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RESEARCH ARTICLE

Safeguarding Pediatric Airways: A Closer Look at Cuff Pressure Control

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ABSTRACT

Background: Proper insufflation of the tube cuff is critical in pediatric endotracheal intubation. However, the widespread use of subjective techniques for measuring cuff pressure by healthcare workers has raised concerns due to the potential for airway damage and subsequent impact on laryngotracheal tissue.

Objective: This study aims to evaluate tube cuff pressure variations based on operator expertise and clinical context among pediatric patients undergoing endotracheal intubation and compare the measurements obtained through subjective techniques with those obtained using an objective method involving a manometer.

Methods: This cross-sectional observational quantitative study obtained Institutional Ethics Committee approval and was conducted between October 2022 and January 2023. Descriptive statistics and frequency distributions were used for variable characterization. The Kolmogorov-Smirnov test assessed normality. A bivariate analysis employed chi-square tests and ANOVA, establishing a 95% confidence interval and significance level at $p < 0.05$.

Results: Seventy pediatric patients (mean age: 7.53 years) participated. Anesthesiology residents primarily performed intubation (28.6%), while tube cuff inflation was predominantly executed by nursing staff (38.6%), except within the intensive care unit where respiratory therapists assumed responsibility (20%). Manometric measurements indicated an average tube cuff pressure of 30.8 cm H_2O (SD 17.4) across all scenarios. Notably, higher pressures were recorded in emergency contexts, with a statistically significant correlation between cuff pressure and insufflation personnel ($P < 0.001$), particularly evident when nursing staff was involved, with a mean difference of up to 18 cm H_2O ($P < 0.001$). A statistically significant link existed between pressure levels and clinical context ($P = 0.030$).

Conclusion: This study underscores the discord between cuff pressures when measured by subjective techniques, highlighting the importance of objective manometric measurements. There is a necessity for comprehensive training of healthcare professionals working in surgical, emergency, and pediatric intensive care units, enabling them to proficiently utilize manometers for precise pressure evaluations that limit the risk of injury due to high pressures or aspiration and subsequent ventilator-associated pneumonia due to inadequate inflation.

Introduction

Endotracheal intubation facilitates airway control for patients, ranging from short durations during surgeries to extended periods in intensive care units. This procedure encompasses not only various clinical scenarios but also involves different healthcare professionals, including general practitioners, specialists such as anesthesiologists, intensivists, pediatricians, internists, and even otolaryngologists. They encounter this procedure routinely in controlled or emergent settings, necessitating collaboration and active participation from nursing assistants, nurse leaders, respiratory therapists, and trainees such as residents and interns[1,2].

The process of inflating the tube cuff is a responsibility shared among the individuals involved in the intubation process. Regardless of the anticipated duration of intubation, significant importance must be placed on the pressure at which the cuff will remain within the patient's airway. This is crucial because tissue damage can manifest early on[4,8].

In pediatric patients, the evidence is quite controversial, and studies like the one proposed here are needed. Recognizing that maintaining appropriate tube cuff pressure is and should be a concern for all involved in the care of these patients, as it poses greater risks in the pediatric population due to reduced lung reserves and tissue immaturity. This underscores the importance of careful airway management in pediatric cases, as higher-than-safe pressures can cause ischemic injury to the airway, leading to post-extubation stridor and, in some instances, reintubation. Conversely, an underinflated tube cuff increases the risk of microaspirations and ventilator-associated pneumonia[5,17] **(Figure 1).**

Although the potential airway damage is evident, there are limited studies conducted in the pediatric population. As a result, much of the current information is extrapolated from adult patients[5,17]. This study aims to analyze variations in tube cuff pressure among pediatric patients undergoing endotracheal intubation, considering clinical factors and operator influence.

Figure 1. Variation in cuff dimensions and sizes within the same endotracheal tube, highlighting significant differences due to pressure.

Methods

STUDY DESIGN AND SETTING:
This analytical cross-sectional observational study at a tertiary pediatric hospital, was ethically approved by the Institutional Ethics Committee. The research spanned from October 2022 to January 2023.

PARTICIPANTS: The study included pediatric patients who required mechanical ventilation with endotracheal intubation utilizing either an endotracheal tube with balloon cuff or a tracheostomy tube with balloon cuff. Exclusion criteria were patients with identified cuff dysfunction, and isolated patients with contact restriction.

SAMPLING AND SAMPLE SIZE: A random probabilistic sampling approach was adopted, assuming a 60% prevalence of tube cuff hyperinflation. With a 95% confidence level and a maximum estimation error of 5%, the calculated sample size was 57 subjects.

DATA COLLECTION AND ANALYSIS: Cuff pressure measurements were obtained using a manometer VBM Cuff Pressure Gauge (Figure 2), with each measurement being based on standardized procedures. Univariate analysis was conducted for sociodemographic and clinical variables. Qualitative variables were categorized based on their nature and level and presented using absolute and relative frequencies. Quantitative variables were summarized using central tendency, mean, or median, along with measures of dispersion like standard deviation or interquartile ranges, based on normality assessed via the Kolmogorov-Smirnov test. For bivariate analysis, parametric variables underwent chi-square tests, determining the strength of association using the contingency coefficient. When expected values were ≤ 5, a Fisher's exact test was used. Polytomous qualitative variables underwent ANOVA homogeneity testing, followed by the Tukey Post-Hoc test under equal variances. 95% confidence intervals were reported in case of significance ($p < 0.05$).

Figure 1. Variation in cuff dimensions and sizes within the same endotracheal tube, highlighting significant differences due to pressure.

Results

The study included 70 pediatric patients, of whom 44 were male and 26 were female. The mean age was 7.53 years, with a standard deviation of 4.55 years (7.30 and 7.92 years, respectively). The age of the patients ranged from one month to 17 years. The average patient weight was 26.6 kg. To account for the pediatric population, body mass index (BMI) was calculated using Centers for Disease Control and Prevention (CDC) guidelines. Based on established formulas for optimal tube size selection, 71.4% of patients received appropriately sized tubes for their age, 20.3% received smaller tubes, and 8.7% received larger tubes (Table 1)

Table 1. Characterization of the Study Population.

	Median (SD)
Age (years)	7.53 (4.48)
Sex	**No (%)**
Female	26 (37.1)
Male	44 (62.9)
Weight Classification	**No (%)**
Healthy Weight	43 (61.4)
Underweight	10 (14.3)
Overweight	11 (15.7)
Obesity	6 (8.6)
	Median (SD)
Tube Cuff Pressure (cmH2O) M (SD)	30.8 (17.4)
Tube Cuff Pressure Classification	**No (%)**
High Pressure	40 (57.1)
Normal Pressure	11 (15.7)
Low Pressure	19 (27.1)
Endotracheal Tube Size	**No (%)**
Appropriate Size	49 (71)
Small Size	14 (20.3)
Large Size	6 (8.7)
Intubation Context	**No (%)**
Emergencies	21 (30)
Scheduled Surgery	38 (54.3)
Intensive Care Unit	11 (15.7)

SD: Standard Deviation.

The personnel responsible for intubation included anesthesiology residents, anesthesiologists, and pediatricians (28.6%, 21.1%, and 21.4% respectively). Balloon insufflation was mainly performed by nursing assistants (38.6%) across all contexts, except for the intensive care unit where respiratory therapists were primarily responsible (20%) **(Table 2).**

Table 2. Personnel Responsible for Intubation and Tube Cuff Insufflation

Intubating Personnel	No (%)
Anesthesiology Resident	20 (28.6)
Anesthesiologist	19 (27.1)
Pediatrician	15 (21.4)
Intensivist	6 (8.6)
General Physician	6 (8.6)
Pediatrics Resident	4 (5.7)
ENT Specialist	0
ENT Resident	0
Insufflating Personnel	**No (%)**
Nursing Assistant	27 (38.6)
Respiratory Therapist	14 (20)
Anesthesiologist	12 (17.1)
Anesthesiology Resident	11 (15.7)
Intensivist	3 (4.3)
Pediatrician	3 (4.3)

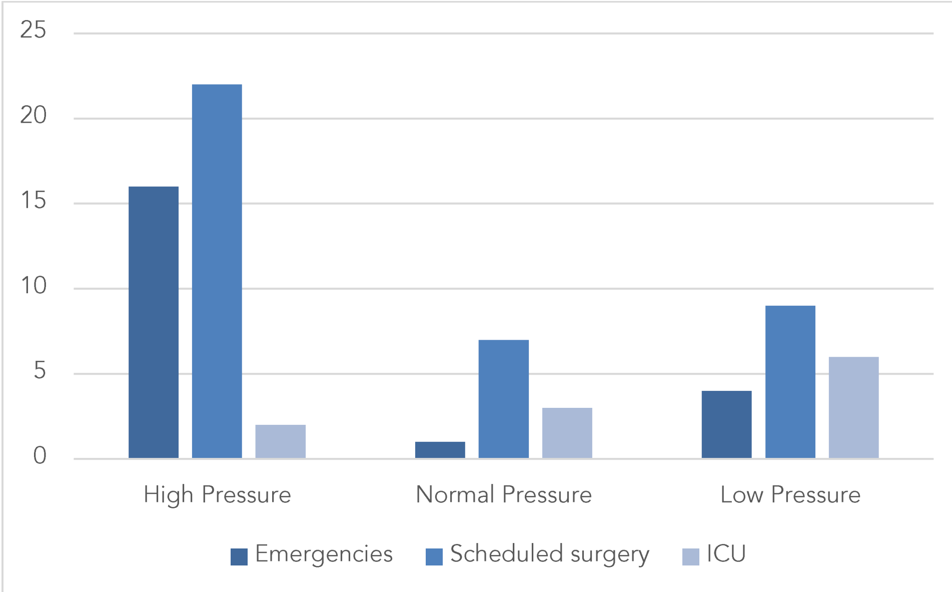
In 70.6% of cases, the balloon inflation was confirmed subjectively, primarily using digital pressure (42.6%), while in 29.4% of cases, no verification method was employed **(Table 3).** The central variable of interest was the objective measurement of tube cuff pressure using a manometer (Kolmogorov-Smirnov test value: 0.825). The mean cuff pressure across all scenarios was 30.8 cmH2O, with a standard deviation of 17.4.

Table 3. Pressure Verification Methods

Pressure Verification Method	No (%)
Digital Palpation	29 (42.6)
Not Performed	20 (29.4)
Passive Deflation	11 (16.2)
Unattended ETT	5 (7.4)
Minimal Leak	3 (4.4)

Notably, higher pressures were observed in emergency contexts (Table 1, Figure 3). A statistically significant relationship was found between tube cuff pressure and the personnel responsible for insufflation (ANOVA $P < 0.001$), particularly evident with nursing personnel exhibiting a mean difference of up to 18 cmH2O (Tukey $P < 0.001$). Additionally, a statistically significant association was noted between pressure levels and clinical settings (χ^2 $P = 0.030$).

Figure 3. Intubation Context by Clinical Setting



ICU: Intensive Care Unit

Discussion

Endotracheal intubation is a procedure that spans multiple clinical scenarios and involves different healthcare providers, whether in controlled or urgent environments. It requires collaboration and active involvement from nursing staff, respiratory therapists, and personnel in training as residents and interns. However, few studies have reported the effect of care on endotracheal tube cuff pressure, particularly in the pediatric population[3,4,5,6].

Managing the cuff pressure of the endotracheal tube is crucial and can pose a challenge in caring for ventilated patients. Proper management of tube cuff pressure is crucial and can pose a challenge in ventilated patient care. Cuff inflation must be adequate to prevent laryngotracheal injury such as vocal cord paralysis and laryngotracheal stenosis[3,7,8,9] while reducing risk of aspiration and ventilator-associated pneumonia[10,11].

Achieving the optimal pressure range involves inflating the cuff with a manometer, as done in our study. However, this method is not widely accepted due to its cost, limited availability, and healthcare professionals' confidence in subjective inflation techniques[12] These alternatives appear cost-effective but are perceptual and inefficient due to their low safety and reproducibility. Techniques like pilot balloon palpation (PBP) (the most common method in our study: 42.6%) rely on digital pressure, making them highly subjective and displaying significant inter-observer variability. Additionally, techniques like minimal leak or loss of resistance (LOR) have yielded inconsistent results[13,14,15]. Confirming the advantages of using a manometer. Furthermore, researchers in India and Brazil have proposed their own devices or adapted blood pressure manometers, achieving good concordance with specific manometers for cuff pressure measurement. While these devices might offer a cost-effective and somewhat more objective way to measure pressure, they could suffer from calibration errors and lack global approval[16,17,18,19].

Despite numerous clinical trials and observational studies conducted in adults, there is a knowledge gap regarding cuff pressures and appropriate tube sizes in the pediatric population. To address this issue, various researchers have attempted to simulate tissue damage in the laryngotracheal tissue using porcine and ovine models[20,21]. In 2016, Senthil et al. conducted an in vitro and in vivo study simulating the pediatric airway. They found an average pressure of 29 ± 19 cmH2O when using conventional formulas for sizing pediatric tubes. For the group with a tube 0.5 mm smaller than the calculated size, the average pressure was 37 ± 35 cmH2O, indicating that smaller devices could become high-volume, high-pressure devices, leading to adverse effects on pediatric airways[22]. In our study, 20.3% of patients were intubated with a tube size smaller than that recommended by the conventional formula used in pediatric patients by the American Society of Anesthesiologists (ASA)[1,2].

To improve safe cuff pressure levels, studies have examined whether frequent monitoring of cuff pressure reduces complications, hospital stays, or mortality. A study by Letvin et al. found no statistically significant differences between frequent monitoring and standard cuff pressure monitoring [23]. Among the few studies conducted in pediatric patients, Shaikh et al. investigated patients in the pediatric intensive care unit at Rainbow Hospital in Telangana, India, comparing frequent monitoring to standard cuff pressure monitoring. They concluded that there was no benefit to frequent monitoring (every 6 hours) in reducing intubation-related adverse effects such as ventilator-associated pneumonia rates, post-extubation stridor, or reintubation rates[24]. In our study, frequent cuff pressure monitoring was not performed. However, Schneider et al. and Nazari et al. emphasized the advantages of regular cuff pressure monitoring[25].

The pediatric population is unique regarding airway management, and there are no universally standardized data for these patients. The optimal cuff pressure value is better established for adults than for pediatric patients. For our study, we adopted a cuff pressure range of 20-25 cmH2O as the optimal value, considering recommendations from the Royal College of Anesthetists in the UK and the American Heart Association (AHA)[13,16,22,26,27]. However, we found that most patients had cuff pressures above the appropriate range (57.1%).

Akwasi et al. conducted a study at Komfo Anokye Teaching Hospital in Kumasi, Ghana, evaluating cuff pressure. They found that 68% of measurements recorded pressures exceeding 30 cm H2O, most often when nurses, nursing students, or anesthesia residents inflated the cuffs[28]. In our study, a significant association was identified between elevated cuff pressure and urgent clinical scenarios, and this high pressure was significantly associated with cuff inflation by nursing staff. This bivariate analysis underscores the importance of the intubation process, the personnel responsible, and the clinical context of execution.

As an interesting finding, in the intensive care unit, cuff pressure was primarily managed by respiratory therapists, and cuff pressure was found to be low in almost 10% of the population. This raises the risk of respiratory infections due to aspiration, furthermore, the hazard of airway injury, given that these patients mostly undergo prolonged intubation, leading to cuff crystallization and subsequent airway injury when extubating. A similar result was evident in a study conducted by the University of Texas, San Antonio, USA, in January 2020, where no cases of hyperinflation were found, and nearly 50% of measurements were within the range of under inflation[29].

Consistent with multiple studies, it has been observed that failure to quantify or control cuff pressure exposes the patient to a relative risk of 1.66:1 of significant tracheal injury compared to patients whose cuff pressure is monitored[30,31].

Despite the high frequency of complications resulting from excessive cuff pressure in the airway, the severity and recurrence of these complications continue to be underestimated. This might be due to the routine administration of anti-inflammatories and antibiotics, which could mask the development of tissue changes. Additionally, the diagnosis might be delayed, as only 70% of laryngotracheal stenoses become symptomatic immediately after extubation[7].

Prevention of airway events is of utmost importance, achieved through staff education and training in pressure monitoring using a manometer as the most reliable and objective tool[24,32]. Current evidence underscores the need for a protocol for cuff pressure control as a support tool to enhance the safety of intubated children[12,33].

Conclusions

This study highlights the lack of agreement between subjective techniques for measuring tube cuff pressure and the objective measurements provided by a manometer. The need to provide training and education to healthcare personnel involved in the care of children undergoing endotracheal intubation in pressure measurement using a manometer is emphasized. This is essential to ensure optimal, objective, and safe pressures, thereby reducing the risk of complications associated with overinflation or inadequate inflation of the tube cuff.

Conflict of Interest Statement:

The authors declare no conflicts of interest.

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