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Comparison of manual and automatic end-tidal control practices in low-flow anesthesia

Automatic end-tidal controlled low-flow anesthesia

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Abstract

Aim: In this study, it was aimed to compare the impact of manual and automated end-tidal control implementation in low-flow anesthesia on anesthesia workload, inhalation agent consumption, and hemodynamic parameters of patients.

Material and Methods: In our study, 96 patients were divided into 2 groups as manual controlled low-flow anesthesia and end-tidal controlled low-flow anesthesia. Sevoflurane and O_2 consumption and efficiency in the groups, end-tidal O_2, inspired and expired sevoflurane values, time to reach target end-tidal O_2 and sevoflurane values, time to deviation from target value, hemodynamic values, operation, anesthesia and awakening time, BIS, MAC and temperature values were followed and compared with the Aisys CS² GE anesthesia device.

Results: There was no statistically significant difference between the groups in terms of demographic data, operation, anesthesia, and recovery time and hemodynamic data. O_2 consumption was higher, time to reach target end-tidal oxygen and target EtO_2 deviation time was longer, O_2 efficiency was lower, and the number of interventions was higher in the manually controlled low-flow anesthesia group. There was no difference between the two groups in terms of total sevoflurane consumption and efficiency.

Discussion: It has been concluded that the end-tidal controlled application of low-flow anesthesia does not increase the use of inhalation agents, the O_2 sensitivity is higher, it is hemodynamically safe, and the workload of the anesthetist is reduced due to the low number of interventions during the application.

Keywords

Low-Flow Anesthesia, Minimal Flow Anesthesia, Automated End-Tidal Anesthesia, Controlled Anesthesia, Sevoflurane

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Introduction

Climate change is regarded as the gravest global health threat in the twenty-first century. It has been suggested that the environmental and economic effects that occur during the delivery of healthcare services can only be reduced by the implementation of sustainable healthcare services. To ensure sustainability in anesthesia, especially anesthetists who control the flow of inhalation agents should consider low-flow anesthesia (LFA) as the up-to-date anesthesia management method of our age and transfer their principles, knowledge, and methods to practices when meeting our daily needs [1,2]. Thanks to the LFA technique significant cost savings and reduced atmospheric pollution can be achieved by minimizing the consumption of anesthetic agents. In addition to these advantages, the low-flow anesthesia technique also contributes to intraoperative protective lung mechanical ventilation techniques by improving the anesthetic gas climate and maintaining heat and humidity [3]. Low-flow inhalation anesthesia is administered using manually controlled or end-tidal controlled techniques. Manually controlled low-flow anesthesia is described as the technique in which the titration of oxygen and anesthetic gas is constantly controlled by the anesthesiologist and manual adjustments are made to achieve adequate depth of anesthesia. End-tidal controlled anesthesia devices, meanwhile, continuously adjust the O_2 flow set in inhalation anesthesia administration and the end-tidal concentrations of inhalation anesthetics by giving feedback. Less intervention is of clinical importance in terms of eliminating user distraction, keeping the record, and patient safety [4,5]. This study aimed to compare the effects of manually and automated end-tidal controlled anesthesia practices in low-flow anesthesia technique on anesthesia workload, anesthetic agent consumption, and hemodynamic parameters of the patient.

Material and Methods

Study Group and Randomization:

After obtaining the Ankara City Hospital ethics committee approval (E1-20-10939), and the patient consent, 96 patients with an ASA status of 1-2, aged 18-65 years who underwent elective surgery and were intubated as orotracheal have been included in this prospective randomized, single-blind study between January 2021 and May 2021. The patients admitted to the study were assigned into two groups by sealed envelope randomization; Group 1: Manually Controlled LFA (MC-LFA) and Group 2: End-tidal Controlled LFA (EtC-LFA).

Exclusion Criteria:

Those aged 65 and over, patients with ASA 3 and above, pregnant women, those at risk of malignant hyperthermia, heart failure, end-stage renal and hepatic failure, those with a BMI of > 30 kg/m2, chronic opioid use, and those who had a surgical operation duration of < 1 hour and did not agree to participate in this study were excluded from this study. During the study, patients who could not reach the target end-tidal sevoflurane value before the skin incision, had a bispectral index (BIS) value above 60, developed unexpected intraoperative hypoxia, surgical complications, and lacked data were excluded from the study.

Anesthesia Management

ECG, pulse-oximetry (SpO_2), non-invasive arterial blood pressure, body temperature, and BIS were monitored, and the lower and upper limits for the alarm of the monitoring were adjusted for each patient. The patients were pre-oxygenated with an FiO_2 = 1 and a flow of 10 L/min for at least 3 min. Anesthesia induction was performed by administering 2 µ/kg fentanyl, 2-2.5 mg/kg propofol, and 0.6 mg/kg rocuronium, and the patients were intubated orotracheally. Sevoflurane administration was started after intubation. The patients were ventilated with the Aisys CS^2 GE anesthesia device in volume-controlled mode (TV 6-8 mL/kg ideal body weight, + 5 cmH_2O PEEP) and set to maintain end-tidal CO_2 ($EtCO_2$) 35 mmHg. In both groups, all patients were followed up by the same two anesthetists. Following the skin incision, remifentanil infusion was started at 1 µ/ kg bolus followed by 0.1-0.5 µ/kg/min, and the infusion dose was modified by dynamic evaluations throughout the operation. During study, KNGSORB (calcium hydroxide, sodium hydroxide, and ethyl violet) was used as CO_2 absorbent, and $FiCO_2$ was monitored. The target end-tidal sevoflurane concentration (FetSevo) of the two groups was 1.7-2 % and end-tidal O_2 (EtO_2) was 35%.

The patient was administered 100% O_2 with a flow rate of 4 L/min for five minutes in the initial high flow period in both groups. In the MC-LFA group, the sevoflurane vaporizer was adjusted to 3% during the high flow period. In the EtC-LFA group, after the patient was connected to the anesthesia device, the end-tidal button was pressed, and Fet-Sevo was set to 1.7-2%. After a five-minute of high flow, the flow rate was reduced by 1L/min in both groups. In the MC-LFA group, anesthesia was maintained with 50% O_2 + 50% air and the sevoflurane vaporizer 3-3.5%. Throughout the operation, O_2 % and sevoflurane vaporizer interventions were performed to maintain the target value range. Measurements were started when the patient was connected to the ventilator in both groups. The duration of the groups to reach the target sevoflurane and O_2 values were noted down. The number of interventions made by the anesthetist to the device in the MC-LFA group was recorded.

From the onset of the operation, the patient's hemodynamic parameters (HR, MAP), inspired sevoflurane (FiSevo) and inspired O_2 (FiO_2), FetSevo and EtO_2, minimum alveolar concentration (MAC), BIS and body temperature values were recorded. A MAP of < 55 mmHg lasting > 5 minutes was considered to be hypotension. Other parameters checked for the study during the operation were as follows:

- Duration to reach target end-tidal sevoflurane and O_2 values,
- O_2 and sevoflurane were administered to the patient by the anesthesia device (the oxygen and sevoflurane consumption of the device, L and mL, respectively),
- Sevoflurane and O_2 consumption of the patient ($V'O_2$ and V'Sevoflurane were calculated in L, mL/min, respectively, by dividing the amount of O_2 and sevoflurane administered to the patient by the anesthesia device by the duration of anesthesia),
- Number of adjustments to reach target FetSevo and EtO_2 in the MC-LFA group,
- Deviation duration from target FetSevo and EtO_2 values (sec),
- Sevoflurane and O_2 sensitivity (obtained by percentage

calculation of the ratio of target FetSevo and EtO_2 deviation duration to total anesthesia duration) [6],

- Oxygen uptake of the patient throughout the operation was calculated using Brody's formula (L) [3,7,8],
- Sevoflurane uptake of the patient during the operation was calculated using Lowe's formula (mL) [3,7,8],
- Sevoflurane efficiency (%, total sevoflurane delivered by the device during anesthesia/patient sevoflurane uptake) [8],
- O_2 efficiency (%, total O_2 delivered / O_2 taken by the device during anesthesia) [8],
- Operation, anesthesia, and awakening time were recorded.

The sevoflurane vaporizer was turned off five minutes before the end of the surgery, but the flow of fresh gas was not changed. At the end of anesthesia, 100% O_2 with a flow rate of 6 L/min was set in both groups. The duration between the end of the low fresh gas flow and switching to the high fresh gas flow of the patients and the extubation was recorded as the "awakening time.".

Determination of Sample Size

The sample size was calculated based on a previous study reported by Wetz AJ et al. [6]. In calculation, G Power 3.1.9. 2 Package program was used. Assuming that the 1.2 ml/s difference between the values of anesthetic gas consumption in MC-LFA and EtC-LFA uses will be considered significant, it was calculated that at least 90 patients should be taken, including 45 patients in each group with a d=0.6 effect size, 80% power, and 0.05 error level.

Statistical Analysis

Mean standard deviation, median, minimum and maximum values were presented in descriptive statistics for continuous data, and percentage values were presented in discrete data. The Shapiro-Wilk test was used to analyze whether the continuous data fit the normal distribution. In the comparison of continuous data in two groups, the t-test was used for data showing normal distribution, and the Mann-Whitney U test was used for data that did not fit the normal distribution. The chi-square test and Fisher's Exact test were used for group comparisons of nominal variables (in cross-tables). IBM SPSS 20 software was used in the analysis, and the results were considered significant at $p < 0.05$.

Results

In our study, 96 patients were included, and the data of 46 patients who underwent MC-LFA and 45 patients (n=91) who underwent EtC-LFA were analyzed.

Gender, age, height, weight, BMI, ASA, anesthesia, surgery, and recovery times of the patients compared between groups ($p > 0.05$) are shown in Table 1. In the comparison between the groups, a significant difference was found in total O_2 consumption (L), minute O_2 ($V'O_2$) consumption (L/min), and O_2 efficiency (%) (Figure 1, $p < 0.05$). It was determined that total O_2 consumption (ml) and V'O2 (L/min) were higher, and O_2 efficiency was lower in the MC-LFA group. Besides, when the time to reach the target EtO2, the number of interventions to sevoflurane concentration and FiO_2 were compared, a significant difference was found (Table 2, $p < 0.001$). It was observed that the time to reach the target EtO_2 was longer, and the number of interventions to the anesthetic gas concentration was higher in the MC-LFA group. A significant difference was found between the groups regarding total target EtO_2 deviation time and total O_2 sensitivity (Table 2, Figures 2 and 3). In the MC-LFA group, the target EtO_2 deviation time was longer and the O2 sensitivity

Table 1. Demographic characteristics, recovery and operation durations, and operative data of patients who underwent EtC-LFA and MC-LFA

	EtC-LFA (n=45) mean±SD	MC-LFA (n=46) mean±SD	p
Age (years)	43.57±11.23	43.52±11.23	0.981
Height (m)	1.64±0.07	1.63±0.06	0.497
Weight (kg)	70.49±10.40	70.46±9.63	0.988
BMI (kg/m^2)	26.01±3.17	26.33±3.28	0.636
Gender			
Female (n/%)	34 (75.6)	36 (78.3)	0.759
Male (n/ %)	11 (24.4)	10 (21.7)	
ASA			
1	9 (20)	12 (26.1)	0.491
2	36 (80)	34(73.9)	
Anesthesia duration (min)			
Mean ± SD	121.24±29.13	122.00±34.57	0.911
Median (Min-Max)	117 (69-183)	128.5 (65-188)	
Operation duration (min)			
Mean ± SD	109.87±28.27	112.93±34.67	0.645
Median (Min-Max)	105(60-172)	115.5(60-180)	
Awakening time (sec)			
Mean ± SD	299.16±96.45	300.78±113.75	0.942
Median (Min-Max)	299 (145-553)	274 (110-592)	
Mean Arterial Pressure (MAP) (mmHg)	82.18±8.65	80.38±8.36	0.315
Heart Rate (HR, beats/minute)	75.71±11.83	77.98±12.64	0.381
Minimum Alveoler Concentration (MAC)	0.90±0.00	0.90±0.00	1.000

Table 2. Anesthetic gas data in EtC-LFA and MC-LFA

	EtC-LFA (n=45) mean±SD	MC-LFA (n=46) mean±SD	p
Total O_2 intake (L)	26.68 ± 7.48 25.73 (11.46-44.39)	27.54 ± 9.36 28.41 (11.61-53.47)	0.629
Total O_2 consumption (L)	61.01 ± 11.53 59.61 (38.85-89.98)	66.86 ± 15.64 69.21 (41.75-101.38)	0.046*
$V'O_2$ (ml- min)	0.51 ± 0.04 0.51 (0.44-0.60)	0.56 ± 0.04 0.55 (0.46-0.67)	0.000*
Total Sevoflurane intake (ml)	3.87±0.66 3.90 (2.2-5.3)	3.94±0.79 4 (2.4-6.1)	0.700
Total Sevoflurane consumption (ml)	20.24 ± 4.75 20 (11-31)	20.26 ± 5.33 19.5 (11-31)	0.988
V'Sevoflurane (ml-min)	0.18±0.01 0.18 (0.15-0.21)	0.17±0.01 0.18 (0.16-0.23)	0.099
Time to reach target FetSevo (sec)	151.04 ± 42.97 150 (65-230)	145.22 ± 46.03 139.5 (70-250)	0.534
Time to reach target EtO_2 (sec)	715.87 ± 31.18 713 (667-860)	1853.46 ± 382.41 1732.5 (1237-2811)	0.000*
Number of interventions for sevoflurane	1.00 ± 0.00 1 (1-1)	4.98 ± 1.92 5 (2-11)	0.000*
Number of interventions for FiO_2	1.00 ± 0.00 1 (1-1)	2.67 ± 1.14 2 (1-6)	0.000*
Total target EtO_2 deviation time (sec)	839.09 ± 108.15 815 (695-1277)	1882.30 ± 346,34 1800 (1406-2811)	0.000*
Total target FetSevo deviation time (sec)	49.15 ± 12.10 48.6 (23.5-72.2)	35.69 ± 13.29 37 (10.9-60.4)	0.000*

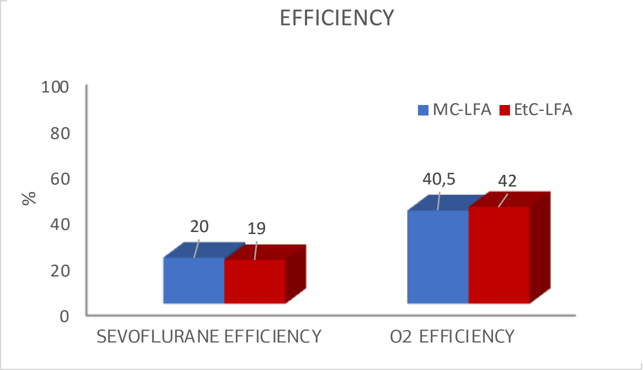

Figure 1. Sevoflurane and O_2 efficiency of patients who underwent EtC-LFA and MC-LFA. Significance levels were *p<0.05.

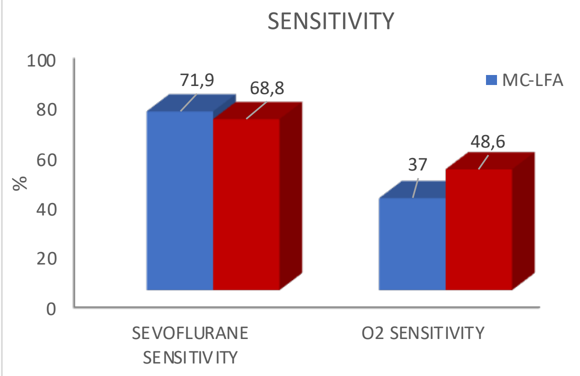

Figure 2. Sevoflurane and O_2 sensitivity of patients who underwent EtC-LFA and MC-LFA. Significance levels were *p<0.001.

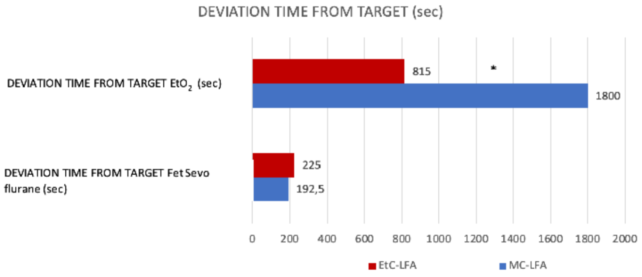

Figure 3. Deviation time from target Fet Sevoflurane and target Et O_2 in patients who underwent EtC-LFA and MC-LFA. Significance levels were *p<0.001.

was lower. When total sevoflurane consumption (Table 2) and hemodynamic data (Table 1) were compared in both groups, no significant difference was found.

Discussion

In our study, no difference was found between the two groups regarding sevoflurane consumption, hemodynamic variables, and target anesthetic agent sensitivity. Sevoflurane concentration and number of interventions to FiO_2 were higher in the manually-controlled group. When compared in terms of target EtO_2 concentration, the findings showed that the deviation from the target was higher, whereas the sensitivity was lower in the manually controlled group. It was concluded that this situation would allow close monitoring in manually-controlled LFA, leading to an increase in the frequency of intervention by the anesthetist, and increase the workload of the anesthetist.

The world population growth and the increase in the number of people able to access healthcare services are causing an increase in the number of surgeries performed every year. The widespread use of sustainable anesthesia practices due to the cost and environmental pollution caused by the increasing anesthesia practices and the increase in technologically superior anesthetic devices make low-flow anesthesia practices more prominent [1,9,10]. In recent years, anesthesia devices that provide constant O_2 and inhalation anesthetic concentrations during anesthesia with an automatic feedback control system have been introduced. These devices allow safer delivery of inhalation anesthetics and O_2 during low or minimal flow anesthesia [11,12]. Maintenance of hemodynamic stability during anesthesia is of great importance. Skalec et al., in their study, compared the hemodynamic effects of manually and end-tidal controlled low-flow anesthesia and found no significant difference between the two groups [12]. Likewise, in our study, no significant difference was found between manually and end-tidal controlled LFA, in terms of hemodynamic data. Singaravelu and Barclay, in their study without determining the target EtO_2 and target FetSevo values with the GE Aisys anesthesia device, reported that the anesthetic agent consumption in the end-tidal controlled group was 40-55% less than in the manually controlled group. However, when the fresh gas flows during the study are examined, it is noticed that the fresh gas flow rate is higher in the manually controlled group at all intervals. The fresh gas flow is higher in the manually controlled group limits the study in terms of comparison of anesthetic agent consumption [5]. In another study by Lucangelo et al., no significant difference was found in terms of anesthetic agent consumption and anesthetic agent efficiency in LFA with manuel control, and EtC with a fresh gas flow of 1 L/min [8]. Besides, Wetz et al. revealed that sevoflurane consumption was lower in the manually controlled group (6 mL/h in the MCA group vs 6.9 mL/h in the EtCA group) in their study, which they restricted to a flow of 0.5 L/min and follow-up of 60 minutes [6]. Mostad et al., on the other hand, reported that in the LFA technique they applied using two different anesthesia devices (Aisys anesthesia device and Flow-I, Maquet), they detected a decrease in desflurane consumption with automatic gas-controlled devices at the end of the first hour of anesthesia [11]. In our study, meanwhile, the total and minute consumption of sevoflurane was 20.24±4.75 mL /min and 0.18±0.01 mL/ min in the EtC-LFA group, and 20.26±5.33 mL /min and 0.17±0.01 mL /min in the MC-LFA group, respectively. The findings obtained in our study are consistent with the results of the study by Lucangelo et al. There is no significant difference between the two groups concerning consumption and efficiency. In another study using Zeus anesthesia device with a fresh gas flow of 1 L/min and desflurane anesthetic agent, oxygen and desflurane consumption were lower in the EtC-LFA group than the MC-LFA group [13]. Different results have been revealed in the studies conducted so far, and this difference may be due to the study design differences and further research on consumption is needed. In the study of Wetz et al., the time to reach the target anesthetic and target EtO_2 value, and the deviation time from the target anesthetic and target EtO_2 value were shorter in the end-tidal controlled group. Moreover, in this study, an average of eight changes in 60 minutes was made in the manually controlled group to maintain the sevoflurane concentration within the determined range, and an average of five changes to maintain the EtO_2 concentration within the targeted range [6]. Lucangelo et al. found the time to reach the target anesthetic concentration in the end-tidal controlled group longer than the manually controlled group in the Aisys (Aisys, GE Healthcare) anesthesia device and with a fresh gas flow of 1 L/min [8]. In our study, it was seen that the target anesthetic concentration was reached in a shorter time in the MC-LFA group, whereas the target EtO_2 concentration was reached in a longer time. Throughout total anesthesia, the target EtO_2 deviation time was 815 seconds in the EtC-LFA group, and 1800 seconds in the MC-LFA group.

The fact that the number of patients in both groups decreased as the duration of anesthesia progressed can be considered a limitation of our study. We are of the opinion that there may be changes in the anesthetic agent and O_2 consumption in longer operations. Considering this situation, we believe that prospective randomized studies with a larger number of patients and longer operation durations can be conducted.

Conclusion

Low flow anesthesia, that is one of the most important components of sustainable anesthesia is an anesthesia technique of our era. Given that end-tidal controlled low-flow anesthesia administrations are hemodynamically safe and O_2 sensitivity is higher, anesthetic agent sensitivity and agent consumption are equivalent without the necessity to intervene in the anesthesia device, it was concluded that it would not increase the cost and reduce the workload of the anesthetist.

Scientific Responsibility Statement

The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.

Animal and human rights statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.

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Conflict of interest

None of the authors received any type of financial support that could be considered potential conflict of interest regarding the manuscript or its submission.

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