



CUFF PRESSURE OF ENDOTRACHEAL TUBES AFTER CHANGES IN BODY POSITION IN CRITICALLY ILL PATIENTS TREATED WITH MECHANICAL VENTILATION

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Background In order to avoid microaspiration and tracheal injury, the target for endotracheal tube cuff pressure is 20 to 30 cm H₂O.

Objective To assess the effect of changes in body position on cuff pressure in adult patients.

Methods Twelve orally intubated and sedated patients received neuromuscular blockers and were positioned in a neutral starting position (backrest, head-of-bed elevation 30°, head in neutral position) with cuff pressure at 25 cm H₂O. Then, 16 changes in position were performed: anteflexion head, hyperextension head, left and right lateral flexion of head, left and right rotation of the head, semirecumbent position (head-of-bed elevation 45°), recumbent position (head-of-bed elevation 10°), horizontal backrest, Trendelenburg position (10°), and left and right lateral positioning over 30°, 45°, and 90°. Once a patient was correctly positioned, cuff pressure was recorded during an end-expiratory ventilatory hold. The pressure observed was compared with the cuff pressure at the starting position. Values outside the target range (20-30 cm H₂O) were considered clinically relevant.

Results A total of 192 measurements were performed (12 subjects x 16 positions). A significant deviation in cuff pressure occurred with all 16 changes ($P < .05$). No pressures were less than the lower limit (20 cm H₂O). Pressures were greater than the upper limit (30 cm H₂O) in 40.6% of the measurements. In each position, the upper target limit was exceeded at least once. Within-patient variability was substantial ($P = .02$).

Conclusion Simple changes in patients' positioning can result in potentially harmful cuff pressures. (*American Journal of Critical Care*. 2014;23:e1-e8)

Endotracheal tubes have become indispensable for securing the airway during surgical procedures and in critically ill patients treated with mechanical ventilation. The cuff of the tube seals the extraluminal airway, facilitating positive-pressure ventilation and reducing aspiration of subglottic secretions. Nowadays endotracheal tubes have high-volume low-pressure cuffs, generally made of polyvinylchloride or polyurethane. Cuff pressure is essential in endotracheal tube management. Guidelines^{1,2} recommend a cuff pressure of 20 to 30 cm H₂O. Inflation of the cuff in excess of 30 cm H₂O damages the tracheal mucosa by compromising capillary perfusion. When pressures are greater than 50 cm H₂O, total obstruction of tracheal blood flow occurs.³ In rare instances, massive overinflation of the cuff may lead to acute complications such as tracheal bleeding or rupture.⁴

In patients with prolonged intubation, more discrete levels of overinflation may lead to long-term complications such as tracheal stenosis or formation of a fistula.⁴ Subinflation of the cuff puts patients at risk for microaspiration of subglottic secretions. This microaspiration is considered the major pathogenic mechanism for ventilator-associated pneumonia,⁵ a complication with marked morbidity and mortality.^{6,7} In an observational study,⁸ the risk of ventilator-associated pneumonia was independently associated with cuff pressure persistently less than 20 cm H₂O.

The cuff pressure of an endotracheal tube varies according to patient-related factors, environmental circumstances, and therapeutic interventions. Factors leading to increased cuff pressure include positive-pressure ventilation,^{9,10} ventilation with nitrous oxide,¹¹ altitude (eg, during helicopter transport),¹² and pathologic processes such as bronchoconstriction, laryngeal spasms, and edema. Factors that may lead to a decrease in cuff pressure include sedation and neuromuscular blockade^{13,14} and decreased core temperature (as during cardiopulmonary bypass).¹⁵ Loss of cuff volume with time has also been

described.¹⁶ Little information, however, is available on the effect of changes in body position on the cuff pressure of endotracheal tubes. Kim et al¹⁷ showed that changing the position of the head resulted in a displacement of the tube. No information was reported about the influence of these displacements on the cuff pressure.

The purpose of this study was to investigate the effect of a variety of changes in body position on the endotracheal tube cuff pressure in patients in an intensive care unit (ICU) who were sedated and receiving mechanical ventilation. We determined absolute deviations and the number of deviations outside the cuff pressure target range of 20 to 30 cm H₂O.

Methods

Study Design and Setting

A prospective, interventional study was done with ICU patients who were sedated and receiving mechanical ventilation. Each patient was his or her own control. The study was conducted between February and May 2011 in the 12-bed ICU of the General Hospital Sint Blasius, Dendermonde (Belgium). The study was approved by the appropriate ethics committees. Informed consent was obtained from each patient or the patient's family.

Patients

A convenience sample of 12 patients was selected. Inclusion criteria were age older than 18 years, oral intubation with a TaperGuard Evac endotracheal tube (Covidien), conventional mechanical ventilation, and adequate sedation (score of ≥ 5 on the Richmond Agitation-Sedation Scale)¹⁸ and analgesia (score of 3-4 on the Behavior Pain Scale).¹⁹ Exclusion criteria were factors that might influence cuff pressure or compromise the safety or well-being of the patient:

Cuff pressures greater than 50 cm H₂O may cause total obstruction of tracheal blood flow.

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pregnancy, palliative care, difficult intubation, decreased mobility of the neck, history of neck surgery, core temperature less than 35°C or greater than 37.5°C, morbid obesity (body mass index >35, calculated as weight in kilograms divided by height in meters squared), and potential contraindications for changes in body position such as unstable spinal cord injury or unstable hemodynamic and/or respiratory status.

The anesthesiologist determined the size of the endotracheal tube. Intubation was performed according to local practices. Correct cuff positioning was confirmed by using laryngoscopy, auscultation revealing bilateral breathing sounds, and chest radiography. Endotracheal tubes were secured with tape in a corner of the mouth. The position of the endotracheal tube was not changed during the procedure.

Procedure

Each patient was brought into a neutral starting position: backrest with a 30° head-of-bed elevation and the head in a neutral position. Each bed had a protractor for measuring the elevation of the head of the bed. After the starting position was established, the suctioning system of the endotracheal tube was disconnected to avoid any influence of suctioning on the cuff pressure. Neuromuscular blockade with intravenous cisatracurium (0.18 mg/kg) was used to prevent patients from breathing against the ventilator and thus causing increases in cuff pressure during the study intervention. The pilot balloon of the

endotracheal tube was connected with a tube leading to a calibrated universal pressure monitor (Ultramedic LTD, BioTech Instruments Inc). This monitor measures pressures from -949 to 1055 cm H₂O with an accuracy of ±1%. The monitor was zeroed before each study patient or procedure. A manifold was connected in the middle

of the length of the tube, and a syringe filled with air was placed on the manifold to control cuff inflation. The syringe connection was sealed after cuff inflation. At the starting position and during an end-expiratory ventilatory hold, the cuff pressure was set at 25 cm H₂O. During the procedure, the pressure monitor was continuously attached to the pilot balloon of the endotracheal tube because reconnecting results in air loss.²⁰

Each patient was brought into 16 different body positions from the starting position (in the same sequence): anteflexion of the head; hyperextension of the head; left lateral flexion of the head; right lateral flexion of the head; rotation of the head to the left; rotation of the head to the right; semirecumbent

position with 45° elevation of the head of the bed, recumbent position with 10° elevation of the head of the bed; horizontal backrest (ie, supine position); Trendelenburg position 10°; left lateral position at 30°, 45°, and 90°; and right lateral position at 30°, 45°, and 90°. These positions were chosen because they are part of daily ICU routine. For the lateral positions, foam blocks with a slopes of 30°, 45°, and 90° were used. Changes in position were executed one after the other. Patients were not returned to the starting position after each measurement to check cuff pressure because this maneuver would have substantially lengthened the time required for the procedure. Moreover, reaching a target position often requires going through a series of previous positions (eg, to achieve a 90° lateral position starting from a semirecumbent position, a patient must go from a recumbent position with 10° head-of-bed elevation to supine to a lateral position of 30°, and a lateral position of 45°. Therefore, returning to the start position to (eventually) adjust the cuff pressure was deemed pointless. In every position, traction on the endotracheal tube was avoided.

Once a patient was brought in a predetermined position, an end-expiratory ventilatory hold was performed for a 4 to 5 seconds and cuff pressure was recorded. The procedure required a collaboration of 4 health care workers: an intensivist (W.S.) guaranteed the sedation, neuromuscular blockade, and end-expiratory ventilator holds; 2 nurses placed the patient in the correct position; and 1 researcher (C.L.) was responsible for monitoring the cuff pressure and avoiding interference with measurement (eg, traction on the endotracheal tube). The total procedure took about 20 to 25 minutes.

Variables

Variables recorded included age, sex, length, weight, body mass index, and diagnostic category. Variables of the endotracheal tube included size, depth of the endotracheal tube to the teeth, location of the tube in the mouth, mode of mechanical ventilation, and positive end-expiratory pressure. Other outcome variables were cuff pressures in the predetermined positions.

Statistical Analysis

Study power was assessed. Because a deviation of 5 cm H₂O would be needed to reach the target cuff pressure limits, the power analysis was based on an anticipated difference of 5 or more cm H₂O, with a standard deviation of 7 cm H₂O. For this difference to be significant ($\beta = 0.80$; $\alpha = 0.05$), a sample of 12 patients was needed.

Each patient was brought into 16 different body positions.

Variables are reported as number and percentage, median and first through third quartile, or mean and standard deviation. The Wilcoxon paired sample test was used to compare cuff pressure in the starting position (25 cm H₂O) with cuff pressure in a defined position. Besides absolute deviations (in centimeters of water), the number of measurements outside the recommended cuff pressure (<20 cm H₂O or >30 cm H₂O) was noted. These observations are considered clinically relevant. The Fisher exact test was used for comparisons between categorical variables. Within-patient variability in cuff pressure across the 16 positions was evaluated by using repeated-measures analysis of variance. The Greenhouse-Geisser method was used to correct for nonsphericity, with $P > .05$ indicating no within-patient variability. SPSS 19 software (IBM SPSS Statistics) was used for analyses. All tests were 2-tailed. Statistical significance was defined as P less than .05.

Results

The characteristics of the 12 patients in the study are given in Table 1. The data included all measurements for each patient. No adverse events occurred. In total, 192 measurements were made (16 positions × 12 patients). Table 2 gives the mean cuff pressure per body position and the number of measurements that were outside the target range. In every position, the cuff pressure differed significantly from the pressure at the starting position. Among the 192 measurements, 78 (40.6%) were greater than the upper target limit of 30 cm H₂O. In contrast, no measurements were less than the lower target limit of 20 cm H₂O. Only 17 measurements (9%) were greater than 25 cm H₂O. Figure 1 illustrates cuff pressures according to body position. In each position, the upper target pressure limit was exceeded at least once.

Within-patient variability was substantial (Figure 2). Repeated-measures analysis of variance indicated significant variability in patients' cuff pressure across the 16 positions ($F = 3.63$; $P = .02$). Cuff pressure remained within the target interval in all 16 positions for only 1 patient. The upper target limit was exceeded 2 times for 1 patient, 3 times for another patient, 5 times for another patient, and 9 times for another patient. In 2 patients, the target limit was exceeded in 6 positions, and in 2 other patients, it was exceeded in 7 positions. In 3 patients, the upper target limit was exceeded 11 times.

Discussion

Our results indicate that simple and frequently executed changes in body position can have a significant effect on the cuff pressure of endotracheal tubes

Table 1
Characteristics of patients in the study sample (N = 12)

Characteristic	Value ^a
Male sex	8 (67)
Age, y	63 (47-72)
Body mass index ^b	23 (20-25)
Diagnostic category	
Medical	3 (25)
Elective surgery	6 (50)
Emergency surgery	8 (67)
Trauma	1 (8)
Size of endotracheal tube, mm internal diameter	
6	1 (8)
7.5	7 (58)
8	3 (25)
8.5	1 (8)
Endotracheal tube fixation, right corner of mouth	9 (75)
Positive end-expiratory pressure, cm H ₂ O	5 (5-5)

^a Data are reported as number (percentage) or median (first-third quartile).

^b Calculated as the weight in kilograms divided by the height in meters squared.

in patients receiving mechanical ventilation. No cuff pressures were less than the 20 cm H₂O lower threshold; 40.6% of measurements exceeded the 30 cm H₂O upper target limit. Additionally, because of high within-patient variability (Figure 2), we could not predict which patient would have high cuff pressure in particular positions. We found no relationship between cuff pressures and patients' characteristics. We think that anatomical differences between patients may be responsible for this observation. Autopsy studies^{14,21} indicated that tracheal cartilage rings can differ substantially from the classic horseshoe shape.

Brimacombe et al²² also described increased cuff pressure after changes in head and neck positions in 10 anesthetized patients. Starting from a 40.8 cm H₂O pressure in a neutral position (30 mm Hg), the mean cuff pressures in anteflexion, extension, and rotation of the head were 51.7, 43.5, and 47.6 cm H₂O, respectively. As in our study, all deviations were significant. Of note, cuff pressure in the starting position in the study by Brimacombe et al was 30 mm Hg (40.8 cm H₂O), which is higher than the currently recommended target pressure. In a crossover study, de Godoy et al²³ evaluated the extent that changes in body position in patients treated with mechanical ventilation resulted in changes in cuff pressure. They looked for the effect of changes from 35° semirecumbent positioning to lateral positioning and back and used a slightly different target cuff pressure interval (24.5-29.9 cm H₂O) than we did. Nevertheless, their findings that

Table 2
Endotracheal tube cuff pressure values after changes in patients' positioning

Position change ^a	Cuff pressure, cm H ₂ O ^b	P for change from starting position (25 cm H ₂ O)	No. (%) of measurements >30 cm H ₂ O
Anteflexion head	35.9 (9.2) 33.5 (27.5-42.0)	.005	9 (75)
Hyperextension head	34.1 (9.5) 30.5 (27.5-42.0)	.004	6 (50)
Lateral flexion head, left	26.9 (2.4) 26.5 (25.3-28.8)	.02	1 (8)
Lateral flexion head, right	28.1 (4.9) 27.0 (25.3-29.8)	.049	2 (17)
Rotation head, left	29.5 (4.8) 27.0 (26.3-33.8)	.003	3 (25)
Rotation head, right	31.5 (9.0) 28.0 (26.3-38.8)	.02	4 (33)
Semirecumbent, 45°	27.8 (2.8) 28.0 (25.3-31.5)	.009	2 (17)
Recumbent, 10°	29.1 (5.6) 28.0 (25.3-31.5)	.02	3 (25)
Horizontal back rest (supine)	29.9 (6.5) 28.5 (25.3-31.5)	.01	3 (25)
Trendelenburg, 10°	30.0 (5.9) 29.0 (25.3-32.0)	.008	5 (42)
Left lateral position, 30°	29.6 (4.4) 30.5 (25.3-32.0)	.01	6 (50)
Left lateral position, 45°	30.6 (4.4) 30.5 (27.3-32.8)	.005	6 (50)
Left lateral position, 90°	32.2 (6.0) 34.0 (27.0-36.8)	.006	7 (58)
Right lateral position, 30°	31.7 (5.5) 31.0 (27.0-34.5)	.003	6 (50)
Right lateral position, 45°	32.8 (4.3) 32.5 (28.3-35.8)	.002	8 (50)
Right lateral position, 90°	31.5 (3.9) 31.0 (29.3-35.0)	.003	7 (58)
Total (192 measurements)	—	—	78 (41)

^a For semirecumbent and recumbent positions, the number of degrees indicates amount of elevation of the head of the bed.

^b Cuff pressure values are reported as mean (standard deviation) and median (first-third quartile).

50.7% of measurements resulted in relevant increases in cuff pressure (defined as an increase from 27.2 cm H₂O to >29.9 cm H₂O) are similar to our results. As in our study, decreases in cuff pressure (from 27.2 cm H₂O to <24.5 cm H₂O) were less common (5% of measurements).

Cuff pressures greater than 30 cm H₂O are clinically important because they compromise the mucosal capillary perfusion and may lead to tracheal injury. In turn, these acute injuries may evolve into tracheal stenosis or formation of a fistula. We

hypothesize that ICU clinicians' awareness of the deleterious effects of excessive cuff pressure is low, because the consequences of such pressure do not become obvious until weeks or months after the patient is discharged from the ICU; thus ICU staff rarely observe the effects. Nevertheless, the incidence of clinically relevant injuries after endotracheal intubation is high. In a prospective study,²⁴ the estimated incidence of tracheal stenosis in patients intubated for 5 to 10 days was 4%, and up to 12% among patients intubated for 11 to 24 days.

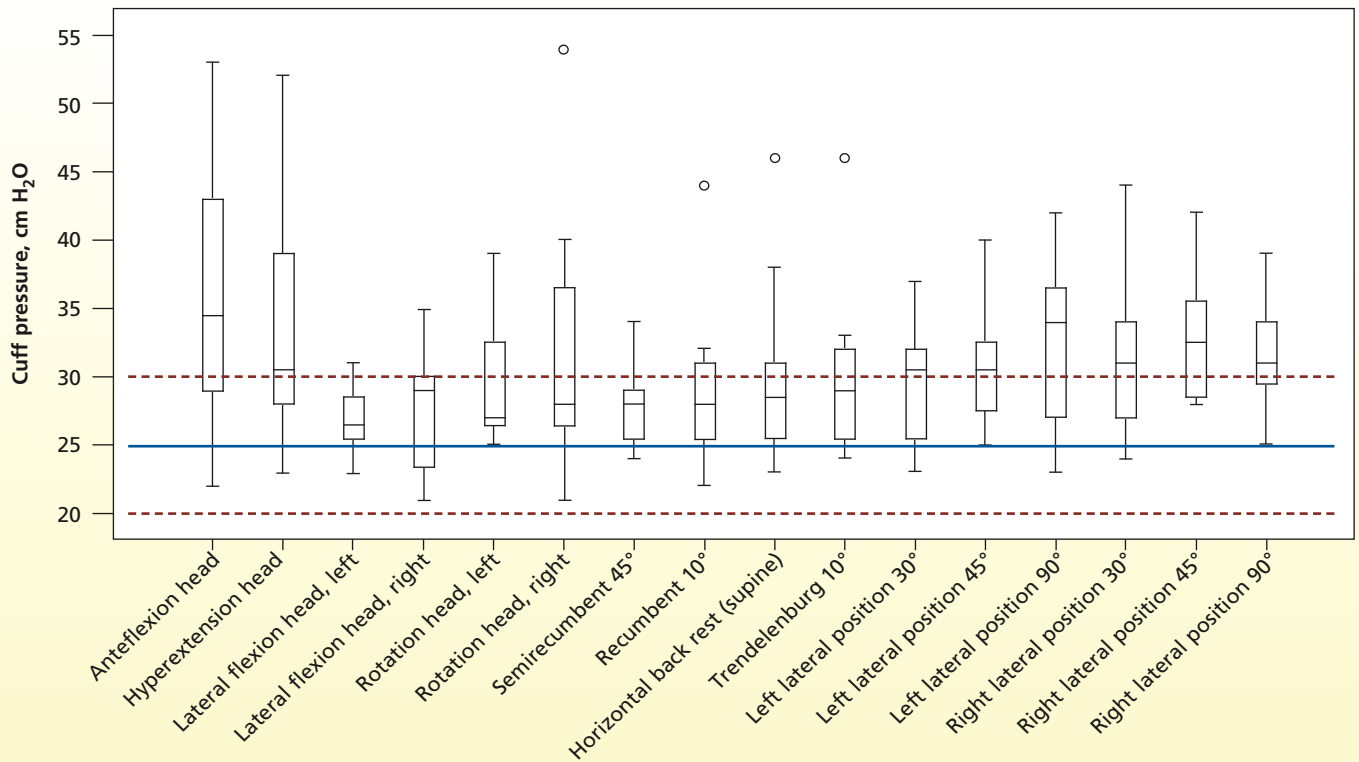


Figure 1 Cuff pressures for each body position. Blue solid line represents cuff pressure at the starting position (25 cm H₂O); red dashed lines indicate recommended cuff pressure interval (20-30 cm H₂O). Boxes indicate lower quartile (bottom of box), median (band near the middle of the box), and upper quartile (top of the box); whiskers indicate the lowest value still within 1.5 of the interquartile range from the lower quartile, and the highest value still within 1.5 of the interquartile range from the upper quartile; and circles indicate outliers. For semirecumbent and recumbent positions, the number of degrees indicates amount of elevation of the head of the bed.

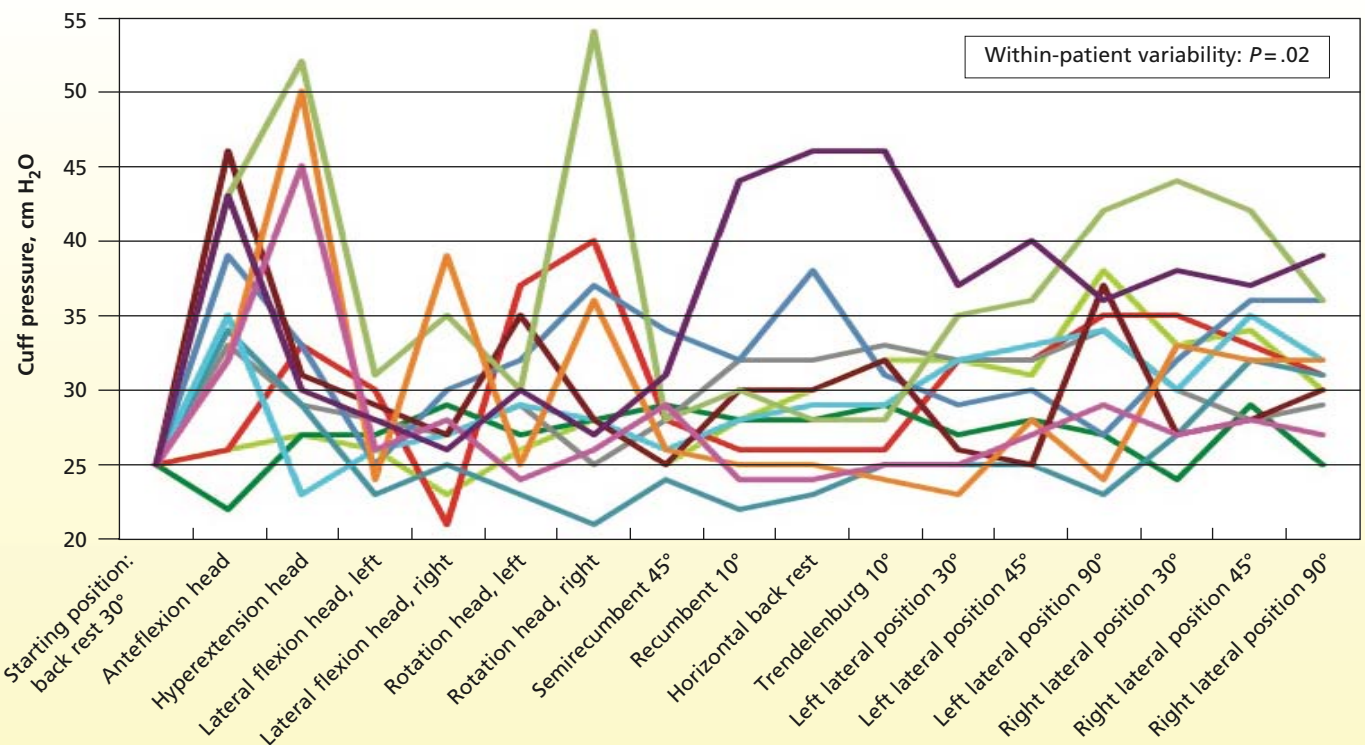


Figure 2 Endotracheal cuff pressures per patient and per position. Each colored line represents a different patient. For starting, semirecumbent, and recumbent positions, the number of degrees indicates amount of elevation of the head of the bed.

Clinicians' awareness of the deleterious effects of excessive cuff pressure may be low.

In addition, intubation-related tracheal injury contributes to health care costs via increased costs of care and length of hospitalization during the index admission and future costs for treatment and repair.²⁵ In a recent study,²⁶ 83% of patients included in an randomized trial had at least 1 tracheal ischemic lesion. Yet, findings on fiber-optic tracheoscopy 2 weeks after intubation were normal in all except 1 patient, who experienced tracheal rupture.

Despite the obvious risks associated with excessive pressure on the tracheal wall, in daily practice, clinicians rarely evaluate cuff pressure to be sure it is correct. Indeed, cuff pressures outside the target range are common,²⁷⁻²⁹ and the frequency with which cuff pressure is measured and adjusted varies from never to at most every 8 hours.³⁰⁻³³ Additionally, cuff pressure is often evaluated by using finger palpation.³⁰ Several investigators³⁴⁻³⁶ have reported the inability of clinicians to adequately estimate cuff pressure by using finger palpation, and this practice generally results in excessive pressures. Monitoring cuff pressure via a manometer results in fewer complications after incubation.³⁷

Our data indicate that cuff pressure should be measured after each change in a patient's body position and supports use of continuous monitoring of cuff pressure with automatic adaptation to a preset pressure. When all other factors that may cause alterations in cuff pressure are considered, the question is whether or not monitoring the pressure by using intermittent manual evaluation remains an option. Care procedures that require monitoring of cuff pressure appear to be multiple and may lead to a further increase in nurses' workload. Devices to provide automated monitoring and adjustments of cuff pressure have been developed. Such devices can maintain the pressure within the target range^{38,39} and reduce the risk of ventilator-associated pneumonia.³⁸

Our study has limitations. First, cuff pressure was measured once, soon after correct positioning of the patient, and was not followed for a more prolonged period. Sole and colleagues^{40,41} found that alterations in cuff pressure after changes in patients' body position often were transient and normalized within 15 minutes. While interpreting the present results, one must realize that cuff pressures were observed for only a very short period of time: although temporary overinflation might be harmless, a temporary decrease in cuff pressure might result in marked microaspiration of subglottic secretions, leading to ventilator-associated pneumonia. Second, we used an endotracheal tube with a tapered cuff. The extent, if

any, that cuff shape influences cuff pressure after changes in body position is unknown. Third, no clinical outcomes were measured. The focus of our study was deviations in cuff pressure outside the target interval, because such changes can be considered clinically relevant. Because the deleterious effect of cuff pressures not in the target range has been demonstrated before, observing how excessive pressures evolve over time and whether or not they result in clinically important complications would be unethical. Finally, we did not measure intra-abdominal pressure although it might have influenced cuff pressure. Still, because one of the requirements for inclusion in the study was stable clinical status, most likely none of our patients had intra-abdominal hypertension.

Our study also has some strengths. First, having each patient serve as his or her own control counters the problem of nonequivalence between an experimental and a control group. Second, factors that might influence the cuff pressure were eliminated as much as possible by the selection process (exclusion criteria), the neuromuscular blockade, and measurement of the cuff pressure during an end-expiratory ventilator hold. Finally, we evaluated the effect of changes in body position over a broad range of positions that are often used in daily practice.

Conclusions

Changes in a patient's body position resulted in significant deviations in the cuff pressure of endotracheal tubes. In 40.6% of the measurements, the cuff pressure exceeded the upper target level, and thus theoretically was clinically relevant. Because simple and frequent changes in a patient's body position may result in potentially harmful cuff pressure, our observations suggest a need for a strict monitoring of this pressure.

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FINANCIAL DISCLOSURES

Sonia Labeau held a doctorate research mandate from University College Ghent (2006-2012) and received fees

for speaking activities for Kimberly-Clark. Dr Blot holds a research mandate from the special research fund at Ghent University and received research grants or fees for advisory board or speaking activities from Novartis, Pfizer, Covidien, Cook Critical Care, and Kimberly Clark. Walter Swinnen had speaking activities without honoraria.

eLetters

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