Clinical and Experimental Health Sciences

Original Article / *Özgün Araştırma*

Comparison Between Cuff Pressures of Endotracheal Tubes Inflated with Saline or Air in Low-Flow Anesthesia

Düşük Akımlı Anestezide Salin ve Hava ile Şişirilen Endotrakeal Tüp Kaf Basınçlarının Karşılaştırılması

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Abstract

Objective: Depending on the increase in inspired fractionated nitric oxide fraction (F_iN_2O), cuff pressures in intubated patients are increased with diffusion into endotracheal cuff during low-flow anesthesia (LFA) with nitrous oxide (N_2O). We compared pressures of air- and saline-inflated endotracheal tube cuffs during LFA with N_2O in our study.

Methods: We included 60 adult patients who were classified by the American Society of Anesthesiologists as I/II in the study. After induction of anesthesia, endotracheal cuffs of patients who were intubated were inflated with air (Group A=30) and saline (Group S=30) to 25 cm water. Thus, two equal randomized groups were separated. The anesthesia technique was maintained with LFA and N_2O. Endotracheal cuff pressures were continuously measured with a pressure manometer, and inspired oxygen and N_2O levels and also 2 and 24 h after surgery for sore throat were recorded.

Results: There was no significant difference about demographic and intraoperative data between the groups. Cuff pressures were significantly higher in Group A than in Group S during all periods (p10 min=0.02, p<0.0001 for others). Group S had significantly higher values than Group A when maximum cuff pressures were compared (37.60±3.16 vs. 29.96±3.34, respectively; p<0.0001). There was a 51.9% positive correlation between cuff pressure and F_iN_2O in Group A (r=0.519, p=0.048). Group Ahad significantly higher level than Group S at postoperative 2 and 24 h when groups were compared for postoperative sore throat without swallowing and swallowing (p<0.05).

Conclusion: Under LFA with N_2O, endotracheal cuff pressures during operation and postoperative sore throat incidences in our study were significantly higher in Group S than in Group A.

Keywords: Low-flow anesthesia, cuff pressure, sore throat

Öz

Amaç: Entübe hastalarda nitrik oksitli (N_2O) düşük akımlı genel anestezide (DAA) inspire edilen nitröz oksit fraksiyonundaki (F_iN_2O) artışa bağlı olarak N2 O'nun endotrakel tüp (ETT) kafı içine diffüzyonu kaf basınçlarında artışa neden olur. Biz çalışmamızda N_2O'lu DAA'de hava ve salin ile şişirilen ETT kaf basınçlarını ve bunun ameliyat sonrası dönemdeki boğaz ağrısına olan etkisini karşılaştırdık.

Yöntemler: Çalışmaya ASA I/II toplam altmış erişkin hasta dahil ettik. Anestezi indüksiyonu sonrası endotrakeal entübasyon yapılan hastaların ETT kafları hava (Grup A, n=30) ve salin (Grup S, n=30) ile 25 cmH_2O olacak şekilde şişirilerek rastgele iki gruba ayrıldı. Anestezi N_2O'li DAA ile sürdürüldü. ETT kaf basınçları bir basınç manometresi ile sürekli olarak ölçüldü ve inspire edilen oksijen ve N_2O seviyeleri operasyon boyunca her 10 dakikada bir kaydedildi. Hastaların cerrahi sonrası 2. ve 24. saatlerde yutkunurken ve yutkunma olmaksızın boğaz ağrıları numerical rating scala (NRS) ile değerlendirildi.

Bulgular: Gruplar arasında demografik ve intraoperatif açısından anlamlı bir fark yoktu. Tüm takip dönemlerindeki kaf basınçları Grup S ile kıyaslandı- ğında Grup A'da maksimum olarak yüksekti (p10.dk=0,02, değer dönemlerde p<0,0001). Grup A'da kaf basınçları ile FiN2O arasında %51,9 pozitif yönde anlamlı bir korelasyon bulundu (r=0,519, p=0,048). Grupların yutkunma ve yutkunma olmaksızın postoperatif boğaz ağrısı skorları kıyaslandığında, Grup A, Grup S'ye göre 2. ve 24. saatte anlamlı olarak yüksekti (p<0,05).

Sonuç: Azotprotoksitli DAA'de ETE tüp kaflarının hava ile kıyaslandığında salin ile şişirilmesi intraoperatif kaf basınçlarını ve cerrahi sonrası dönemde boğaz ağrısı sıklığını azaltmıştır.

Anahtar kelimeler: Düşük akımlı genel anestezi, kaf basıncı, boğaz ağrısı

INTRODUCTION

Endotracheal tube (ETT) cuffs create a mechanical barrier between the trachea wall and the tube, thereby reducing the likelihood of aspiration during ventilation and preventing air leakage (1). High ETT cuff pressures are frequently observed in intensive care units, especially during nitrous oxide (N_2O) anesthesia (2, 3). The optimal values for ETT cuff pressures are between 20 and 30 cm water (H_2O) (4). Compared with anesthesia procedures for which other anesthetic agents are used, it has been shown that cuff pressures are higher than 40 cm H_2O in 90.6% of postoperative patients after N_2O anesthesia (5). If highly inflated cuff pressures surpass the tracheal capillary perfusion pressure, postoperative complications may occur that can cause ischemic damage in the tracheal mucosa (6).

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Low-flow anesthesia (LFA) is an anesthesia technique applied with a semi-closed rebreather whereby at least 50% of the exhaled gas is reused in circulation. At the same time, fresh gas flow in this system can be reduced below 1 L/min (7). An increase is observed in the inspired fractionated N_2O fraction (F_iN_2O) based on the decrease in the N_2O uptake during low flow in LFA with N_2O (7, 8). N_2O is approximately 35 times more soluble in blood than nitrogen. For this reason, it increases the volume and pressure of the cuff by diffusing easily from the blood into air gaps such as the ETT cuff (8). The increase in air-inflated cuff pressures in the postoperative period causes an increased morbidity, especially in situations where F_iN_2O increases LFA with N_2O (9). The H_2O/gas solubility coefficient of N_2O is almost the same as the blood/H_2O coefficient (0.435 and 0.468, respectively) (10). Therefore, in addition to many alternative methods to prevent this change in cuff pressure due to N_2O, it has been shown that inflation of the tracheal cuff with H_2O or saline reduces tracheal mucosal injury and morbidity by reducing cuff pressure (11).

The primary purpose of the present study was to compare ETT cuff pressures following inflation of ETT cuffs with air and saline during LFA with N_2O. The secondary aim of our study was to investigate the effects of ETT tube cuffs inflated with these two different substances on postoperative sore throat.

METHODS

The study was carried out at the Department of Anesthesiology and Reanimation between May 2016 and July 2016. Approval from the KTU Medical School Local Ethics Committee (no. 2016/40) was obtained. Written informed consent was obtained from all patients. Patients in the American Society of Anesthesiologists (ASA) I–II risk group aged 18–65 years who maintained a neutral position of the head and the neck, who had no known laryngeal or tracheal defects, and who were scheduled to undergo general surgery and orthopedic and plastic surgery in our hospital's operating room with an expected surgery duration of 60–180 min were included in the study.

Patients with any neurological or psychiatric disorder, severe cardiovascular or respiratory disease, history of smoking, history of upper respiratory tract infection within the last 10 days prior to the operation for which they had been prescribed medication, morbid obesity, allergies to anesthetic agents to be used, alcohol or drug addiction, and lung complications such as chronic obstructive pulmonary disease were excluded in the study owing to potential complications with intubation and tracheotomy. Patients with a history of malign hypothermia whose surgery could take less than 60 min and longer than 180 min, who would require surgery in the Trendelenburg and reverse Trendelenburg position, or would not be intubated successfully in one attempt owing to unexpected complications with intubation (Cormack Lehane scores 3 and 4) were also excluded.

In the present study, high-volume and low-pressure ETTs (Haiyan Kangyuan Medical, Haiyan, China) were used. All the tubes were checked for leaks before being used. As a result of the "power analysis" conducted, the number of patients was 60 in a power range of 80% and a confidence interval of 95%. Patients included in the study were randomized into two groups whereby, following endotracheal intubation, the cuff pressures of ETTs were inflated randomly with saline (Group S, n=30) and air (Group A, n=30) using the closed envelope method.

Patients admitted into the operation room were intravenously administered 2 mg of midazolam as premedication. After the patients were taken to the operating table, electrocardiogram, peripheral oxygen saturation (SpO_2), non-invasive arterial pressure (Spacelabs Healthcare, WA, USA), BIS (Aspect Medical Systems, Inc., Newton, MA, USA), and Train-of-Four (TOF) (TOF-Watch SX, Dublin, Ireland) were applied for standard monitoring. Cuff pressure follow-ups were performed with a cuff pressure manometer (VBM Medizintechnik GmbH, Neckar, Germany).

After pre-oxygenation with 100% oxygen for 3 min, 2–3 mg/kg of propofol and 1–1.5 µg/kg of fentanyl were administered for anesthesia induction, and 0.6 mg/kg of rocuronium was administered for neuromuscular blockade. Laryngoscopy was performed after bispectral index (BIS) scores decreased below 60 (Macintosh blade no. 3 or 4). The ETT procedure was performed by anesthesiologists who had at least 3–4 years of experience. Straight ETTs with internal diameters of 8.0–8.5 mm for male patients and 7–7.5 mm for female patients were used. Tracheal intubation was confirmed by capnography. ETT tube cuff pressures were inflated to 25 cm H_2O using a cuff manometer. In both groups, anesthesia was performed using a mixture of 1:1 oxygen/nitrous oxide, and 2%–3% sevoflurane was administered for the first 10 min at a flow rate of 6 L/min, which was then reduced to 1 L/min. At 10 min before surgery, this was switched to the high-flow rate of 6 L/min, N_2O was turned off, and patients were given 100% oxygen. Fentanyl and rocuronium were administered intermittently to all patients as needed. All patients were ventilated with a tidal volume of 6–8 mL/kg, frequency of 10–12/min, as well as end-tidal CO_2 ($EtCO_2$) of 32–35 mm Hg. For cuff pressures exceeding 40 cm H_2O during follow-up, pressures were reduced again to the initial value of 25 cm H_2O by means of a pressure manometer.

Patients' heart rate (HR), SpO_2, mean arterial pressure (MAP), BIS values, cuff pressure values, $EtCO_2$, inspired O_2 (F_iO_2) and N_2O (F_iN_2O) values, and internal positive end-expiratory pressure (PEEP) and peak airway pressure values were recorded prior to the induction (baseline) at intraoperative intervals of 10 min and just before extubation. In addition, the duration of operation and intubation and maximum cuff pressures were recorded. The depth of intraoperative anesthesia was maintained by maintaining the BIS value between 40 and 60. Without tachycardia and hypertension, the concentration of sevoflurane was titrated to a maximum of 3% with increments of 1% when BIS was >60.

When the TOF was over 25% at the end of the operation, the non-depolarizing muscle relaxant used was antagonized with 0.04 mg/kg of neostigmine + 0.01 mg/kg of atropine. Further, when the respiratory functions were adequate and the cardiovascular findings were stable (TOF >75% and BIS score >80), the patient was extubated after removal of the oropharyngeal secretions. All extubated patients were taken to the postoperative collection unit after operation. After 1 h of monitoring, patients with an Aldrete score of ≥9 were sent back to the service (12). In addition, sore throat with and without swallowing was assessed by external observers at postoperative 2 and 24 h in both groups. In assessing the severity of sore throat, the Numerical Rating Scale (NRS) scoring system (NRS 0, lack of pain and NRS 10, the highest level of pain) was used.

Statistical Analysis

SPSS version 23.0 (SPSS Inc., Chicago, IL, USA) statistical package

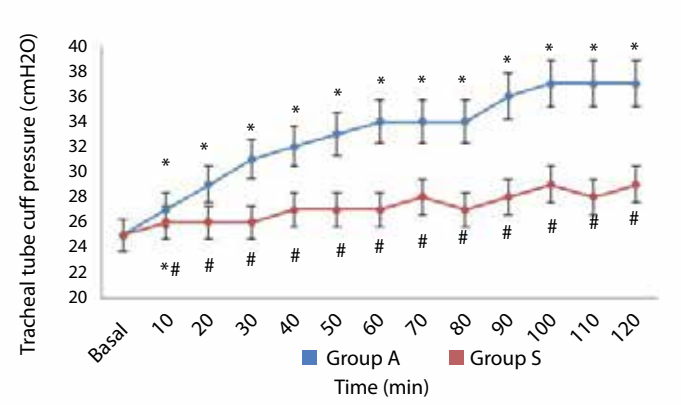

Figure 1. Cuff pressure changes in the groups (Mann–Whitney U test was used for comparison of two inter-group values, whereas Wilcoxon sign test was used for intra-group comparisons). Group A, air; Group S, saline. *Compared with the baseline, p<0.05, #Compared with Group A, p<0.05.

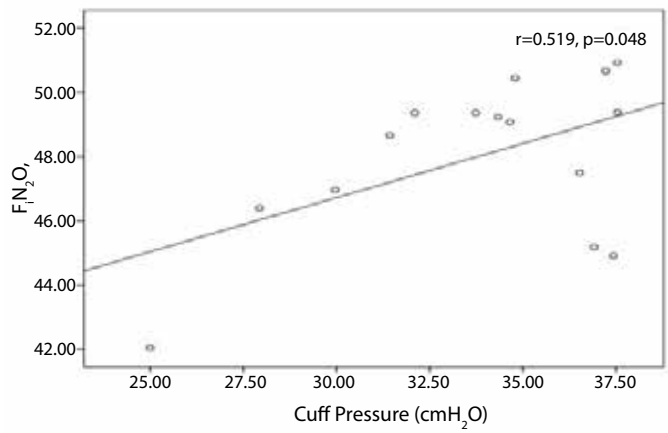

Figure 2. Correlation between cuff pressure and F_iN_2O in Group A. F_iN_2O, inspired fractionated nitric oxide fraction; Group A, air.

Table 1. Patient demographic and intraoperative data.

	Group A n=30	Group S n=30	p
Age (year)	46.33±11.96	46.37±14.84	0.953[a]
Sex (F/M)	14/16	12/18	0.602[b]
Weight (kg)	79.07±16.38	80.70±13.32	0.700[a]
Height (cm)	164.93±8.55	167.33±9.03	0.337[a]
BMI (kg/m^2)	28.67±5.96	28.27±5.93	0.739[a]
ASA (I/II)	10/20	17/13	0.059[b]
Operation time (min)	107.17±26.70	107.67±28.24	0.929[a]
Tracheal entubation time (min)	128.41±28.17	131.56±32.64	0.690[a]

Values indicate mean±SD and numerical values. Mann–Whitney U test and chi-square test were used for comparison.
BMI: body mass index; ASA: American Society of Anesthesiologists; Group A: air; Group S: saline.
[a,b]There is no statistically significant difference between the groups (p>0.05).

program was used. Mean values and standard deviations (SDs) were used for statistical analysis. Numbers and percentages were used to summarize qualitative data in the evaluation of the findings obtained in the study. Data were assessed using descriptive statistical methods (frequency, percentage, and SD). The chi-square test was used to compare Group S and Group A variables (e.g., ASA and gender) that are not measurable.

The Kolmogorov–Smirnov distribution test was performed to verify suitability in terms of the measurable variables (e.g., age, weight, BMI, duration of operation, tracheal intubation time, cuff pressure, sore throat scores) for Group S and Group A. The non-parametric Mann–Whitney U test was used for independent groups to compare the two groups, whereas the non-parametric Wilcoxon sign test was used for dependent groups to examine the intra-group changes as each variable was found to be p<0.05. A Spearman correlation analysis test was performed to investigate the interrelationships between measurements.

The results were evaluated within the 95% reliability index with p<0.05 being significant.

RESULTS

A total of 60 patients completed the study. Table 1 shows the comparative analysis of some demographic and intraoperative data between the two groups of patients. There was no statistically significant difference between the groups.

There was no significant difference between the groups when the mean HR, MAP, SpO_2, BIS, and $EtCO_2$ measurements of patients were compared during follow-up of the patients (baseline, intubation, 10 min, 20 min, 30 min, 40 min, 60 min, 70 min, 80 min, 90 min, 100 min, 110 min, 120 min, and extubation) (Mann–Whitney U test, p>0.05). The cuff pressures were significantly higher in Group A than in Group S in all follow-up periods (Mann–Whitney U test, $p_{10\ min}$=0.02, other periods p<0.0001; Figure 1). In Group A, cuff pressures were significantly higher than baseline values during intubation for all follow-up periods (Wilcoxon sign test, p<0.0001; Figure 1), whereas they were significantly high only at 10 min in Group S (Wilcoxon sign test, p<0.05). Maximum cuff pressures were significantly higher in Group A than in Group S (37.60±3.16 and 29.96±3.34, respectively, Mann–Whitney U test, p<0.0001). There was no significant difference between the groups during the follow-up periods (Mann–Whitney U test, p>0.05) in terms of changes in F_iO_2, F_iN_2O, internal PEEP, and peak airway pressures. In Group A, there was a strong, positive correlation of 51.9% between cuff pressures and F_iN_2O (r=0.519, p=0.048, Spearman correlation analysis, Figure 2).

Figure 3 shows the postoperative sore throat scores of groups with and without swallowing. Compared with Group S, the sore throat scores of patients in Group A at postoperative 2 (0.633±0.765 and 2.167±0.986, respectively, Mann–Whitney U test, p=0.000) and 24 (0.167±0.461 and 1.533±1.137, respectively, Mann–Whitney U test, p=0.000) h were significantly higher while swallowing.

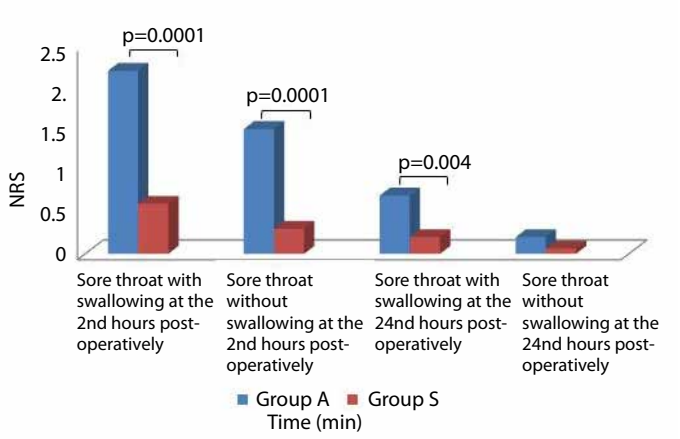

Figure 3. Sore throat scores with and without swallowing in the postoperative period (Mann–Whitney U test was used for comparison). NRS, Numerical Rating Scale; Group A, air; Group S, saline.

DISCUSSION

In our study, we found that during low-flow N_2O anesthesia, ETT cuff pressures were lower in the saline-inflated group than in the air-inflated group, and that the sore throat frequency was lower in the postoperative period.

Laryngotracheal complications due to ETT can even be observed in short operations. Although the pathophysiology of airway complications after intubation has not yet been fully elucidated, it has been reported that the main factor causing tracheal morbidity may lead to postoperative sore throat, hoarseness, difficulty in swallowing, coughs, and tracheal ruptures due to high cuff pressure and volume (13–16). In addition, cuff pressure is affected by many factors such as tracheal diameter, laparoscopic surgery, patient positions such as Trendelenburg and reverse Trendelenburg, use of N_2O during operation, as well as high-flow or LF anesthesia (9, 17–19).

It is often recommended to maintain the cuff pressures between 20 and 30 cm H_2O during the intraoperative period (20, 21). The mucosal perfusion of the trachea is known to begin to deteriorate when the cuff pressure exceeds 30 cm H_2O, and the tracheal circulation is completely blocked when the pressure exceeds 60 cm H_2O (22). In a study conducted by Bernhard et al. (23) on humans, cuff pressures greater than 50 cm H_2O cause ischemic changes to the trachea wall within 15 min. Another study by Segobin et al. (22) concluded that a cuff pressure greater than 50 cm H_2O will result in total occlusion of the tracheal blood flow. We also sought to prevent the harmful impact of high pressures on the tracheal mucosa by maintaining it within normal limits through follow-up every 10 min.

In the practice of anesthesia, room air is frequently used to inflate the endotracheal cuff, creating an air-filled gap in the body. N_2O is approximately 35 times more soluble in blood than nitrogen (blood/gas solubility coefficient for N_2O/N_2 is 0.468/0.013) (24). For this reason, it diffuses easily from the blood into air-containing gaps such as the endotracheal cuff. It has been shown through many in vivo and in vitro studies that N_2O, which is frequently used as an analgesic agent in general anesthesia, causes an increase in the pressure and volume of the cuff by diffusing into the cuff (9, 25). In a gas analysis conducted by Stanley on intubated patients with ETT cuffs, it was shown that the change of volume in the cuff is caused by N_2O diffusion in 76%–88% of cases, oxygen in 2%–10% of cases, and heat difference in the remaining cases (26).

Intraoperative cuff pressure changes have been generally examined through high-flow anesthesia, and not many studies were found that were conducted using LFA. LFA is used to describe inhalation anesthesia techniques in which at least 50% of exhaled air is breathed by patients in a semi-closed system (27). Interest in LFA has increased steadily owing to better gas conditioning and its economic and ecological benefits (7). In addition, LFA has been reported to reduce microatelectasis and protect against postoperative pulmonary complications through heating and humidification of gases (28, 29).

In LFA with N_2O, F_iN_2O increases (7, 8) owing to the slowing of the N_2O uptake during low flow after the initial high flow (7, 8). In a study by Postaci et al. (9) comparing air-inflated endotracheal pressures in high- and low-flow N_2O anesthesia, it was found that F_iN_2O is higher in the LFA group, and that cuff pressures in the low-flow period between 10 and 90 min in the postoperative stage are significantly higher. We also used the LFA for both groups in our study and found no significant difference between the F_iO_2 and F_iN_2O values in saline- and air-inflated groups depending on the constant flow rate. In addition, we believe that there is a positive correlation between F_iN_2O and the cuff pressures in Group A, which is the reason for the higher cuff pressures in the air-inflated group. The rate of volume increase is dependent on the N_2O diffusion coefficient of the cuff material, whereas the amount of volume increase in the cuff is dependent on inspired N_2O, cuff compliance, cuff inflation volume, N_2O gradient in the cuff, and inspired gas (30, 31). Cuff pressures higher than 40 cm H_2O were observed in 91% of postoperative patients after N_2O anesthesia, whereas they were reported in 45% of patients for other general anesthesia methods (5). In addition, the increase in cuff pressure owing to the use of LFA for N_2O was an expected result.

An attempt to reduce the frequency of sore throats in the postoperative period was made through the inflation of the cuff with N_2O/oxygen mixture (6), use of different shaped cuffs (4, 32), and inflation of ETT cuffs with saline (25), distilled H_2O (33), and N_2O (34) in order to prevent ETT cuff pressure increase during N_2O anesthesia.

Since the H_2O/gas and blood/gas solubility coefficients of N_2O are almost equal (0.468/0.435), inflation of ETT cuffs with saline or distilled H_2O minimizes cuff pressure and volume variation (24, 33, 35). Combes et al. (25) investigated intra-operative cuff pressure changes, tracheal mucosal changes, and postoperative complications by inflating endotracheal cuffs with air and saline in 50 patients for whom N_2O was administered for maintenance of anesthesia; they saw that cuff pressures were stable in the saline group, whereas there was a considerable increase in the air group, reaching over 40 cm H_2O during anesthesia. Ahmad et al. (33) compared cuffs inflated with air and distilled H_2O in a study where they investigated changes in cuff pressures in patients given N_2O anesthesia before elective abdominal and extremity surgeries. They observed that ETT cuffs inflated with distilled H_2O during N_2O anesthesia were significantly lower during the procedure than the air-inflated group. Similarly, we found that ETT cuff pressures in the saline-inflated group were significantly lower than those in the air-inflated group.

Sore throat is a common complication after ETT. Studies show that the frequency of sore throat after ETT is between 14% and 57% (32, 36-38). Sore throat observed in the postoperative period after ETT is influenced by many factors such as age and gender of the patient, ETT diameter, cuff design, number of intubation attempts, professional competency of the anesthesiologist performing the operation, blood pressure, and movement of the ETT during surgery (17). It is known that the underlying cause behind the frequency of sore throats is the fact that the high volume of cuffs comes in contact with the trachea across a larger area. In a study by Loeser et al. (39), cuffs with a high volume and low pressure have been shown to cause more damage to the tracheal mucosa. In a study in which Chang et al. (32) investigated the effect of different cuff shapes on postoperative sore throat, they found a decrease in sore throat in the postoperative period as the cuff's contact with the tracheal mucosa decreases.

Calder et al. (40) investigated the frequency of postoperative sore throat in pediatric surgeries with an average of 60 min long general anesthesia as another cause of sore throat. In their study, an increase in ETT cuff pressures resulted in a postoperative sore throat frequency of 0 cm H_2O at 0%–10%, 11–20 cm H_2O at 4%, 21–30 cm H_2O at 20%, and 31–40 cm H_2O at 68%, and the ETT cuff pressure increased by >40 cm H_2O at 96%. In their study, we have found that a sudden increase in sore throat is observed especially at cuff pressures above 30 cm H_2O.

Combes et al. (25) observed that tracheal cuff pressures and tracheal mucosal injury are higher in the air-inflated group than in the saline-inflated group during N_2O anesthesia, and that this was associated with the development of sore throat in the postoperative period. In our study, the cuffs were inflated with saline to prevent postoperative sore throat due to increased air pressure and increased contact of the cuff with the tracheal mucosa on account of N_2O switching to the air-inflated cuff in the LFA technique involving N_2O. As a result, we found that inflation of ETT tube cuffs with saline for the N_2O LFA technique prevented the increase of cuff pressure and decreased the frequency of sore throat in the postoperative period.

Our study has some limitations. First, although the cuff manometer used in the present study is widely used in other studies, there are 2 cm H_2O sections on the device. Although it does not cause major differences, the device cannot precisely detect cuff pressure changes lower than 2 cm H_2O. Second, anatomic structures such as the internal diameters of the trachea and glottis differ according to geographical regions. Studies have shown that there are differences with regard to the internal diameters of the subglottis and upper trachea in Indian and Western populations (41). Since the present study is a single-center study, the results are limited to a particular region. For this reason, multicenter studies are needed. Third, in the present study, evaluation of sore throat in the postoperative period was carried out using subjective methods, not with direct or histological methods.

CONCLUSION

There is an increase in cuff pressures due to the increase in F_iN_2O and N_2O diffusion into the cuff during N_2O LFA, especially during the low-flow period. In our study, we found that the increase in ETT cuff pressures for N_2O LFA in the air-inflated group was prevented through inflation with saline, and that the frequency of sore throat was much lower in the postoperative period.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Karadeniz Technical University School of Medicine (04.05.2016/24237859-40).

Informed Consent: Written informed consent was obtained from all participants who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.B., G.E.; Design - A.B., G.E.; Supervision - A.B., G.E.; Resource - A.B., G.E.; Materials - A.B., G.E.; Data Collection and/or Processing - A.B., G.E.; Analysis and/or Interpretation - A.B.; Literature Search - A.B.; Writing - A.B., G.E.; Critical Reviews - A.B., G.E.

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Conflict of Interest: The authors have no conflict of interest to declare.

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