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Endotracheal tube cuff pressure assessment: expectations versus reality

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Abstract

Background: Damage to the trachea, although rare, is a serious complication in anesthesiology and intensive care. The main mechanism of such injury is a direct mechanical action associated with excessive pressure in the cuff of the endotracheal tube (ETT). The aim of the study was to evaluate the actual pressure in the cuffs during surgical interventions, correlate this measure with the subjective assessment of the anesthesiologist, and compare different methods of inflating the ETT cuff.

Methods: Ninety patients were randomly divided into two equal groups. In the study group, the "minimum leakage" technique was used to inflate the cuff. In the control group, the adequacy of pressure was determined by palpation of the cuff balloon. In both groups, the actual pressure was then measured using a mechanical manometer connected to the cuff.

Results: The average ETT cuff pressure was 30.4 ± 4.9 cmH_2O (2.98 ± 0.48 kPa) in the study group and 68.9 ± 23.3 cmH_2O (6.75 ± 2.28 kPa) in the control group. The pressure in the ETT cuffs was within the standard safe range (i.e. 20–30 cmH_2O) in 2/45 (4.4%) and 23/45 (51.1%) patients in the control and the study group, respectively.

Conclusions: In the majority of cases, the pressure achieved via evaluation by the method of palpation of the control cuff was not adequate. Among various non-mechanical methods of measuring and controlling pressure in the cuff of the intubation tube, the minimum occlusion volume technique deserves attention.

Key words: tracheal injury, intubation, safety in the operating room, minimal occlusion volume method.

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Tracheal intubation is one of the most common anesthetic procedures, and, like any other intervention, is accompanied by certain risks. Traumatic intubation is associated with many different complications, ranging from dental damage and post-extubation cough to iatrogenic tracheal injuries [1]. Post-intubation tracheal rupture (PTR) is a rare but serious complication that can be potentially fatal. The incidence and mortality rate of PTR vary according to different studies. Unfortunately, there are no systematic data or extensive meta-analyses on the frequency of these cases [2, 3]. According to various data, the frequency of this complication can range from 1 : 20.000 to 1 : 75.000 during single-lumen tube intubation [4]. And, more often than not, those reports are based either on studies conducted in the 1970s, or individual case reports. The most common clinical signs include subcutaneous emphysema, pneumomediastinum, and unilateral or bilateral pneumothorax. Sometimes PTR can occur without significant visible manifestations, which in turn makes diagnosis difficult [5].

The risk factors of this complication can be divided into anatomical and mechanical. Anatomical factors include congenital anomalies of the trachea (such as weakness of the tracheal membrane), chronic obstructive pulmonary disease (COPD) and other inflammatory lesions of the tracheobronchial tree, diseases that change the position of the trachea (e.g., enlargement of mediastinal lymph nodes or a tumor), corticosteroid use, age, female sex, and short stature. Unsatisfactory results of a physical assessment of the respiratory tract are also separately classified as anatomical factors. The LEMON scale is also prognostically valuable in this context [4, 6]. Mechanical factors include multiple attempts at

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intubation, inexperience of the anesthesiologist, protrusion of the guide from the tip of the endotracheal tube (ETT), overinflation of the cuff, incorrect positioning of the ETT, repositioning of the tube without deflation of the cuff, inappropriate size of the ETT, severe coughing and movements of the head and neck during intubation (e.g., due to insufficient depth anesthesia/muscle relaxation) [7, 8].

High pressure in the cuff can cause not only such a threatening condition as PTR, but also other complications: cough, tracheal ischemia, sore throat, recurrent paralysis of the laryngeal nerve, or tracheal stenosis [9]. On the other hand, insufficient pressure in the cuff can lead to dislocation of the tube, ineffective ventilation, as well as microaspiration of secretions from the oropharynx. Therefore, the optimal pressure in the cuff of the tube is considered to be 20–30 cmH_2O. This range provides reliable protection against aspiration, adequate ETT fixation, and does not significantly increase the risk of iatrogenic damage to the trachea [9–11].

There are many techniques for measuring ETT cuff pressure. Perhaps the most widespread technique is palpation of the control cuff, but it is primarily based on subjective feeling and does not always reflect the real pressure in the cuff [12]. This technique is much less reliable than mechanical methods of pressure measurement. The use of digital or analog manometers allows for more accurate measurement of cuff pressure, thereby preventing cuff overinflation and under-inflation. Despite that, in developing countries opportunities for cuff pressure control are limited. Only 3.1% (6/196) of the care providers involved in the survey admitted having ever used a tracheal cuff manometer, while 31.1% knew the recommended tracheal cuff pressure. A nationwide telephone survey of anaesthesia faculty fellows revealed that a tracheal cuff manometer was not available, nor had one ever been used in any of the 13 tertiary hospitals surveyed. The 'pilot balloon palpation method' and 'fixed volume of air from a syringe' were the most commonly utilized methods of cuff pressure estimation by the care providers, at 64.3% and 28.1%, respectively [13]. Of special note are cuff inflation and pressure control techniques, which do not require additional equipment or consumables, but are much more closely correlated with the recommended pressure range. Such methods include the technique of "minimum leakage" or "minimum occlusive volume". This method is based on gradually inflating the cuff with the minimal volume of air necessary to achieve tightness in the circuit, which enables acceptable pressure to be achieved without using measuring devices, significantly reducing the potential for complications. At the same time, this technique does not lead to an increase in the cost of anesthesia, which is especially relevant in settings with limited resources.

Cuff pressure measurement is an initial step to eliminate complications of tracheal intubation. The purpose of this study was to assess actual cuff pressure using an analog manometer in intubated patients undergoing surgery. The secondary aim was to compare different cuff inflation techniques.

METHODS

The study was approved by the appropriate Commission on Issues of Bioethical Expertise and Ethics of Scientific Research Bogomolets National Medical University (decision #156 from 21/02/22). Written informed consent was obtained from all patients. Ninety patients, randomly divided into 2 groups, were included in the study conducted in Gynecological Department 5 of the Maternity Hospital in Kyiv, as well as the National Military Medical Clinical Center "Main Military Clinical Hospital". Patients underwent non-urgent surgical interventions, mainly within the abdominal cavity and pelvic organs. Exclusion criteria were a history of difficult airways or multiple attempts of intubation, and BMI over 35 kg m^{-2}. The method of anesthesia in all cases was general low-flow inhalation anesthesia. An oral or nasal ETT was used: 8.0 mm size for male and 7.0 mm size for female patients (cuff material: medical PCV, cuff type: PHT). A standard 20 mL syringe was used to inflate the cuff with air. No N_2O was used during the study. In both groups, tracheal intubation was performed after standard induction of anesthesia and mechanical ventilation was started. The inflation of the cuff in the study group (n = 45) was carried out according to the "minimum leakage" method, after which the pressure indicators were recorded with a manometer. In the control group (n = 45), the cuff was inflated by an anesthesiologist and was assessed by palpation of the cuff balloon. After the pressure was deemed satisfactory by subjective assessment, the pressure was measured using a manometer connected to the cuff. Measurements were made in cmH_2O within several minutes after intubation. Continuous variables are presented as a mean and standard deviation, while categorical variables are presented as a median with min-max levels. Categorical data were analyzed using Fisher's exact test. Both groups were divided into "normal" or "overinflated" pressure levels, for which the odds ratio (OR), its standard error and 95% confidence interval (CI) were calculated. $P < 0.05$ was considered statistically significant.

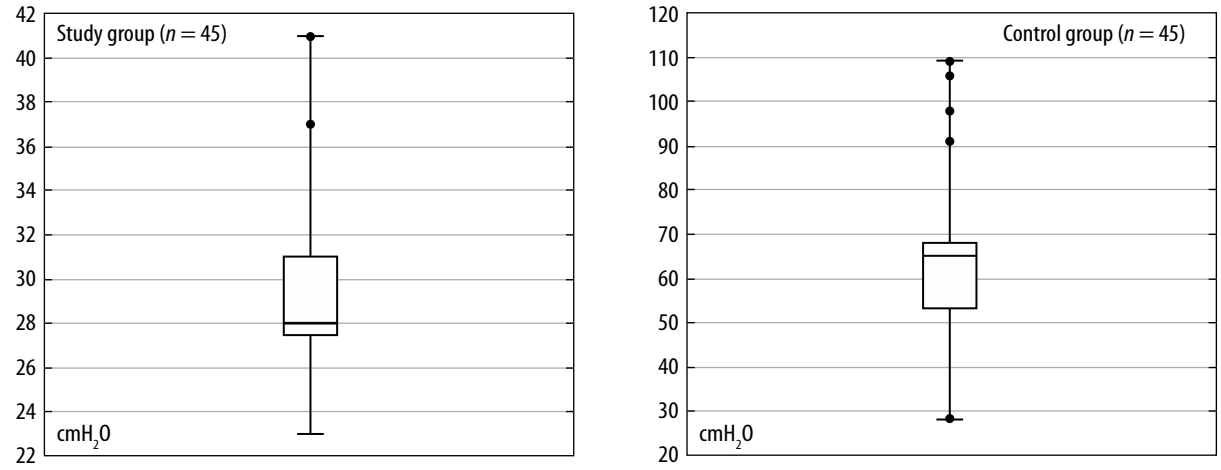

FIGURE 1. Pressure in the endotracheal tube cuff in the study and control groups

RESULTS

A total of 40 women and 50 men, with an average age of 44.3 ± 13.6 years and ASA grade 1–2, were included in the study. The *t*-value for the sample size was 10.42574 ($P < 0.001$). The mean BMI was 27.1 ± 6.4 kg m^{-2}. The average pressure in the studied group, where the cuff was inflated using the minimal occlusive volume technique, was 30.4 ± 4.9 cmH_2O (2.98 ± 0.48 kPa), while in the control group it was 68.9 ± 23.3 cmH_2O (6.75 ± 2.28 kPa) ($P < 0.001$). The criterion for the degree of inflation of the cuff in the control group was the subjective assessment of pressure by the anesthesiologist. In all cases this assessment was satisfactory; however, this did not prevent overinflation of the cuff, which resulted in the measured pressure being several times higher than the recommended norms. The maximum pressure recorded in the control group was 109 cmH_2O (10.68 kPa).

In the control group, in only 2/45 (4.4%) the pressure reached the required safe range (i.e. 20–30 cmH_2O), while in the study group there were 23/45 (51.1%) such cases (OR = 22.4, 95% CI [4.84], $P < 0.001$).

Cases of insufficient pressure (less than 20 cmH_2O), which could lead to aspiration and other pulmonary complications, were not found in either of the groups.

DISCUSSION

Maintaining a safe pressure range in the ETT cuff is definitely an important factor in preventing the development of various complications of tracheal intubation [11]. However, certain factors prevent the implementation of such an approach in routine practice. Kampo *et al*. [12] note in their study that cuff pressure devices remain inaccessible to many anesthesiologists, especially in middle- and low-income countries. Although a large number of digital and analog devices have been available on the market for a long time, they are not available to everyone, particularly in resource-limited settings. According to the authors, they did not observe a significant difference in pressure in the cuff between palpation and measurement with a manometer; on average the difference was above 10 cmH_2O (0.98 kPa). But the number of complications in the group of empirical determination reached up to 86%, against 0.8% in the group with controlled pressure. Such discrepancies may be due to different approaches in the training of anesthesiologists, insufficient coverage of the problem, etc. These results are subject to further discussion – the study was conducted in 389 women (obstetrics department of the Tamale Teaching Hospital) who were contraindicated for spinal anesthesia or failed neuraxial blockade. We believe that factors such as rapid sequence induction, as well as circumstances that were contraindications to spinal anesthesia, could generally increase the risk of post-intubation complications.

In the study of Souza *et al*. [10], where they analyzed 25 cases of intubation and prolonged mechanical ventilation in patients in the intensive care unit, the sample of patients was more homogeneous. At the same time, the authors compared two different methods: manual measurement using a manometer and the "minimum required volume" technique. This technique consists of introducing the smallest necessary volume of air or liquid necessary to prevent leakage in the circuit. This does not always correlate with a safe interval of 20–30 cmH_2O (1.96–2.94 kPa), although it is definitely also "empirical" in its essence. As was noted in the results of our study, this technique is significantly more likely to result in a pressure falling within the safe range than techniques that rely on the subjective assessment of the pressure by a specialist. Such alternatives deserve attention, especially as a transitional stage in the implementation of safe anaesthesia standards in low- and middle-income countries.

Despite the differences in the designs of the above studies, their results are predictably similar: the use of measuring devices to determine the pressure in the cuff of the intubation tube leads to a decrease in post-intubation complications. That being said, regular measurement of cuff pressure is not routinely performed in many settings.

The relevance of pressure measurement methods in the cuff of intubation tubes is even more important in the context of the rising variety of available ETT models, which may differ in their structure, sizes, materials, methods of application, etc. Various studies prove that both the use of excessive pressure introduced by conventional cuffs and ultra-low pressure in small-volume cuffs can lead to various complications. For example, the latter have an increased risk of developing aspiration pneumonia [13].

Despite the fact that some studies note the indisputable advantage of the low-volume, low-pressure cuff, more recent reviews question this conclusion and call for further discussion. The article by Coelho *et al*. [13] provides a comprehensive narrative review of the use of airway and respiratory devices in the prevention of ventilator-associated pneumonia (VAP), a significant concern in intensive care units due to its association with increased morbidity, mortality, duration of mechanical ventilation, and antibiotic consumption. The review highlights the critical role of specialized artificial airways and devices in reducing the incidence of VAP. However, it also acknowledges the debate over the efficacy of these interventions and their potential adverse effects. This discussion underscores the multifaceted nature of VAP prevention, emphasizing the importance of a balanced approach that considers both the benefits and limitations of technological solutions in the context of comprehensive patient care strategies.

Key insights from the article suggest that while the deployment of advanced airway management devices can play a role in VAP prevention, their application should be judicious and tailored to individual patient needs. It reinforces the idea that prevention strategies must be part of a broader, integrated care protocol that includes diligent hygiene practices, appropriate antibiotic stewardship, and ongoing assessment of patient response to interventions.

Unlike different volumes, different materials from which the cuffs are made do not seem to have such a strong influence on the development of certain complications. The systematic review and meta-analysis conducted by Saito *et al*. [15] aimed to evaluate the effectiveness of polyurethane (PU) tracheal tube cuffs in preventing ventilator-associated pneumonia (VAP) compared to conventional polyvinyl chloride (PVC) tube cuffs. After a thorough search of several databases, six studies involving a total of 1226 patients were included in the analysis. The results showed that the use of PU cuffs did not significantly reduce the incidence of VAP as compared to PVC cuffs, with a relative risk (RR) of 0.68 (95% CI: 0.45–1.03), indicating no statistically significant difference. The study also noted significant statistical heterogeneity among the included studies (I^2 = 65%). Furthermore, the quality of evidence was rated as "very low" and a trial sequential analysis (TSA) indicated that the actual sample size was only 15.8% of the target sample size, suggesting that more research is needed to definitively confirm the effectiveness of PU cuffs in VAP prevention.

CONCLUSIONS

The actual pressure in the cuff measured using an analog manometer in intubated patients is significantly different from the subjective assessment of anesthesiologists. The use of empirical methods of determining pressure, such as palpation of the ETT cuff balloon, is an unreliable method that does not correlate in its effectiveness with mechanical measurement. The minimal occlusion volume technique may be a viable alternative in cases where mechanical measurement of cuff pressure is not available.

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