EAJM 2011; 43: 92-8

The Eurasian Journal of Medicine

Original Article

Comparison of the Coaxial Circle Circuit with the Conventional Circle Circuit

Konvansiyonel Sirküler Sistemle Koaksiyel Sirküler Sistemin Karşılaştırılması

Ayse Mizrak[1], Murat Bilgi[1], Senem Koruk[1], Suleyman Ganidagli[1], Erkan Karatas[2], Unsal Oner[1], Rauf Gul[1], Levent Sahin[1]

[1]Department of Anesthesiology and Reanimation, Faculty of Medicine, Gaziantep University, Gaziantep, Turkey
[2]Department of Ear Nose and Throat (ENT), Faculty of Medicine, Gaziantep University, Gaziantep, Turkey

Abstract

Objective: The coaxial circle system helps prevent heat loss during surgery, and it also acts as a humidifier. This study aimed to compare the coaxial breathing system and the conventional system in their ability to warm and moisturize inhaled gases, and we also analyzed lung function protection and saccharin clearance time in patients who underwent tympanomastoidectomy (TMT) with the aid of these two systems.

Materials and Methods: Forty adult patients of ASA physical status I-II were scheduled for elective TMT. A standard volume-dependent ventilator setting was used to establish normocapnia. The coaxial circle system was used in the treated group (n=20), whereas the conventional circuit system was used in the control group (n=20). Saccharin clearance, VC (vital capacity), FRC (functional residual capacity), FEV_1 (forced expiratory volume in 1 second), airway pressure, relative humidity and temperature of inspired gas, body temperature and adverse and hemodynamic effects were measured at different perioperative periods.

Results: The relative humidity (mg H_2O Lt -1) of inspired gas in the treated group was higher than in the control group at 5, 15, 30, 45, 60 and 90 minutes after anesthesia induction. The temperature of inspired gas (Centigrade) in the treated group was higher than in the control group ($p<0.05$) after 5, 10, 15, 30, 45, and 90 minutes of anesthesia. Postoperative saccharin clearance time was lower than before the operation in the treated group ($p<0.05$). Postoperative FRC was lower than preoperative FRC in the study and control groups ($p<0.05$).

Conclusion: The coaxial circle system decreased postoperative saccharin clearance time and increased postoperative FRC, relative humidity and the temperature of inspired fresh gas, without any adverse perioperative effects in patients who underwent TMT.

Key Words: Coaxial circle system, Standard circle system, Tympanomastoidectomy, Pulmonary function tests, Saccharin clearance test

Özet

Amaç: Koaksiyel halka sisteminin kullanılması cerrahi sırasındaki ısı kaybını önler. Ki o bir nemlendirici olarak rol oynar. Bu çalışma timpanomastoidektomi (TMT) operasyonu geçiren hastalarda Konvensiyonel sistem ve koaksiyel sistemin, sakarin klirens zamanı ve akciğer fonsiyon testlerinin korunması ve inhale edilmiş gazın ısınma ve nemlenmesinin karşılaştırılmasını amaçlamıştır.

Gereç ve Yöntem: Elektif timpanomastoidektomi yapılan ASA I-II fiziksel statüsünde yetişkin 40 hasta seçildi. Normokapniyi sağlamak için standart volüm ayarlı ventilatör kullanıldı.Tedavi grubunda (n=20), koaksiyel halka sistemi,kontrol grubunda (n=20) Konvensiyonel halka sistemi kullanıldı. Farklı peroperatif dönemlerde, Sakkarin klirens zamanı, VC, FRC, FEV_1, hava yolu basıncı, inhale edilmiş gazın ısısı ve nisbi nemi, vücut ısısı hemodinamik etkiler ve yan etkiler ölçüldü.

Bulgular: İnspire edilmiş gazın nisbi nemi anestezinin 5, 10,15, 30, 45 ve 90. dakikalarında tedavi grubunda kontrol grubundan daha yüksek bulundu. İnspire edilmiş gazın ısısı anestezinin 5, 10,15, 30, 45 ve 90. dakikalarında tedavi grubunda kontrol grubundan daha yüksek bulundu ($p<0.05$). Tedavi grubunda postoperatif sakkarin klirens zamanı preoperatif değerden daha düşük bulundu ($p<0.05$). Çalışma ve kontrol grubunda postoperatif FRC preoperatif FRC'den daha düşüktü.

Sonuç: TMT yapılan hastalarda Koaksiyel halka sistemi herhangi bir peroperatif yanetki yapmadan Postoperatif sakkarin klirens zamanını azaltmış, inspire edilmiş taze gazın postoperatif FRC'yi, nisbi nemini ve ısısını arttırmıştır.

Anahtar Kelimeler: Akciğer fonsiyon testleri, Koaksiyel halka sistemi, Sakkarin klirens testleri, Standart halka sistemi, Timpanomastoidektomi

Received: May 11, 2011 / **Accepted:** July 07, 2011

Correspondence to: Murat Bilgi, Department of Anesthesiology and Reanimation, Faculty of Medicine, Gaziantep University, Gaziantep, Turkey
Phone: +90 505 374 50 59 Fax:+90 342 360 22 44 e-mail: drmuratbilgi@gmail.com

doi:10.5152/eajm.2011.21

Introduction

A number of previous investigations have demonstrated the adverse effects of inadequate heat preservation and suboptimal humidification of inspired gases. The importance of delivering warm, humidified gas to patients ventilated through an endotracheal tube is widely accepted. Adequately maintaining the moisture and temperature of inhaled gases during anesthetic procedures and analyzing lung function protection and saccharin clearance time are critical for preventing perioperative respiratory complications. Mechanical ventilation with endotracheal intubation bypasses the upper airway and the process of providing heat and moisture to inspired gases. A continuous loss of moisture and heat occurs during the procedure, and this predisposes patients to serious airway damage. Deleterious findings include retardation of the mucociliary escalator [1-3] heat loss and morphological damage to the tracheobronchial epithelium. Effective mucociliary activity is the ability of respiratory mucosal surfaces to remove foreign particles, keep the mucosal surfaces moist and fresh and regularly replenish airway fluids. The mucous and ciliary system can be assessed by measuring mucociliary clearance [4-6]. Ciliary function is related to temperature, osmotic pressure, acidity (pH), surgery, infections, and genetic and iatrogenic factors. Abnormal ciliary function may result in chronic sepsis of the upper and lower airways [7-9]. Changes in pulmonary function associated with inadequate humidity include reductions in pulmonary compliance and functional residual capacity and increases in pulmonary shunting, hypoxemia and atelectasis.

In patients with normal lung function, few clinically relevant adverse effects are seen after short-term anesthesia [10]. Despite the additional cost, humidification may be provided using the circle system with a heat modifier or a heat and moisture exchanger [11]. However, vaporizing humidifiers have several disadvantages, including water condensation that can cause infection, a high maintenance cost, and an increased workload for nursing staff [12]. Several attempts have been made to find a solution for retaining heat and humidity in inspired gases. The moisture output aspect of the circle system has been improved with the use of a coaxial circle system [13]. Chalon et al. reported that this system preserved normal surfactant activity, helped keep secretions liquefied and reduced heat loss [14].

In the present study, we compared a coaxial circle system with a traditional circle system in terms of moisture output and the effects on saccharin clearance time of the upper airway, vital capacity (VC), functional residual capacity (FRC), forced expiratory volume (FEV_1), airway pressure and the ability to moisturize and heat inspired gas in patients who underwent TMT during normal gas flow anesthesia.

Materials and Methods

The study was performed in accordance with the most recent version of the Helsinki Declaration. After approval by the Institutional Ethics Committee, we obtained written informed consent from the patients prior to their enrollment in the study. Forty adult patients of ASA physical status I-II and age 18-42 years were scheduled for elective TMT under general anesthesia. The study took place from August 2007 to January 2009. The following patients were excluded from the study: those who did not consent to participation in the study; patients having problems with communication and taste; pregnant women; patients with acute or chronic upper or lower airway infection; those taking regular analgesics; those suffering from acute or chronic pain syndromes or respiratory infections; those taking sedative medications within 24 hours prior to surgery; patients sensitive to propofol, lidocaine or fentanyl; patients with heart blocks, heart failure, diabetes mellitus; and those with hepatic, pulmonary, or neurological disease, or psychiatric illness.

Forty adult patients of ASA physical status I-II were scheduled for elective tympanomastoidectomy. A randomization list was prepared using a random number function on a computer spreadsheet. Patients were assigned to one of two study groups. No patient was premedicated. A standard ventilator setting was used to establish normocapnia. A coaxial circle system was used in the treated group (n=20), and a conventional circle system was used in the control group (n=20). After the patients were taken to the operating room, standard measures including electrocardiography, non-invasive blood pressure (MAP), $EtCO_2$ and pulse oximetry were monitored (Monitor; Siemens SC 7000, Sweden). Before anesthesia induction, a BIS-XPTM monitoring electrode was placed on the patient's forehead after careful cleaning of the skin according to the manufacturer's instructions and was attached to a BIS-XPTM monitor (Aspect Medical Systems, Newton, MA, USA). Twenty coaxial circle systems were used for the treated group. The breathing system was attached to the anesthesia machine (Excel 410, Datex-Ohmeda, Hatfield, UK) according to the manufacturer's instructions, and the adjustable pressure-limiting valve was fully closed. A fresh gas flow of 6 L/min oxygen was used to fill the reservoir bag, while the inner tube was occluded with an inter-surgical testing device, until the pressure indicated by the machine's in-circuit pressure gauge reached 30 cmH_2O. Fresh gas flow was then reduced to the anesthesia machine's minimum (250 mL/min). The breathing system was considered intact if pressure was maintained at 30 cmH_2O for 5 seconds; the breathing system was deemed faulty if the pressure failed to reach 30 cmH_2O or was not maintained for five seconds [15]. Relative humidity and temperature were measured at the endotracheal tube at 5 minutes and again at 30 minutes with a hygrometer (Drager, Serial No: 044936, model 5204644-A4). A 20-gauge cannula was inserted in the dorsum of the hand, and isotonic saline solution was infused at a rate of 300 ml/h. After preoxygenation at 4 L/min for 1-2 minutes, propofol 2-2.5 mg/kg (Propofol 1% Fresenius, 10 mg/ml), fentanyl 1 µg/kg (Fentanyl-Janssen, 5 ampoules, 0.05 mg/ ml) and rocuronium 0.5 mg/kg (Rocuronyüm bromur, Esmeron, Organon, Oss, Holland) were given to each patient, and tracheal intubation was performed. Anesthesia was maintained with sevoflurane with 4 L/min of 50% oxygen and 50% nitrous oxide. Mechanical ventilation was provided at a tidal volume of 8 ml/kg at a respiratory rate required to maintain end-tidal carbon dioxide concentration ($PEtCO_2$) at 35 to 40 mmHg. The BIS index was maintained between 40 and 50 during general anesthesia. End-tidal concentrations were measured using a cannula near the connector of the tracheal tube. Mucociliary clearance time was measured by a saccharin test in both groups immediately before anesthesia induction and 12 h after anesthesia delivery. The mucociliary clearance test was performed at room temperature with the patient sitting and the patient's head in an upright position. First, the patient was asked to clean his/her nasal secretions. With the help of port cotton, ¼ of a saccharin tablet was placed into one of the patient's nasal cavities 1 cm posterior to the anterior border of the medial surface of the inferior turbinate. The patient was asked not to sneeze or sniff. The duration (measured to the nearest minute) that the patient could taste saccharin when swallowing was recorded as the clearance time [1]. Saccharin clearance time, vital capacity (VC), functional residual capacity (FRC) and forced expiratory volume (FEV_1) were measured using a spirometer (SpiroAnalyzer ST-75, Fukuda Sangyo Co., ltd extech instruments digital psychrometer, model RH390) and recorded during the preoperative period and at 12 minutes postoperation. MAP, HR, $EtCO_2$, SPO_2, BIS, airway pressure, relative humidity and temperature of inspired and expired gas, body and operating room temperature and the duration of anesthesia and surgery were recorded at baseline and intraoperative minutes 0, 5, 10, 14, 30, 45, 60, 90 and 120. In addition, patients were observed during the recovery time, and adverse perioperative respiratory effects, hypertension (MAP>120 mmHg), hypotension (MAP<60 mmHg), bradycardia (HR<50 beats/ min), tachycardia (HR>100 beats/min), hypoxemia (defined as $SPO_2 \leq 90\%$), and postoperative nausea, vomiting, coughing, straining, and fever (body temperature> 37.2°C) were noted if present during the 2-hour postoperative period. All values were assessed by one anesthesiologist. Recovery time was recorded as the time from the end of volatile anesthetic administration until verbal communication.

Statistical analysis

According to data obtained in a previous study according to pre-postoperative FRC, alpha=0.05 and a power of 95%, a study population of 36 subjects (PS Power and Sample Size Calculation, version 2.1.30, 2003) would be appropriate for statistical analysis. The study results were evaluated using the SPSS statistical analysis package (Statistical Package for Social Sciences, Release 15.0 for Windows). Data are presented as the means±SD. Statistical significance was reported for p values <0.05. Multiple comparisons were evaluated with a paired sample t-test. Inter-group differences in demographic data, duration of anesthesia and surgery, recovery time, preoperative and postoperative VC, FRC, FEV_1 and saccharin clearance time, intraoperative room moisture, intraoperative room and body temperature, intraoperative airway pressure, intraoperative and postoperative hemodynamic data (MAP, HR), SPO_2, $EtCO_2$ and duration of surgery were evaluated using the Mann Whitney U-test.

Results

Demographic characteristics (age, sex, weight, height, BMI, and ASA physical status), anesthesia duration and surgery recovery time were similar between the groups. The incidence of smoking was similar in the treated and control groups (Table 1). No differences were found between the groups regarding preoperative and postoperative VC, FRC, or FEV_1. Additionally, there was no difference between the groups in terms of room moisture, room and body temperature, or intraoperative airway pressure. Postoperative saccharin clearance time was lower than before the operation in the treated group. Preoperative FRC was higher than postoperative FRC in the control (p=0.0001, Table 2) and treated groups (p=0.0001, Table 2). The moisture content and temperature of expired gas in the treated and control groups were similar (p<0.05, Table 2). The incidence of hypertension, hypotension, bradycardia, tachycardia, nausea, vomiting, coughing, straining, and fever were similar between the groups during the 2-hour postoperative period. Only one patient in the treated group was given ephedrine (10 mg intravenously) for hypotension.

The moisture of inspired fresh gas in the treated group was higher than in the control group at 5, 15, 30, 45, 60 and 90 min after anesthesia induction (p<0.05, Figure 1). The moisture and temperature of expired gas were similar between the control and treated groups. The temperature of inspired fresh gas in the treated group was higher than the control group after 5, 10,15, 30, 45, and 90 min of anesthesia (p<0.05, Figure 2). Hemodynamic data including MAP, HR, $EtCO_2$, and SPO_2 were similar in the treated and control groups during the 120-minute intraoperative period (Figure 2).

Table 1. Demographic Data, Duration of Anesthesia (min), Duration of Surgery (min), Recovery Time (min) of the Groups

	Study Group (n=20)	Control Group (n=20)	p
Age (year)	28±11	31±11	NS
BMI (Body Mass Index) (kg/m_2)	24.1±3.9	25.1±5.4	NS
Gender (M/F)	9/11	10/10	NS
Smoking (%) (n)	35 (7)	25 (4)	NS
Duration of Anesthesia (minute)	150±31	147±35	NS
Duration of Surgery (minute)	137±30	138±21	NS
Recovery time (min)	7±3.5	8±3.4	NS

n= 20, p>0.05 when compared with the control group, NS: Non significant

Table 2. The VC, FRC, FEV_1, Saccharin Clearance, the Moisture (mg H_2O/Lt), Temperature (oC) Values and Intraoperative Airway Pressure of the Patients

	Study Group (n=20) mean±SD	Control Group (n=20) mean±SD	p
Preoperative VC (Liter)	2±0.8	2±0.9	NS
Postoperative VC (Liter)	1.9±0.9	2±0.9	NS
Preoperative FEV_1 (Liter)	1.2±0.7	1.3±0.6	NS
Postoperative FEV_1 (Liter)	1.1±0.6	1.2±0.6	NS
Preoperative FRC (Liter)	2.5±1.1	2.6±1.2	NS
Postoperative FRC (Liter)	2.3±0.9*	2.2±1.1*	0.0001
Preoperative saccharin clearance (Min)	13.2±4.5*	15.6±2.9	0.0001
Postoperative saccharin clearance (Min)	8.2±3	12.1±4.2	NS
The Moisture of Expired gas (mg H_2O/Lt)	76.9±10.1	79.2±4.1	NS
The Temperature of Expired gas (°C)	24.0±4	26.8±3.7	NS
The Room Moisture (mg H_2O/Lt)	30±10.6	30.7±5.1	NS
Room Temperature (°C)	20.1±5.2	22.5±1.4	NS
Body (Core) Temperature (°C)	36.2±0.2	36±0.3	NS
Intraoperative Airway Pressure (CmH_2O)	19±4.2	21.6±4.1	NS

n=20 VC (Vital Capacity), FRC (Functional Residual Capacity), FEV_1 (Forced Expiratuvar volume at 1.st. second). NS: Non significant, *p<0.05 The postoperative FRC and the postoperative saccharin clearance when compared the preoperative values in the both group

Discussion

In the present study, we found that the coaxial circle system (Figure 3) decreased saccharin clearance time and increased postoperative FRC as well as the relative humidity and temperature of inspired fresh gas in patients who underwent TMT, without any perioperative adverse effects. During anesthesia, the absolute humidity of inspired gases is recommended to be >23 mg H_2O/Lt to reduce the risk of respiratory tract dehydration [16]. Bronchial lesions, atelectasis and endotracheal tube occlusion have been clearly described as a result of suboptimal humidification [17, 18]. The risk of atelectasis [19] and the need for suction [20] may be increased upon over-humidification. In previous years, the coaxial design was adapted for circle absorbers [21].

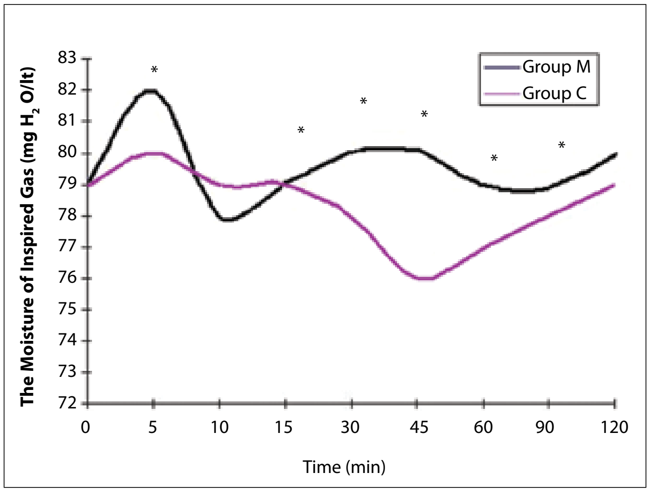

Figure 1. *The moisture (mg H_2O Lt-[1]) of inspired fresh gas of the groups. *p<0.05 when compared with group C at 5, 15, 30, 45, 60 and 90th minutes.*

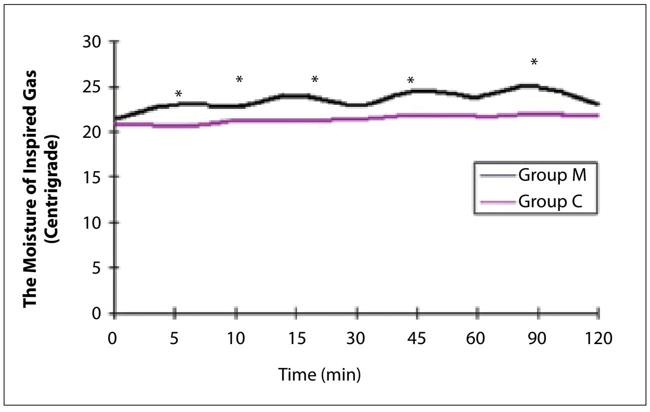

Figure 2. *The temperature (Centigrade) of inspired fresh gas of the groups. *p<0.05 when compared with group C at 5, 10,15, 30, 45, 90th minutes during anesthesia.*

In the present study, because of similarities in room moisture, room temperature, and, in particular, the warmth and moisture content of inspired fresh gas, there was no difference in core temperature between the groups. During general anesthesia, appropriate humidification is advised to ensure normal functioning of the ciliated epithelium of the respiratory tract in adults [22], and the loss of heat and moisture expected when using a coaxial circle system can be prevented [23]. The Universal F breathing system is a coaxial circle system. Inspired gases flow through the inner tube, while warmed expired gases pass via the wider outer tube to the CO_2 absorber. During ventilation, the inspired gas is warmed by the heat produced during CO_2 absorption and by heat exchange with the warmed expired gas. This system also acts as a humidifier. The use of the coaxial circle system helps prevent heat loss during surgery and is an efficient, cost-effective method for maintaining body temperature during surgery [24].

Figure 3. *The Coaxial Circle System. The system allows the expiratory valve to be situated conveniently at the canister end of the expiratory limb. The inspiratory limb encloses a coaxial tube and delivers fresh gas close to the patient, immediately upstream of the inspiratory one-way valve. The benefits of the system are largely independent of respiratory pattern [50].*

In the present study, during approximately 2 hours of anesthesia, the absolute humidity levels of inspired gas were 49.5 and 34.55 mg H_2O/Lt in the treated group and 29.8 and 29.9 mg H_2O/Lt in the control group at 60 and 90 minutes, respectively. The intraoperative temperatures of inspired fresh gas in the treated and control groups were 21.5, 20.5, 20.9, 20.4, 20.5, 24.5°C and 21.0, 20.7, 21.1, 21.2, 21.4, 21.8°C, respectively. Similar to the study by Chalon et al. [25] the humidity figures recorded in the present study are superior to those obtained with the regular adult circle system. In addition, [26] reported that tube and bag systems such as the Mapleson D and its Bain modification have a higher humidity output than the regular circle. The main drawback of these systems is that inhaled CO_2 concentrations may reach unacceptable levels if the fresh gas inflow is too low. In the present study, we provided sufficient fresh gas flow (4 Lt/min) in both groups, and $EtCO_2$ did not reach unacceptably high levels during general anesthesia.

Chalon et al. [13] used coaxial tubes mounted on a modified circle system. The fresh gas inflow could be directed into the inspiratory limb or directly into the lime canister. The humidity delivered by this system varied from 17 to 29 mg H_2O/Lt after a period of stabilization lasting 90 minutes. The addition of a coaxial version raised inspired humidity further [13, 27]. Several animal [28] and human [29] studies have shown that bronchial lesions such as inflammation, epithelial cell injury, and mucociliary clearance impairment may be present after only a few hours of mechanical ventilation with poorly humidified gas. Marfatia and Burton [30] and Marfatia et al. [31] showed extensive damage in the tracheobronchial tree of rabbits that had inhaled dry gases from a tracheal tube. Toremalm et al. [32] had previously shown that administration of dry gases arrested the activity of the mucociliary transport system. Many techniques, such as stroboscopy, photon–electron techniques and phase contrast microscopy, are used to determine ciliary beat frequency [33, 34] and and rhinoscintigraphy is a method used to determine the effectiveness of drug therapy for various nasal pathologies [6, 35]. However, these techniques are too expensive and not suitable for routine use. In this study, although the incidence of smoking was similar in the two groups, postoperative mucociliary clearance times were 8.2±3 min and 12.1±4.2 min in the treated group and control groups, respectively. The saccharin test is one method for measuring mucociliary clearance in the upper airway. A normal saccharin clearance time is 9-17 minutes, and times longer than 25 minutes are considered pathologic. Smoking is another factor that damages the mucociliary clearance process [36, 37]. The changes in viscoelasticity properties of mucous and the ciliotoxic effects of smoking disturbs the mucociliary clearance [36, 38] Yue et al. [39] showed that nasal mucociliary clearance can change as a result of nasal membrane dryness. In the current study, no significant differences were seen between the two groups in preoperative and postoperative VC or FEV_1. The FRC is the lung volume that acts as a reservoir of air for physiological use. This reserve volume is particularly important during periods of apnea that occur during the induction of general anesthesia. The use and positioning of inhaled and intravenous anesthetics influence outward chest wall forces [40]. and humidifying the anesthetic gases may have prevented a change in FRC. Essentially, we hypothesize that the warming involved in the coaxial arrangement may better maintain humidity and temperature and help preserve pulmonary and ciliary function during long procedures such as tympanomastoidectomy. In tracheal-intubated patients, the normal humidification and heat-conserving mechanisms in the nose and upper airway are bypassed. Therefore, the use of heat and moisture exchangers (HME) has become increasingly popular in anesthesia [41]. However, HME may increase the degree of circuit dead space as well as inspiratory and expiratory resistance. Furthermore, the resistance of an HME may increase with the duration of use [42, 43]. Similarly, Pelosi et al. [44] found that the tested HME significantly increased minute ventilation, ventilatory drive, and breathing work during pressure support ventilation. In addition, Kelly et al. [45] reported that the use of an HME may increase artificial airway occlusion. The moisture output aspect of the circle system has been further enhanced with the use of a coaxial circle system [46].

In the present study, adverse effects such as fever, coughing, vomiting and nausea were observed at similar rates in both groups. No patient required any treatment for these temporary side effects. Because an unrecognized disconnection or displacement of the central inner tube could lead to inhalation of expiratory gases, leading to hypercarbia and hypoxemia, the integrity of the coaxial circle system must always be checked visually before initiating general anesthesia [47, 48]. Various tests of central inner tube integrity for coaxial circle systems have been proposed, all of which rely on pressurization of the circuit or creation of a venturi [49].

To some extent, the findings of the present study are limited by the relatively small sample size of 40 patients. A larger sample would provide more reliable data for observation and evaluation. Similar studies with larger patient groups are required to corroborate the findings of the present study.

In conclusion, increased inspired humidity with the coaxial circle system offers many advantages during general anesthesia in adults compared with the conventional circle system, including an increase in FRC, activity of the mucociliary transport system, and the relative humidity and temperature of inspired fresh gas.

Conflict of interest statement: The authors declare that they have no conflict of interest to the publication of this article.

References

1. Deniz M, Uslu C, Ogredik EA, et al. Nasal mucociliary clearance in total laryngectomized patients. Eur Arch Otorhinolaryngol 2006; 263: 1099-104. **[CrossRef]**
2. Kesımcı E, Bercın S, Kutluhan A, et al. Volatile anesthetics and mucociliary clearance. Minerva Anestesiol 2008; 74: 107-11.
3. Nakagawa NK, Franchını ML, Drıusso P, et al. Mucociliary clearance is impaired in acutely ill patients. Chest 2005; 128: 2772-7. **[CrossRef]**
4. Naxakıs S, Athanasopoulos I, Vlastos IM, et al. Evaluation of nasal mucociliary clearance after medical or surgical treatment of chronic rhinosinusitis. Eur Arch Otorhinolaryngol 2009; 266: 1423-6. **[CrossRef]**
5. Plaza VP, Carrıon VF, Marın PJ, et al. Saccharin test for the study of mucociliary clearance: reference values for a Spanish population. Arch Bronconeumol 2008; 44: 540-5.
6. Uslu H, Uslu C, Varoglu E, et al. Effects of septoplasty and septal deviation on nasal mucociliary clearance. International journal of clinical practice 2004; 58: 1108-11. **[CrossRef]**
7. Bush A, Cole P, Harırı M, et al. Primary ciliary dyskinesia: diagnosis and standards of care. Eur Respir J 1998; 12: 982-8. **[CrossRef]**
8. Tsang KW, Rutman A, Kanthakumar K, et al. Haemophilus influenzae infection of human respiratory mucosa in low concentrations of antibiotics. Am Rev Respir Dis 1993; 148: 201-7.
9. Yang J, Lıu B, Cao Z. The effects on nasal mucociliary clearance system of excising partial inferior turbinectomy with HUMMER or microwave. Lin Chung Er Bi Yan Hou Tou Jing Wai Ke Za Zhi 2007; 21: 213-6.

10. Chalon J, Tayyab MA, Ramanathan S. Cytology of respiratory epithelium as a predictor of respiratory complications after operation. Chest 1975; 67: 32-5. [CrossRef]
11. Branson RD, Davıs K Jr, Campbell RS et al. Humidification in the intensive care unit. Prospective study of a new protocol utilizing heated humidification and a hygroscopic condenser humidifier. Chest 1993; 104: 1800-5. [CrossRef]
12. Craven DE, Goularte TA, Make BJ. Contaminated condensate in mechanical ventilator circuits. A risk factor for nosocomial pneumonia? Am Rev Respir Dis 1984; 129: 625-8. [CrossRef]
13. Chalon J, Simon R, Ramanathan S, et al. A high-humidity circle system for infants and children. Anesthesiology 1978; 49: 205-7. [CrossRef]
14. Chalon J, Loew DA, Malebranche J. Effects of dry anesthetic gases on tracheobronchial ciliated epithelium. Anesthesiology 1972; 37: 338-43. [CrossRef]
15. Szypula KA, Ip JK, Bogod D, et al. Detection of inner tube defects in co-axial circle and Bain breathing systems: a comparison of occlusion and Pethick tests. Anaesthesia 2008; 63: 1092-5. [CrossRef]
16. Kleemann PP. Humidity of anaesthetic gases with respect to low flow anaesthesia. Anaesth Intensive Care 1994; 22: 396-408.
17. Cohen IL, Weınberg PF, Feın IA, et al. Endotracheal tube occlusion associated with the use of heat and moisture exchangers in the intensive care unit. Crit Care Med 1988; 16: 277-9. [CrossRef]
18. Martin C, Perrin G, Gevaudan MJ, et al. Heat and moisture exchangers and vaporizing humidifiers in the intensive care unit. Chest 1990; 97: 144-9. [CrossRef]
19. Willıams RB. The effects of excessive humidity. Respir Care Clin N Am 1998; 4: 215-28.
20. Maggiore SM, Lellouche F, Pıgeot J, et al. Prevention of endotracheal suctioning-induced alveolar derecruitment in acute lung injury. Am J Respir Crit Care Med 2003; 167: 1215-24. [CrossRef]
21. Bain JA, Spoerel WE. A streamlined anaesthetic system. Canadian Anaesthetists' Society journal 1972; 19: 426-35. [CrossRef]
22. Kleemann PP. The climatisation of anesthetic gases under conditions of high flow to low flow. Acta Anaesthesiol Belg 1990; 41: 189-200.
23. Enlund M, Wiklund L, Lambert H. A new device to reduce the consumption of a halogenated anaesthetic agent. Anaesthesia 2001; 56: 429-32. [CrossRef]
24. Sessler DI, Sessler AM, Hudson S, et al. Heat loss during surgical skin preparation. Anesthesiology 1993; 78: 1055-64. [CrossRef]
25. Chalon J, Kao ZL, Dolorico VN, et al. Humidity output of the circle absorber system. Anesthesiology 1973; 38: 458-65. [CrossRef]
26. Ramanathan S, Chalon J, Capan L, et al. Rebreathing characteristics of the Bain anesthesia circuit. Anesth Analg 1977; 56: 822-5. [CrossRef]
27. Chalon J, Goldman C, Amırdivani M, et al. H. Humidification in a modified circle system. Anesth Analg 1979; 58: 216-20. [CrossRef]
28. Williams R, Rankın N, Smith T, et al. Relationship between the humidity and temperature of inspired gas and the function of the airway mucosa. Crit Care Med 1996; 24: 1920-9. [CrossRef]
29. Chalon J, Alı M, Ramanathan S, et al. The humidification of anaesthetic gases: its importance and control. Canadian Anaesthetists' Society journal 1979; 26: 361-6. [CrossRef]
30. Burton JD. Effects of dry anaesthetic gases on the respiratory mucous membrane. Lancet 1962; 1: 235-8. [CrossRef]
31. Marfatia S, Donahoe PK, Hendren WH. Effect of dry and humidified gases on the respiratory epithelium in rabbits. J Pediatr Surg 1975; 10: 583-92. [CrossRef]
32. Toremalm NG. Air-flow patterns and ciliary activity in the trachea after tracheotomy. A method of determination in vitro of the rate of ciliary beat in a tracheal model. Acta Otolaryngol 1961; 53: 442-54.
33. Lındberg S, Runer T. Method for in vivo measurement of mucociliary activity in the human nose. The Annals of otology, rhinology, and laryngology 1994; 103: 558-66.
34. Nuutinen J. Asymmetry in the nasal mucociliary transport rate. The Laryngoscope 1996; 106: 1424-8. [CrossRef]
35. Digiuda D, Galli J, Calcagni ML, et al. Rhinoscintigraphy: a simple radioisotope technique to study the mucociliary system. Clinical nuclear medicine 2000; 25: 127-30.
36. Stanley PJ, Wilson R, Greenstone MA, et al. Effect of cigarette smoking on nasal mucociliary clearance and ciliary beat frequency. Thorax 1986; 41: 519-23. [CrossRef]
37. Tamashiro E, Xiong G, Anselmo-Lima WT, et al. Cigarette smoke exposure impairs respiratory epithelial ciliogenesis. Am J Rhinol Allergy 2009; 23: 117-22. [CrossRef]
38. Gillissen A, Glaab T, Buhl R. Clinical Value of Forced Expiratory Volume in 1 s (FEV(1)) in Chronic Obstructive Pulmonary Disease. Med Klin 2009; 104:119-24. [CrossRef]
39. Yue WL. Nasal mucociliary clearance in patients with diabetes mellitus. J Laryngol Otol 1989; 103: 853-5. [CrossRef]
40. Villars PS, Kanusky JT, Levitzky MG. Functional residual capacity: the human windbag. Aana 2002; 70: 399-407.
41. Henriksson BA, Sundling J, Hellman A. The effect of a heat and moisture exchanger on humidity in a low-flow anaesthesia system. Anaesthesia 1997; 52: 144-9. [CrossRef]
42. Mebıus C. A comparative evaluation of disposable humidifiers. Acta Anaesthesiol Scand 1983; 27: 403-9.
43. Ploysongsang Y, Branson R, Rashkin MC, et al. Pressure flow characteristics of commonly used heat-moisture exchangers. Am Rev Respir Dis 1988; 138: 675-8. [CrossRef]
44. Pelosi P, Solca M, Ravagnan I, et al. Effects of heat and moisture exchangers on minute ventilation, ventilatory drive, and work of breathing during pressure-support ventilation in acute respiratory failure. Crit Care Med 1996; 24: 1184-8. [CrossRef]
45. Kelly M, Gillies D, Todd DA. Heated humidification versus heat and moisture exchangers for ventilated adults and children. Cochrane database of systematic reviews Cochrane Database Syst Rev 2010; 14: 4711. [CrossRef]
46. Chalon J, Patel C, Ramanathan S, et al. Humidification of the circle absorber system. Anesthesiology 1978; 48: 142-6. [CrossRef]
47. Hannallah R, Rosales JK. A hazard connected with re-use of the Bain's circuit: A case report. Canadian Anaesthetists' Society journal 1974; 21: 511-3. [CrossRef]
48. Jellish WS, Nolan T, Kleınman B. Hypercapnia related to a faulty adult co-axial breathing circuit. Anesth Analg 2001; 93: 973-4.
49. Heath PJ, Marks LF. Modified occlusion tests for the Bain breathing system. Anaesthesia 1991; 46: 213-6. [CrossRef]
50. Cook LB, Chakrabarti MK. Circle systems with a coaxial inspiratory limb. Investigation with a lung model. Anaesthesia 1996; 51: 247-54. [CrossRef]