of 15 to 30 cm H<sub>2</sub>O for 95% of the time, compared with 56% of the time that pressures were in the desired range during the control condition. Outcome data were not collected.<sup>21</sup>

Using the same pneumatic device, Nseir and colleagues<sup>23</sup> conducted an experimental study in 12 piglets. Six piglets with the pneumatic device had pressure within the targeted range of 15 to 30 cm H<sub>2</sub>O for 98% of the time, compared with 65% of the time in the 6 control piglets. All piglets had damage of the tracheal mucosa. However, the cuff was inflated with 50 mL of air 8 times each day for 30 minutes for all piglets as part of the protocol, which most likely accounted for the damage. Other outcome data were not collected.<sup>23</sup>

Valencia and colleagues<sup>31</sup> did a trial with an automatic device to regulate the ETT cuff pressure. Subjects were randomized to either usual care (n = 69) or the automatic device (n = 73) within 24 hours of intubation. Low cuff pressure (< 20 cm H<sub>2</sub>O) was observed in 45% of the measurements during the control condition versus 0.7% in the automatic group. No differences were noted in the rate of VAP, causative organisms, or mortality.<sup>31</sup> Because subjects were enrolled up to 24 hours after intubation, aspiration of secretions could have occurred before the device was tested, which may have accounted for the lack of differences in VAP rates. It is also possible that 20 cm H<sub>2</sub>O was not a high enough pressure to seal the airway to prevent aspiration.<sup>32</sup>

### Decreases in Cuff Pressure Over Time

ETT cuff pressure often decreases over time. Using intermittent monitoring, Sole and colleagues<sup>33,34</sup> noted decreases in ETT cuff pressure within 4 to 12

hours after adjustment of the pressure to 20 cm H<sub>2</sub>O. Sridemma and colleagues<sup>35</sup> reported that cuff pressure decreased to 20 cm H<sub>2</sub>O in 4 to 5 hours after initial adjustment to 25 cm H<sub>2</sub>O. Similar findings were noted when cuff pressure was monitored continuously.<sup>22,24</sup> Longer duration of intubation was associated with greater decreases in pressure over time.<sup>22</sup>

## Methods

### Design and Consent

This study was a randomized, repeated-measures crossover design (Figure 1). Subjects were randomly assigned to either the intervention or control condition on day 1 with a crossover to the other condition on day 2. In this design, subjects serve as their own controls.

The institutional review boards at both the university and the clinical agency approved the study. Informed consent was obtained from surrogates of critically ill patients who met the eligibility criteria. Surrogates had to be able to read or understand English or Spanish. If the patient was alert and responsive, verbal consent was also obtained at the time of data collection.

### Study Setting

The study was conducted at a tertiary care facility in the southeastern United States. Subjects were recruited from 5 critical care units: medical, surgical, neuroscience, cardiac, and burn-trauma. Subjects were under the care of either a medical or surgical intensivist team.

### Sample

A convenience sample of 32 critically ill patients were enrolled in the study between July 2007 and June 2008. Inclusion criteria were age 18 years or older, oral endotracheal intubation, and conventional mechanical ventilation. Tracheostomy, high-frequency oscillatory ventilation, and prone positioning were exclusion criteria. The statistician (X.S.) estimated the sample size needed to assess the ability of the intervention to maintain the ETT cuff pressure within an optimal range. A sample of

**Cuff pressure associated with impaired tracheal capillary perfusion ranges between 30 and 50 cm H<sub>2</sub>O.**

24 patients who experienced both the control and intervention conditions was needed to detect a large effect (1.00) at an  $\alpha$  of .05 with at least 80% power. Based on estimated attrition between days 1 and 2 of data collection, the target enrollment was 32 patients. Data were collected during both control and intervention conditions for 25 patients (Figure 1). Intervention data were available for 27

patients. Seven patients were extubated between the first and second day of data collection, resulting in differences in sample size.

### Instruments

Demographic data were collected from the medical record and via direct observation of physiological variables and ventilator settings. Continuous measurements of ETT cuff pressure were obtained with a pressure transducer (Transpac, Medex Inc, Dublin, Ohio) and a 3-way stopcock with a 15-cm extension (MX43660, Medex Inc) attached to the ETT pilot balloon. The transducer was connected to a portable monitor (Intellivue 24, Philips, Andover, Massachusetts). All connections were taped to prevent disconnection and leaks, and a bright green label "For Respiratory Use Only" was affixed to promote patient safety. The portable monitor was connected to a laptop computer, and Dataplore software (Dataplore, ixellence GmbH, Wildau, Germany) that continuously recorded cuff pressure every 0.008 seconds. Activity data (eg, turning and suctioning) were recorded by

study personnel on a tablet personal computer by using Spectator Go! software (Biobserve, Bonn, Germany).

### Procedure

Trained study personnel (registered nurses) were present in the room for the study period, collected all data, and delivered the intervention. They demonstrated competency in setting up the equipment, recording observational data, downloading cuff pressure data, and implementing the intervention.

Interrater reliability was established for all procedures. Ongoing observation of adherence to data collection procedures was done by the principal investigator.

Data were collected during the 7:00 AM to 7:00 PM shift. Clocks on all recording devices were synchronized before data collection. During both control and intervention conditions, continuous monitoring of ETT cuff pressure was initiated and the pressure was adjusted to 22 cm H<sub>2</sub>O, or higher if needed to

achieve a seal. Regardless of group, air was added to the cuff if a leak was audible or a ventilator alarm for low exhaled tidal volume indicated an inadequate cuff pressure (clinical trigger). Physiological data were recorded hourly, and observations of patient care and activities (eg, turning) were recorded on the tablet personal computer by the research assistant as they occurred.

*Control condition.* All staff and study personnel were blinded to the continuous cuff pressure readings by our covering the display screen and turning off the alarm for the ETT cuff pressure. Usual care was delivered by nursing and respiratory care staff.

*Intervention.* The monitor alarms were set for both low (15 mm Hg; 20 cm H<sub>2</sub>O) and high (22 mm Hg; 30 cm H<sub>2</sub>O) ETT cuff pressure. If the alarm sounded, a quick assessment of the potential causes of the alarm was done. If a low alarm was sustained for more than 15 seconds, air was added to the ETT cuff with a tuberculin syringe attached to the stopcock on the transducer. Adjustments were made in 0.1- to 0.2-mL increments until a pressure of at least 22 cm H<sub>2</sub>O was achieved. If a high alarm was sustained for more than 15 minutes, air was removed from the ETT cuff in 0.1- to 0.2-mL increments until the pressure was sustained below 30 cm H<sub>2</sub>O. At the end of each data collection period, the transducer was detached and the ETT cuff pressure was adjusted to a minimum pressure of 20 cm H<sub>2</sub>O if needed (facility standard of care).

### End Points

The primary end points for this study were (1) the proportion of time that the ETT cuff pressure was out of range (<20 cm H<sub>2</sub>O or >30 cm H<sub>2</sub>O) during the control and intervention days, (2) variation of ETT cuff pressure values, and (3) a quantifiable measure of ETT cuff interventions due to out-of-range pressure readings. A secondary end point was to measure the time from the start of the intervention period to the first intervention to adjust ETT cuff pressure.

### Data Analysis

Data were converted from millimeters of mercury to centimeters of water for analysis and reduced to 1-minute averages by using SAS software (SAS, Cary, North Carolina). Continuous measurements of ETT cuff pressure were treated as functional data in that the cuff pressure can be viewed as a function of time and often changes (nonstationarity).<sup>36</sup> Frequencies and percentages of the ETT cuff pressure values outside the optimal range for both the intervention and control group were computed and evaluated. Baseline characteristics were compared between the

Underinflation was found in 54% of patients whereas overinflation occurred in 73%.

Continuous endotracheal tube cuff pressure was obtained with a pressure transducer attached to the pilot balloon.

2 conditions by using Student *t* tests and  $\chi^2$  analyses. A significance level of *P* = .05 (with Bonferroni adjustment) was used to determine any significant difference in baseline measures.

The effects of intervention versus control on both out-of-range proportions and variation in cuff pressure values were assessed by using the generalized estimating equations (GEE) approach.<sup>37,38</sup> By this method, a robust inference about the relationship between the response and its predictors can be made while accounting for the intercorrelation among repeated measures for a given subject. This GEE approach also incorporates those subjects who have 1-day data only into the analysis. Two models were fit in the GEE analysis. The first model included the treatment indicator variable only, providing a crude estimate of the intervention effect. The second model adjusted for selected covariates to assess their possible confounding effects on the intervention. A logit transformation was applied because data were recorded in proportions. The Wald test statistic was used to test for the treatment effect in both models.

Last, data from the control day were analyzed to determine if the cuff pressure decreased over time without intervention. A simple linear model was fit by regressing the cuff pressure on time for each subject, which yielded a slope estimate together with its standard error. A negative slope corresponds to a decreasing pattern of cuff pressure over time. A modified *t* test was used to answer this research question.

## Results

### Sample

Demographic data and baseline characteristics for all subjects are summarized in Table 1. Mean age for the sample was 62 (SD, 20) years. Most participants were white (*n* = 24), male (*n* = 25), and admitted for surgery or because of trauma (*n* = 19). Patients had been intubated a mean of 4 days (SD, 3 days) at the beginning of the study. One subject had an 8.0-mm ETT for continuous aspiration of subglottic secretions, whereas all others had a standard 7.5- or 8.0-mm tube. Nearly all subjects were treated with synchronized intermittent mandatory ventilation (90% on the control day; 93% on the intervention day). The others were on assist-control ventilation. The patients' physiological characteristics were stable and did not change significantly (*P* > .05) between the control and intervention conditions (Table 2).

### ETT Cuff Pressure Out-of-Range Proportion

The proportion of out-of-range cuff pressure values was significantly higher during the control

**Table 1**  
Baseline characteristics of sample

Characteristic	Value
Age, mean (SD), y	61.62 (19.93)
Sex, No. (%) of patients	
Male	25 (78)
Female	7 (22)
Race, No. (%) of patients	
White	24 (75)
African American	7 (22)
Asian	1 (3)
Height, mean (SD), cm	173.37 (10.44)
Weight, mean (SD), kg	83.13 (22.22)
Body mass index, <sup>a</sup> mean (SD)	25.66 (7.58)
Diagnosis type, No. (%) of patients	
Medical	10 (31)
Surgical	13 (41)
Trauma/burn	6 (19)
Other	3 (9)
APACHE III score, mean (SD)	67.32 (27.49)
Days intubated, mean (SD)	4.14 (3.05)

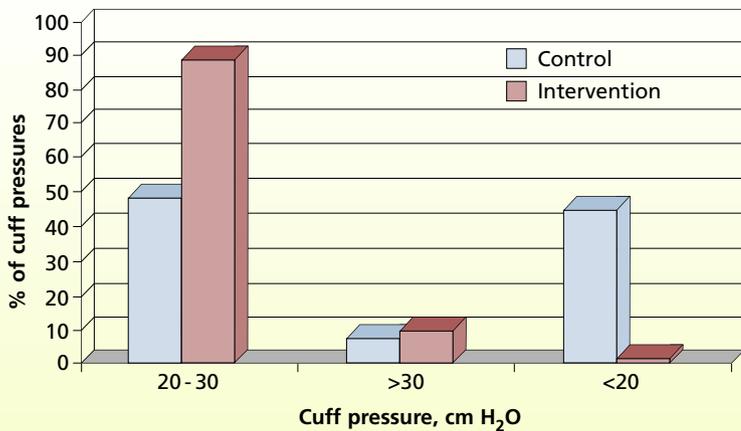
Abbreviation: APACHE, Acute Physiology and Chronic Health Evaluation.  
<sup>a</sup> Calculated as the weight in kilograms divided by the height in meters squared.

**Table 2**  
Comparison of physiological variables between control and intervention conditions at start of data collection<sup>a</sup>

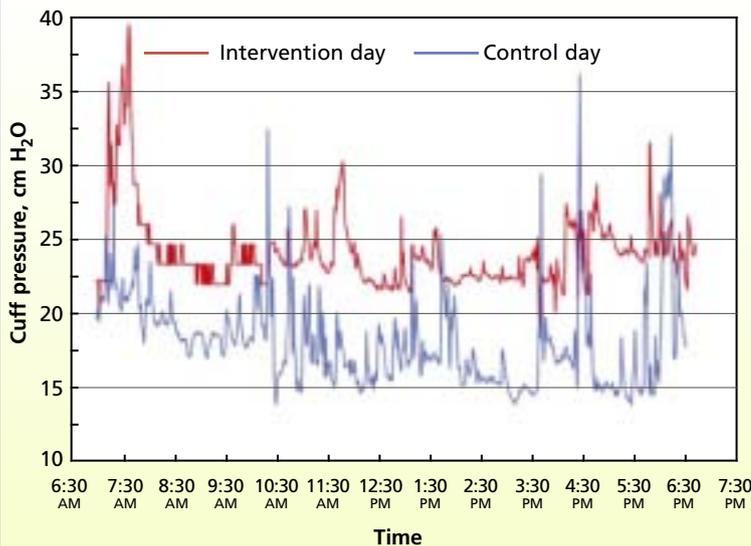
Variables	Control	Intervention
Fraction of inspired oxygen (FIO <sub>2</sub> )	0.36 (0.08)	0.36 (0.10)
Positive end-expiratory pressure, cm H <sub>2</sub> O	8 (3.5)	8 (3.5)
Oxygen saturation, %	97 (2.5)	97 (2.5)
End-tidal carbon dioxide, mm Hg	39.3 (9.3)	35.6 (8.3)
Mean airway pressure, cm H <sub>2</sub> O	13.3 (5.0)	13.1 (5.4)
Peak airway pressure, cm H <sub>2</sub> O	26.6 (10.0)	26.3 (10.3)
Position of endotracheal tube at lip line, cm	25.0 (2.1)	25.1 (1.5)
Heart rate, beats per minute	91 (18)	95 (21)
Temperature, °C	37.2 (0.7)	37.3 (0.9)
Respiratory rate, breaths per minute	18 (7)	19 (7)
Mean arterial pressure, mm Hg	86 (17)	85 (12)
Score on Glasgow Coma Scale	9 (2)	9 (3)

<sup>a</sup> All values are mean (SD).

condition (51.7%) than during the intervention (11.1%). The cuff pressure was higher than 30 cm H<sub>2</sub>O 7.4% of the time during the control condition and 9.9% of the time during the intervention. The cuff pressure was less than 20 cm H<sub>2</sub>O 44.3% of



**Figure 2** Proportion of cuff pressures within the normal range, high, and low in the control and intervention conditions.



**Figure 3** Example of cuff pressure in control and intervention conditions for one subject.

the time during the control condition compared with 1.2% of the time during the intervention (Figure 2). When GEE analysis was applied, the relative frequencies when the ETT cuff pressure was within range was significantly higher on the intervention day than on the control day ( $z = -6.603, P < .001$ ). After age, sex, BMI, sedation level, days intubated, and size of ETT were adjusted for, the proportion of time that ETT cuff pressures remained within range was significantly higher on the intervention day than on the control day ( $z = -6.726, P < .001$ ). The crude estimate of  $\gamma$  is  $-2.1550$  and the adjusted estimate is  $-2.1234$ , indicating the covariates did not confound the intervention effect. Figure 3 shows an example of cuff pressure for one patient.

### Variability of ETT Cuff Pressure

The standard deviation of the ETT cuff pressure was calculated for each patient and compared between intervention and control conditions. Although most patients showed less variation in cuff pressure on the intervention day, the difference was not significant for either the unadjusted ( $P = .12$ ) or the adjusted ( $P = .24$ ) GEE model.

Cuff pressure often increased during various activities recorded during the study (eg, coughing, turning, suctioning). An additional GEE analysis was done after removal of the pressure values from the periods when an activity was recorded by the research assistant. In this analysis, variation in ETT cuff pressure was significantly lower on the intervention day. The intervention effect was significant in both the unadjusted ( $P = .02$ ) and adjusted ( $P = .04$ ) GEE models. The effect of airway pressure on the cuff pressure was not assessed because the measure was recorded hourly; however, suctioning and coughing were associated with higher airway pressures.

### ETT Cuff Pressure Interventions

Twenty-seven patients had data collected during the intervention condition. The pressure alarm sounded from 7 to 190 times during this period (mean, 35; SD, 35; median, 26), and 1 patient also had an audible leak that required treatment before the alarm sounded. The number of interventions ranged from 2 to 14 per patient (mean, 8; SD, 3), and 91% of these were to add air to the cuff. Most of the alarms that did not require intervention were transient high-pressure alarms associated with coughing, suction, turning, and agitation.

The time from beginning of data collection to the first intervention ranged from 3 to 238 minutes (mean, 74; SD, 79; median, 40). Addition of air was the sole intervention for 20 patients, whereas air removal was the only intervention for 1 patient. Six patients required both addition and removal of air. The mean total amount of air added to the cuff was 0.28 (SD, 0.13) mL. The mean amount of air removed from the cuff was 0.14 (SD, 0.04) mL.

### Changes in ETT Cuff Pressure Over Time

Data collected during the control day were analyzed to assess whether ETT cuff pressure decreased over time without intervention. Transient increases in pressure data associated with recorded activities were removed from the analysis. A set of slope estimates together with standard errors were obtained by fitting a simple linear model of cuff pressure on time for each patient. The  $t$  test statistic

was -5.529 ( $P < .001$ ), indicating a significant decrease in ETT cuff pressure over time.

## Discussion

The intervention was effective in maintaining the ETT cuff pressure within a range of 20 to 30 cm H<sub>2</sub>O nearly twice as often as during the control condition (88.9% vs 48.3%). Variability in cuff pressure was also reduced with the intervention. These findings are similar to the reported 95% to 98% of values that are within range when automatic devices are used to maintain the cuff pressure.<sup>21-23,31</sup> The slightly lower percentage of cuff pressure values that were within range in our study may be attributed to the manual adjustment of cuff pressure versus automatic control of the pressure. The research assistant had to be alert to the alarm, respond to it, and make a decision about whether intervention was needed. The pneumatic devices do these steps automatically. Other possible reasons for this difference are the longer duration of intubation at the start of the study (mean, 4 days) and the lower starting ETT cuff pressure of 22 cm H<sub>2</sub>O (versus 25 cm H<sub>2</sub>O in some studies). In addition, air was not removed in response to a high-pressure alarm until that pressure was sustained for more than 15 minutes because most increases in pressure were transient.<sup>24</sup> High pressure values within this 15-minute window are included in the proportion of out-of-range values.

A mean of 8 interventions were necessary during the 12-hour intervention period, and most were to add air to the cuff. The starting pressure of 22 cm H<sub>2</sub>O is at the lower end of the desired therapeutic range and may have accounted for this finding. Only 9% of the interventions were to remove air from the cuff. The proportion might have been higher had the starting pressure been higher.

Cuff pressure decreased over time without intervention. This result validates findings reported for both intermittent<sup>33-35</sup> and continuous measurement of cuff pressure.<sup>22,24</sup> In our study, some patients required intervention within the first hour after the pressure was adjusted to 22 cm H<sub>2</sub>O at the beginning of data collection. Sridermma et al<sup>35</sup> reported a decrease to 20 cm H<sub>2</sub>O within 4 to 5 hours after adjustment to 25 cm H<sub>2</sub>O. Setting the pressure to 25 cm H<sub>2</sub>O and reassessing every 4 hours may be warranted and requires further evaluation. The duration of intubation may also be a factor, as the cuff may become less compliant over time.

Only a small amount of air (0.1 to 0.2 mL) was required for cuff pressure adjustments. Adjustments were made with a tuberculin syringe to increase precision. Only 2.5 to 3.3 mL of air is needed to

achieve a cuff pressure of 20 cm H<sub>2</sub>O, so this finding is not unexpected.<sup>10</sup> In practice, larger volume syringes (10 mL) are often used to inflate the ETT cuff, and a smaller syringe may be more precise during initial inflation of the ETT cuff.

The technology for continuous measurement of cuff pressure was efficient and could be implemented in clinical practice. Newer bedside monitors are integrated with electronic medical records and would provide retrievable data. However, bedside monitors do not provide detailed waveforms and display values only as whole numbers, resulting in less precision. The nurse or respiratory therapist would have to convert pressure from millimeters of mercury to centimeters of water for comparison and decision making. Safety precautions would also be necessary to prevent disconnection of the transducer and rapid deflation of the cuff, as would strategies to ensure that medications or fluids are not connected to the stopcock.<sup>39</sup> The technology was safely used for research purposes, but a trained research assistant was present at the bedside at all times. The Dataplore software program provided rich detail in cuff pressure waveforms and displayed more precise values in decimals. But its use required purchase of expensive software and an additional bedside computer for monitoring and download of data. The software was ideal for research purposes, but not for everyday management of patient care.

From a practical standpoint, it was labor intensive to monitor the pressure and respond to alarms in a timely manner. Throughout the data collection, a member of the research team recorded activities and responded to low-pressure alarms within 15 seconds. The research assistant also assessed the duration of high pressure to determine the need for removal of air. The number of transient alarms that did not require intervention was high and could result in alarm fatigue and failure to assess and respond in a busy critical care unit.

A few limitations were identified. Data were collected during the 12-hour day shift to assess the many activities and interventions that are routinely done. In the design of the study, we assumed that responses would be similar, regardless of time of day. Findings may be different on the 12-hour night shift. Data were collected for only a small portion of a patient's

Perfect of out-of-range pressure values were higher during control versus intervention.

Cuff pressure decreased over time without intervention.

total time on mechanical ventilation. Because of the limited duration of data collection, the effect of the intervention on other outcomes, such as VAP, was not assessed. A comprehensive assessment of cuff pressure throughout the duration of mechanical ventilation may provide greater evidence of the relationship of cuff pressure to outcomes of mechanical ventilation.

### Implications for Practice and Research

Both nurses and respiratory therapists should ensure adequate management of ETT cuff pressure. In the United States, nurses often rely on the therapists to manage the ETT.<sup>6,7</sup> In other countries, nurses assume this responsibility.<sup>40</sup> Cuff pressure values vary and decrease over time. It is difficult to maintain cuff pressures within the therapeutic range unless continuous monitoring or an automatic regulating device is attached. Identifying a higher target starting pressure (eg, 25 cm H<sub>2</sub>O) and a greater frequency for measurement may be warranted. However, cuff pressure decreases by 2 cm H<sub>2</sub>O when attaching a cufflator to the pilot balloon,<sup>39</sup> so frequent measurement of cuff pressure may have its own inherent risks. The target pressure may need to be different for newer thin-walled polyurethane cuffs versus traditional cuffs, as limited research shows that these newer tubes seal at a lower pressure. Since cuff pressure fluctuates and often dips below 20 cm H<sub>2</sub>O, it is important to incorporate procedures for oropharyngeal suctioning and oral care as part of airway management to prevent VAP.

Future research should address the optimal pressure and frequency of cuff pressure measurement for preventing outcomes such as VAP and tracheal damage. Commercial devices that maintain the cuff pressure must be tested to evaluate their effectiveness. No researchers in the United States have tested the pneumatic devices studied in Europe. A redesign of the ETT cuff to promote a better seal may be a consideration for device manufacturers. Additional research is needed for tubes with the newer thin-walled cuffs. Identification of variables that influence cuff pressure, such as type of tube and duration of intubation, is also needed. Technology that captures continuous ventilator setting data and related physiological values, such as peak and mean airway pressure, may also be helpful in identifying factors that influence the ETT cuff pressure. Knowledge of these variables may assist in designing additional interventions to maintain the cuff pressure within an optimal range.

### Conclusions

Out-of-range cuff pressure values were noted frequently without intervention. Although it was

labor intensive, the intervention was effective in maintaining the cuff pressure within an optimal range. In addition, the cuff pressure decreased over time without intervention.

### FINANCIAL DISCLOSURES

This study was supported by a grant (1R21NR010262) from the National Institute of Nursing Research.

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**CE Test** Test ID A1120023: Evaluation of an Intervention to Maintain Endotracheal Tube Cuff Pressure Within Therapeutic Range.

*Learning objectives:* 1. Review the physiological significance of endotracheal tube (ETT) pressure. 2. Compare continuous ETT cuff pressure monitoring with intermittent manual monitoring techniques. 3. Discuss adjustments required to maintain optimal ETT cuff pressures.

**1. Which of the following endotracheal tube (ETT) cuff pressures is recommended to provide an adequate seal and reduce the risk of complications?**

- a. Between 10 and 20 cm H<sub>2</sub>O
- b. Between 20 and 30 cm H<sub>2</sub>O
- c. Between 30 and 50 cm H<sub>2</sub>O
- d. Less than 20 cm H<sub>2</sub>O

**2. In Nseir's research, underinflation of the ETT cuff is associated with which of the following?**

- a. Oversedation
- b. Nerve damage
- c. Absence of sedation
- d. Subglottic scarring

**3. Tracheal damage, subglottic stenosis, hoarseness, nerve damage, and fistula are associated with which of the following?**

- a. ETT cuff pressures between 30 and 50 cm H<sub>2</sub>O
- b. Underinflation of the ETT cuff
- c. Repeatedly checking ETT cuff pressures
- d. ETT cuff pressures of 25 cm H<sub>2</sub>O

**4. ETT cuff pressures over time will do which of the following?**

- a. Stay the same
- b. Gradually decrease
- c. Gradually increase
- d. Vary

**5. Pneumatic devices that automatically control ETT cuff pressures do which of the following?**

- a. Maintain cuff pressure better than intermittent adjustments
- b. Decrease incidence of ventilator-associated pneumonia
- c. Increase mortality
- d. Maintain ETT cuff pressures as well as intermittent adjustments

**6. According to the study by Sole and colleagues, how soon will ETT cuff pressures decrease after an initial adjustment?**

- a. After 1 hour
- b. In 12 to 24 hours
- c. In 4 to 12 hours
- d. Within 1 to 4 hours

**7. What percent of the time does automatic control of ETT cuff pressures keep pressures within range?**

- a. 80% to 85%
- b. 88.9%
- c. 85% to 90%
- d. 95% to 98%

**8. Your patient has an audible ETT cuff air leak and the ventilator alarm indicates low exhaled tidal volume. After assessing the patient and the ventilator, you determine that the ETT cuff has low volume. Using the information from this study, how would you resolve this situation?**

- a. Add air to the ETT cuff until the leak stops.
- b. Add air to the ETT cuff in increments of 0.1 to 0.2 ml with a tuberculin syringe until a pressure of at least 22 cm H<sub>2</sub>O is achieved.
- c. Add 2.5 to 3.3 ml of air to the ETT cuff.
- d. Remove all air from the ETT cuff and reinflate it to the volume indicated on the pilot balloon.

**9. The alarm on the continuous ETT cuff pressure monitor of your patient indicates high pressure. How do you resolve the situation according to this study?**

- a. Remove air from the ETT cuff until the high-pressure alarm stops.
- b. Remove air from the ETT cuff in increments of 0.1 to 0.2 ml with a tuberculin syringe until pressure below 30 cm H<sub>2</sub>O is sustained.
- c. Suction the airway of your patient.
- d. Remove all air from the ETT cuff and reinflate it to the volume indicated on the pilot balloon.

**10. When attaching a cufflator to the ETT pilot balloon, a higher target starting pressure may be required as the cufflator decreases the cuff pressure by which of the following amounts?**

- a. 2 cm H<sub>2</sub>O
- b. 5 cm H<sub>2</sub>O
- c. 6 cm H<sub>2</sub>O
- d. 10 cm H<sub>2</sub>O

**11. Which of the following describes the overall conclusion of this study?**

- a. Continuous ETT pressure monitoring reduces nursing and respiratory therapy time.
- b. Continuous ETT pressure monitoring decreases ventilator complications.
- c. Continuous ETT pressure monitoring can assist in maintaining optimal ETT cuff pressures effectively.
- d. Continuous ETT pressure monitoring is cost effective.

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