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ORIGINAL ARTICLE

Dynamic Shifts in Tracheal Tube Cuff Pressure: Impact of Ventilation Modes, Patient Positioning, and Duration in ICU Settings- A Prospective Observational Study

Rajswee Rana, M.B.B.S., M.D., Vaishnavi Pandith, M.B.B.S., M.D., Ankit Agarwal, M.B.B.S., M.D., P.D.C.C., Gaurav Jain, M.B.B.S., M.D., P.D.C.C.

All India Institute of Medical Sciences, Virbhadra road, 249203, Rishikesh, Dehradun, Uttaranchal, India.

Corresponding author:
Dr. Rajswee Rana
All India Institute of Medical Sciences, Virbhadra road, 249203, Rishikesh, Dehradun, Uttaranchal, India.
E-mail: rrajswee@gmail.com
Phone: +977- 9817921434

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ABSTRACT

Background and aims: In intensive care unit (ICU), various factors like patient positioning, duration of tracheal intubation and modes of mechanical ventilation can significantly affect endotracheal tube cuff pressures. Failure to maintain optimal cuff pressure may result in various complications. This study aims to evaluate the effect of these factors on cuff pressure.

Methods: A prospective observational study was conducted in the ICU of a tertiary care hospital. Adult patients intubated with a cuffed endotracheal tube for mechanical ventilation were enrolled. The cuff pressure measurements were taken at four time points: T1- in controlled ventilation in supine position; T2- after two hours in controlled ventilation and in supine position; T3- in controlled mode immediately after transitioning to a propped up position from supine position and T4- in spontaneous mode in a propped up position.

Results: The mean cuff pressure at T1 was 25.34 cm H_2O (SD 3.75, 95% CI 24.06-26.62), at T2 was 21.66 cm of H_2O (SD 3.40, 95% CI 20.49-22.83), at T3 was 20.03 cm H_2O (SD 3.30, 95% CI 18.89-21.16) and at T4 was 15.17 cm H_2O (SD 4.24, 95% CI 13.71-16.63). Mean cuff pressures were found to significantly vary with time, change in position and mode of ventilation. It was highest during controlled ventilation in supine position, which progressively decreased at the end of two hours, after keeping the patient in propped up position and further more during spontaneous ventilation.

Conclusion: Ventilation mode, patient positioning, and the duration of mechanical ventilation significantly affect tracheal tube cuff pressure in ICU patients.

Keywords: *Cuff pressure; digital manometer; endotracheal tube; variation.*

INTRODUCTION

In any patient with a tracheal tube in an Intensive Care Unit (ICU), tracheal tube cuff pressure should be adequate to prevent aspiration while not exceed pressures that could hinder mucosal perfusion. Failure to maintain this range of 20-30 mm of Hg, may result in complications such as local necrosis, nerve damage, micro-aspiration and ventilator-associated pneumonia (VAP).[1]

Maintaining an optimal tracheal cuff pressure is a difficult task which might be influenced by many factors.[2] Patient positioning, duration of tracheal intubation and changes in airway pressures during different modes of mechanical ventilation are common interventions that can significantly affect cuff pressures.[3,4] Nonetheless, this has been seldom evaluated under clinical circumstances, especially when considering ICU patients.[5] The pressure exerted on the walls of the trachea depends upon its compliance as well as the pressure at the pilot balloon of its tracheal tube cuff.[6] Though there are many manometers available, many centres still rely on subjective methods for estimating cuff pressures. This can lead to inaccuracies causing both over- or under- inflation of tracheal tube cuffs.[7,8] This problem is further accentuated by inadequate monitoring of cuff pressure.[9] The dynamics of cuff pressure remain unclear, with limited research available especially in ICU populations who require prolonged mechanical ventilation. This study focuses on key variables affecting cuff pressure (mode of ventilation, time and position) aiming to provide insights that may guide future investigations.

METHODS

This was a prospective observational study conducted in the ICU of a tertiary care hospital. This research was conducted after the protocol was cleared by the Institutional Ethics Committee (Letter no: AIIMS/IEC/22/21). Written informed consent was obtained from the patients' family members. Patients of age 18-65 years who were admitted to the ICU and intubated with a cuffed endotracheal tube for mechanical ventilation were enrolled in the study. Exclusion criteria were 1. pre-existing chronic cardio-respiratory disease, 2. obesity (body mass index >30 kg/m^2), 3. pregnant and breastfeeding, 4. refusal for consent, 5. airway anatomical malformations, 6. limited neck movement or neck mass and 7. raised intra-abdominal pressure.

All mechanically ventilated patients were positioned as per the ICU protocol. The cuff pressure measurements were taken at four time points: T1- in controlled ventilation in supine position; T2- in controlled ventilation after two hours after supine position; T3: in controlled mode immediately after transitioning to a propped up position from supine position and T4- in spontaneous mode in a propped up position. Cuff pressure was measured using a digital manometer (AG Cuffill®) (Figure 1).

Figure 1: AGCuffil digital manometer

We planned to detect a minimum mean difference of 2.5 cm of H_2O between two readings with a power of 80% and expected a standard deviation of 5 cm of H_2O. All statistical significance was set at a p value of <0.05. To account for attrition, we included a dropout rate of 10% to get a final sample size of 35 patients recruited in this study. The sample size was calculated using open EPI Online Statistical Software Version 3.01. The statistical analysis was performed using statistical package of social sciences (SPSS 29.0, IBM CORP, ARMONK, NY, US). The data was presented as descriptive statistics including mean ± standard deviation or number (percentage). The normalcy of data was analyzed by Shapiro-Wilk test. Paired t-test was done for position and mode changes while repeated measures ANOVA for overall comparison. A Wilcoxon signed-rank test was used for non-normally distributed data. A p-value <0.05 was considered to be statistically significant.

RESULTS

The baseline characteristics of patients enrolled in the study are presented in Table 1. Since all the cuff pressure measurements were normally distributed, paired t test was used to compare two variables. The cuff pressures are reported as means, standard deviations (SD) and their 95% confidence intervals (CI). To evaluate the effects of time (T1–T2), position (T1–T3), and ventilation mode (T3–T4) on cuff pressure, repeated measures ANOVA was used. The data is presented in Table 2 and Table 3.

Table 1. Demographic summary

Age	**Value (in years)**
Median age (Q1, Q3)	41 (26, 54)
Gender	**Count**
Male	21
Female	14
Diagnosis	**Frequency**
Respiratory failure	14
Sepsis	11
Trauma	6
Post-surgical complication	4
Comorbidity	**Frequency**
Hypertension	12
COPD	9
Diabetes	8
None	6

Variation of tracheal tube cuff pressure with time

The mean cuff pressure in controlled ventilation in supine position (T1) was 25.34 cm of H_2O, (SD ± 3.75, 95% CI 24.06-26.62) while mean at the end of 2 hours of controlled ventilation in supine position (T2) was 21.66 cm of H_2O, (SD ± 3.40, 95% CI 20.49-22.83). At the end of 2 hours, the mean cuff pressure was lower than the initial value with a mean difference of 3.38 cm of H_2O (SD ± 2.73, 95% CI 2.75-4.62) which was statistically significant ($p<0.001$).

Variation of tracheal tube cuff pressure with position

The mean cuff pressure in controlled ventilation in propped up position (T3) immediately after changing position from supine was 20.03 cm of H_2O (SD ± 3.30, 95% CI 18.89- 21.16). This was lower than the value measured after 2 hours of cuff inflation, mean difference 1.63 (SD ±1.97, 95% CI 0.95- 2.3) which was statistically significant ($p<0.001$).

Variation of tracheal tube cuff pressure mode of ventilation

The mean cuff pressure in spontaneous mode of respiration (T4) was 15.17 cm H_2O, SD ± 4.24, 95% CI 13.71- 16.63). In comparison to the cuff pressure at propped up position, it was lower with a mean difference of 4.86 cm of H_2O (SD ± 2.86, 95% CI 3.87- 5.84) which was statistically lower ($p<0.001$).

The cuff pressures and changes at different time points are shown in Figure 2.

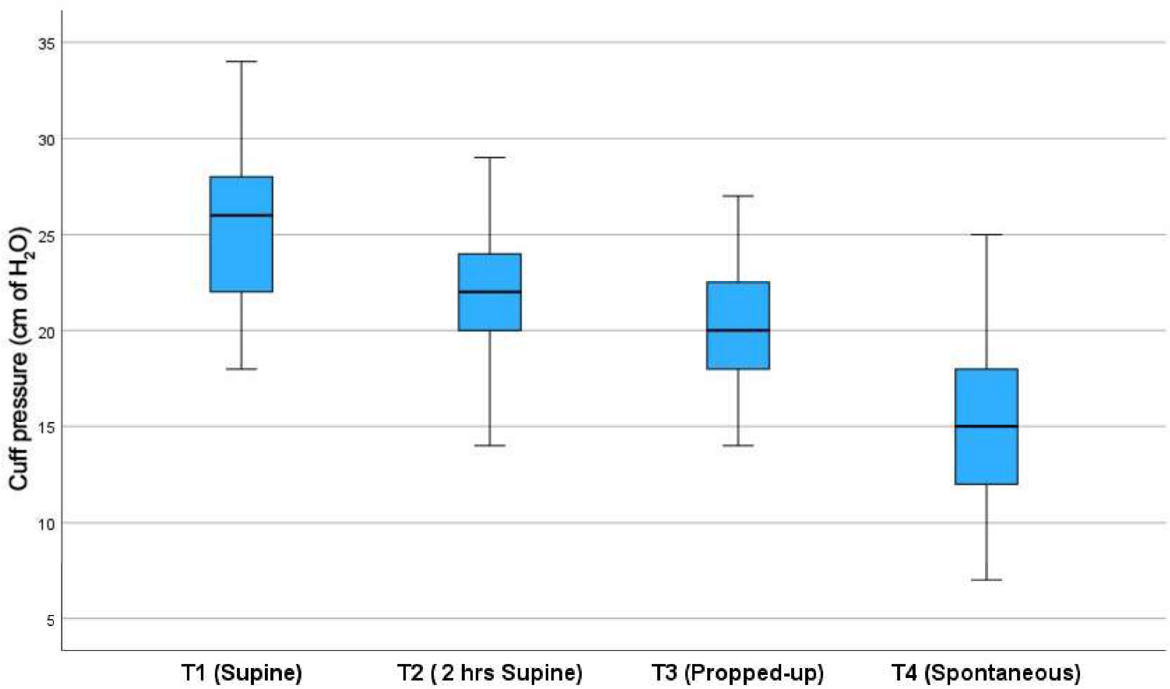

Figure 2: Box plot showing the mean cuff pressures at different time points. *(The bottom and the top edge of the box represent the first and third quartiles respectively. The whiskers represent the range with values outside the horizontal bars at the end of whiskers representing the outliers.)*

Table 2. Cuff pressure at different time points (all measurements in cm of H_2O)

SN	Time of measurement	Mean (SD)	95% CI
1.	Supine (T1)	25.34 (3.75)	24.06-26.62
2.	Supine after 2 hours (T2)	21.66 (3.40)	20.49-22.83
3.	Propped up (T3)	20.30 (3.30)	18.89- 21.16
4.	Spontaneous mode (T4)	15.17 (4.24)	13.71- 16.63

Table 3. Change in cuff pressures with time (all measurements in cm of H_2O)

SN	Comparison between two time points	Mean difference (SD)	95% CI	p value
1.	T1 vs T2	3.38 (2.73)	2.75-4.62	<0.001
2.	T2 vs T3	1.63 (1.97)	0.95-2.31	<0.001
3.	T3 vs T4	4.86 (2.86)	3.87-5.84	<0.001

DISCUSSION

Mean cuff pressures were found to significantly vary with time, change in position and mode of ventilation. It was highest at T1 (controlled ventilation in supine position), likely due to the influence of positive airway pressure and the supine position. At T2 (controlled mode of ventilation at two hours in supine position), a slight reduction in mean cuff pressure was observed, likely reflecting gradual air loss or adaptation of the tracheal wall over time. T3 (controlled ventilation in propped-up position) led to a further reduction in cuff pressure which may be attributed to changes in airway geometry during the positional shift. T4 (spontaneous breathing in propped-up position), had the lowest mean cuff pressure likely due to the absence of positive airway pressure in this mode of ventilation.

Despite knowing the fact that failure to maintain the ideal range of cuff pressure (20 – 30 cm of H_2O) can lead to a variety of significant consequences, tracheal tube cuff pressure is still not routinely measured.[11] Even if measured, the tracheal tube cuff pressure can be influenced by numerous factors, most of which are unavoidable in critically ill patients admitted to the ICU with a lengthy stay on mechanical ventilation.[12]

A significant reduction in cuff pressure was observed after 2 hours. This time-dependent decrease aligns with previous studies indicating that cuff pressures tend to diminish over time, even under stable conditions. Nseir et al. had demonstrated that prolonged use of high-volume, low-pressure cuffs can lead to increased cuff porosity which may be the cause for subsequent pressure reduction.[9] This reduction can also be attributed to gradual air loss through the cuff material, the compliance of tracheal walls and dynamic changes in airway pressures during mechanical ventilation. Continuous fluctuations, such as those caused by patient coughing or ventilator asynchrony, contribute further to the decline in cuff pressures, especially in non-sedated patients where these episodes are more frequent. One study found that the percentage of time spent with low cuff pressures significantly increased over the recording period, consistent with the observed reduction in cuff pressures over time.[10] A similar trend was noted in another prospective observational study that intermittently measured cuff pressures using mechanical manometers and continuously with pressure transducers over 12 hours. Continuous monitoring revealed extensive variations in cuff pressures, emphasizing the strong association between cuff pressure variation and the duration of tracheal tube placement. Intermittent monitoring, however, failed to detect these variations effectively, likely due to the mechanical manometer's lower precision compared to the digital manometer used in the current study.[11]

Another objective of our study was to assess how patient positioning influences cuff pressure. Mechanically ventilated patients with endotracheal tubes demonstrated a statistically significant reduction in cuff pressure when transitioning from supine to propped-up position, underscoring the impact of positional changes on ETT cuff pressures. The mean reduction of cuff pressure suggests the dynamic influence of airway geometry and gravitational effects on cuff performance.[12] While there were no studies done comparing effect of cuff pressure by supine and propped-up positions, some studies have compared supine and prone positions. A prospective and interventional study conducted by Kim D et al. involving 55 patients showed parallel results with the current study.[13] The change in position solely from supine to prone without the movement of head and neck demonstrated increase in the endotracheal tube cuff pressure during mechanical ventilation. However, the position change was from supine to prone which differed from the current study observing the position change from supine to propped up irrespective of any change in the head and neck posture. Secondly, this study carried out the measurements using a manual manometer while our measurements were taken with a digital manometer which gives more accurate and precise result. It is impossible to pinpoint the exact reason why the cuff pressure reduced in the propped-up position. Possible explanations could be that the cuff redistributes pressure along the tracheal wall due to decreased intrathoracic pressure, contributing to the observed reduction. Effect of gravity in diaphragm positioning may also contribute to these effects. Minonishi et al, conducted a study where the body posture was changed from supine to prone without affecting the alignment of the head and neck showing that the cuff pressure decreased after shifting from the supine to the prone position by rotating the head to the right during mechanical ventilation.[14]

The transition from controlled ventilation to spontaneous breathing showed a significant reduction in cuff pressure. This result aligns with prior studies indicating that ventilation mode transitions markedly affect ETT cuff pressure. The decrease can be attributed to reduced airway pressure during spontaneous breathing, which affects the tracheal wall dynamics and cuff performance.[15] This interaction of the respiratory system pressure changes and the tracheal tube cuff can cause more air loss than while spontaneously breathing.

Another possibility for the drop in cuff pressure might be the air escaping from the ETT cuff surface or through the pilot balloon valve. The current study's findings are confirmed by Shin et al.'s experimental work in dogs, which concluded that the ETT cuff pressure tended to drop over 60 minutes regardless of the mode of ventilation.[16] Another study in horses by Touzot Jourde's et al. also established that ETT cuff pressure dropped within the first 30 minutes of anaesthesia.[17] Two possible explanations for such a reduction in ETT cuff pressure are tracheal muscle relaxation and cuff material fatigue.[14] Motoyama et al. discovered a similar finding in mechanically ventilated human patients.[16] The tracheal tube cuff pressure dropped to less than 20 cm of H_2O in 45% of measurements taken from critically sick patients 2 hours after it had been adjusted to 24 cm of H_2O. One counter argument could be that since the measurements were taken with a manual manometer, leakage of compressed air in the cuff during frequent cuff pressure measurement could have occurred.[18] However our study had an advantage over this because a digital manometer was employed for the measurement, resulting in a negligible escape of air.

The observed reduction in cuff pressure underlines the importance of continuous or frequent monitoring to prevent complications such as micro-aspiration during spontaneous breathing across all time points. The decrease from T1 to T2 illustrates that cuff pressures reduce even in a stable position over time. This could be due to factors such as air leakage through the cuff material or the tracheal wall's compliance.

The transition from the supine to the propped-up position (T2 to T3) further reduces cuff pressure. This change might be attributed to gravity's effect and altered tracheal geometry, influencing cuff inflation dynamics.

The most notable reduction in cuff pressure was seen when patients switched to spontaneous breathing (T4). This could result from decreased airway pressures and reduced ventilator-induced fluctuations compared to controlled mechanical ventilation, leading to a decline in cuff pressures. Nseir et al. highlighted that prolonged use of high-volume, low-pressure cuffs results in increased porosity and subsequent pressure reduction due to gradual air loss and tracheal wall compliance.[19] Continuous monitoring studies have shown that cuff pressures can vary significantly due to patient activities like coughing or ventilator asynchrony.[17] This variation was not effectively captured in intermittent monitoring, emphasizing the importance of continuous assessment.

Duguet et al. found discrepancies in cuff pressure management, noting higher pressures when pneumatic devices were used.[20] This underscores the role of the measurement device in determining cuff pressure trends. A key strength of our study is modality used for measurement. We used a digital manometer, which provides accurate and precise measurements, ensuring reliable data.

Additionally, the inclusion of ICU patients who typically remain intubated for extended periods, offers greater clinical relevance than studies conducted in intraoperative settings where intubation is brief. Another strength lies in the analysis of not only the absolute cuff pressure values but also the direction of changes, offering deeper insights into pressure dynamics. Furthermore, this study adds to the relatively limited body of literature examining how different modes of mechanical ventilation influence cuff pressure.

Our study has a few limitations. This study only included three factors that might affect the tracheal tube cuff pressure. One factor that may be at play include the point of the breathing cycle where the cuff pressure was measured. This was not standardised for measurement in our study. This could have very much affected the results. Future advancements, such as devices capable of displaying continuous cuff pressure waveforms with built-in high- and low-pressure alarms, may significantly improve non-invasive monitoring. We hope that the findings of this study encourage further comprehensive research aimed at fully understanding and optimizing cuff pressure management in critical care settings.

CONCLUSION

This study shows that ventilation mode, patient positioning, and the duration of mechanical ventilation significantly affect tracheal tube cuff pressure in ICU patients. As continuous monitoring is not yet widely available which would be the definitive measurement of choice, cuff pressure should be checked regularly—ideally before any change in patient position or at least every four hours. Regular monitoring, preferably with a digital manometer, remains essential to reduce the risk of complications and to improve airway safety in critical care settings.

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