Comparison of the Coaxial Circle Circuit with the Conventional Circle Circuit

Konvansiyonel Sirküler Sistemle Koaksiyel Sirküler Sistem Karşılaştırılması

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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), FEV1 (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 H2O Lt-1) of inspired gas in the treated group was higher than in the control group at 5, 10, 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


Bulgular: İnspire edilmiş gazın nisbi nemi anestezinin 5, 10, 15, 30, 45 ve 90 dakkikalardan tedavi grubunda kontrol grubundan daha yüksek bulundu. Inspire edilmiş gazın nisbi nemi anestezinin 5, 10, 15, 30, 45, ve 90 dakkikalardan tedavi grubunda kontrol grubundan daha yüksek bulundu (p<0.05). Tedavi grubunda postoperatif sakkarin klirens zamanı preoperatif değerdenden 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 yaneti yapmadan Postoperatif sakkarin klirens zamanını azaltmış, inspire edilmiş taze gazın postoperatif FRC’yi, nisbi nemini ve vücut isısını artırmıştır.

Anahtar Kelimeler: Ağışçiger fonsiyon testleri, Koaksiyel halka sistemi, Sakkarin klirens testleri, Standart halka sistemi, Timpanomastoidektomi
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 (FEV1), 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), EtCO2 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 cmH2O. 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 cmH2O for 5 seconds; the breathing system was deemed faulty if the pressure failed to reach 30 cmH2O 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 (Rocuronium 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 (PETCO2) 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, 1/4 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 (FEV1) were measured using a spirometer (SporoAnalyzer 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, EtCO2, SPO2, 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 SPO2<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, FEV1, and saccharin clearance time, intraoperative room moisture, intraoperative room and body temperature, intraoperative airway pressure, intraoperative and postoperative hemodynamic data (MAP, HR, SPO2, EtCO2, 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 FEV1. 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=0.001, 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, EtCO2, and SPO2 were similar in the treated and control groups during the 120-minute intraoperative period (Figure 2).
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 H₂O/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].

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

<table>
<thead>
<tr>
<th></th>
<th>Study Group (n=20)</th>
<th>Control Group (n=20)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>28±11</td>
<td>31±11</td>
<td>NS</td>
</tr>
<tr>
<td>BMI (Body Mass Index) (kg/m²)</td>
<td>24.1±3.9</td>
<td>25.1±5.4</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>9/11</td>
<td>10/10</td>
<td>NS</td>
</tr>
<tr>
<td>Smoking (%) (n)</td>
<td>35 (7)</td>
<td>25 (4)</td>
<td>NS</td>
</tr>
<tr>
<td>Duration of Anesthesia (minute)</td>
<td>150±31</td>
<td>147±35</td>
<td>NS</td>
</tr>
<tr>
<td>Duration of Surgery (minute)</td>
<td>137±30</td>
<td>138±21</td>
<td>NS</td>
</tr>
<tr>
<td>Recovery time (min)</td>
<td>7±3.5</td>
<td>8±3.4</td>
<td>NS</td>
</tr>
</tbody>
</table>

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

Table 2. The VC, FRC, FEV₁, Saccharin Clearance, the Moisture (mg H₂O/Lt), Temperature (°C) Values and Intraoperative Airway Pressure of the Patients

<table>
<thead>
<tr>
<th></th>
<th>Study Group (n=20) mean±SD</th>
<th>Control Group (n=20) mean±SD</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative VC (Liter)</td>
<td>2±0.8</td>
<td>2±0.9</td>
<td>NS</td>
</tr>
<tr>
<td>Postoperative VC (Liter)</td>
<td>1.9±0.9</td>
<td>2±0.9</td>
<td>NS</td>
</tr>
<tr>
<td>Preoperative FEV₁ (Liter)</td>
<td>1.2±0.7</td>
<td>1.3±0.6</td>
<td>NS</td>
</tr>
<tr>
<td>Postoperative FEV₁ (Liter)</td>
<td>1.1±0.6</td>
<td>1.2±0.6</td>
<td>NS</td>
</tr>
<tr>
<td>Preoperative FRC (Liter)</td>
<td>2.5±1.1</td>
<td>2.6±1.2</td>
<td>NS</td>
</tr>
<tr>
<td>Postoperative FRC (Liter)</td>
<td>2.3±0.9*</td>
<td>2.2±1.1*</td>
<td>0.0001</td>
</tr>
<tr>
<td>Preoperative saccharin clearance (Min)</td>
<td>13.2±4.5*</td>
<td>15.6±2.9</td>
<td>0.0001</td>
</tr>
<tr>
<td>Postoperative saccharin clearance (Min)</td>
<td>8.2±3</td>
<td>12.1±4.2</td>
<td>NS</td>
</tr>
<tr>
<td>The Moisture of Expired gas (mg H₂O/Lt)</td>
<td>76.9±10.1</td>
<td>79.2±4.1</td>
<td>NS</td>
</tr>
<tr>
<td>The Temperature of Expired gas (°C)</td>
<td>24.0±4</td>
<td>26.8±3.7</td>
<td>NS</td>
</tr>
<tr>
<td>The Room Moisture (mg H₂O/Lt)</td>
<td>30±10.6</td>
<td>30.7±5.1</td>
<td>NS</td>
</tr>
<tr>
<td>Room Temperature (°C)</td>
<td>20.1±5.2</td>
<td>22.5±1.4</td>
<td>NS</td>
</tr>
<tr>
<td>Body (Core) Temperature (°C)</td>
<td>36.2±0.2</td>
<td>36±0.3</td>
<td>NS</td>
</tr>
<tr>
<td>Intraoperative Airway Pressure (CmH₂O)</td>
<td>19±4.2</td>
<td>21.6±4.1</td>
<td>NS</td>
</tr>
</tbody>
</table>

n=20 VC (Vital Capacity), FRC (Functional Residual Capacity), FEV₁ (Forced Expiratory volume at 1st second), NS: Non significant, *p<0.05 The postoperative FRC and the postoperative saccharin clearance when compared the preoperative values in the both group.
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 CO₂ absorber. During ventilation, the inspired gas is warmed by the heat produced during CO₂ 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].

In the present study, during approximately 2 hours of anesthesia, the absolute humidity levels of inspired gas were 49.5 and 34.55 mg H₂O/Lt in the treated group and 29.8 and 29.9 mg H₂O/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 CO₂ 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 EtCO₂ 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 H₂O/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. Torelalm 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 viscoelasticty properties of mucus and the ciliotoxic effects of smoking disturb 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 FEV1. 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


