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Comparison of anaesthetic gas consumption and stability of anaesthesia using automatic and manual control over the course of anaesthesia

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Abstract

Background: The automatic control module of end-tidal volatile agents (EtC) was designed to reduce the consumption of anaesthetic gases, increase the stability of general anaesthesia and reduce the need for adjustments in the settings of the anaesthesia machine. The aim of this study was to verify these hypotheses.

Methods: The course of general anaesthesia with the use of the EtC module was analysed for haemodynamic stability, depth of anaesthesia, end-expiratory concentration of anaesthetic, number of ventilator key presses, fentanyl supply, consumption of volatile agents and anaesthesia and operation times. These data were compared with the data obtained during general anaesthesia controlled manually and were processed with statistical tests.

Results: Seventy-four patients underwent general anaesthesia for scheduled operations. Group AUTO-ET (n = 35) was anaesthetized with EtC, and group MANUAL-ET (n = 39) was controlled manually. Both populations presented similar anaesthesia stability. No differences were noted in the time of anaesthesia, saturation up to MAC 1.0 or awakening. Data revealed no differences in mean EtAA or the fentanyl dose. The AUTO-ET group exhibited fewer key presses per minute, 0.0603 min^{-1}, whereas the MANUAL-ET exhibited a value of 0.0842 min^{-1}; $P = 0.001$. The automatic group consumed more anaesthetic and oxygen per minute (sevoflurane 0.1171 mL min^{-1}; IQR: 0.0503; oxygen 1.8286 mL min^{-1}, IQR: 1,3751) than MANUAL-ET (sevoflurane 0.0824 mL min^{-1}, IQR: 0.0305; oxygen 1,288 mL min^{-1}, IQR: 0,6517) ($P = 0.0028$ and $P = 0.0171$, respectively).

Conclusion: Both methods are equally stable and safe for patients. The consumption of volatile agents was significantly increased in the AUTO-ET group. EtC considerably reduces the number of key presses.

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Key words: anaesthesia, general; anaesthetic, volatile, sevoflurane; automatic control

The method of minimal/low-flow anaesthesia has been utilized since the 1950s. The method is used to reduce the consumption of fresh anaesthetic gases, decrease the costs of general anaesthesia and maintain constant temperature and humidity of inspiratory gas mixtures [1–3]. The technique has beneficial effects on the development of medical technologies, resulting in the introduction of modern vaporizers and closed circuit anaesthesia systems [4, 5].

The next step to improve anaesthetic management involves the introduction of anaesthetic machines with gas control modules. The devices constantly analyse the composition of a gas mixture, both inspiratory and expiratory, and assure closed-loop control of the flows of individual components. The modules described above were applied to Zeus (Draeger Medical, Lubeck, Germany) [6] and Aisys Carestation (GE, Madison, USA) devices [7]. The use of automated modules (EtC, *end tidal control*) reduces the consumption of anaesthetic gases and increases the stability of anaesthesia by steady changes in the flow of individual components of gas mixtures. The modules are designed to

limit the number of necessary adjustments of the settings of ventilatory parameters, which potentially increases the safety of anaesthetised patients [8, 9].

The aim of the present study was to verify the hypothesis that the EtC module reduced the consumption of fresh gases in a low-flow system while maintaining similar stability of general anaesthesia assessed by cardiovascular responses and bispectral index (BIS) measurements of the depth of anaesthesia. Moreover, we assessed whether the use of the EtC module might reduce the number of manual interventions to correct the anaesthesia parameters.

METHODS

The course of general anaesthesia was compared in 74 patients undergoing abdominal and thyroid surgical procedures. American Society of Anesthesiologists (ASA) 1–3 patients were enrolled. Patients requiring combined anaesthesia with the use of epidural catheters or another method of regional anaesthesia were not included. The exclusion criterion was procedure duration shorter than 15 minutes. The study design was approved by the Bioethics Committee at the Wrocław Medical University (KB- 675/2015). Given that both methods are commonly used in clinical practice and the study was observational, patient consent was not required.

Two anaesthesia workstations with GE Aisys Carestation devices were used. The devices enable electronic control of an anaesthetic vaporizer to an accuracy of 0.2 vol%. One of the workstations was equipped with the EtC module for automated control of the concentration of anaesthetic gases in the respiratory mixture based on measurements of end-tidal concentrations of the individual components of the mixture. In the second device, the concentration of anaesthetic gases was controlled manually.

The study patients were divided into two groups: the AUTO-ET group of 35 patients undergoing general anaesthesia with the use of the EtC module and the MANUAL-ET group including 39 subjects where gas concentrations were controlled manually.

The patients underwent general anaesthesia with intravenous induction, endotracheal intubation and inhalational maintenance of anaesthesia using a mixture of air, oxygen and sevoflurane. Intravenous induction was performed using propofol (2 mg kg^{-1}), fentanyl (1.5 μg kg^{-1}) and rocuronium (0.6 mg kg^{-1}). The gas flow rates presented below were used for conduction. In the MANUAL-ET group, the initial flow of fresh gases (FGF) was 4 L min^{-1}, and the anaesthetic (4 vol %) was inhaled until an age-adjusted MAC of 1.0 was obtained in the end-expiratory mixture. When the desired level of anaesthetic saturation was achieved, the flow was reduced to 1 L min^{-1} for fresh gases; the concentration of sevoflurane was corrected systematically to maintain MAC 1.0. In the AUTO-ET group anaesthetised using the EtC module, target parameters of fresh gases were set at a low flow level (1 L min^{-1}), while the concentration of sevoflurane in the expired air was set to equal the age-adjusted MAC of 1.0. The vaporiser, air and oxygen were controlled automatically. In both cases, the standard methods of volume-controlled ventilation were applied, with TV 6 mL kg^{-1}, respiration rate 12 min^{-1}, $EtCO_2$ within the range of 35 to 40 mm Hg and EtO_2 within the range of 35 to 40%. After completing the anaesthetic procedure, the consumption of anaesthetic gases, oxygen and air was recorded.

The course of general anaesthesia was recorded according to the protocol, which included demographic data, type of surgery, systolic arterial pressure, bispectral index and end-expiratory concentration of an inhalational anaesthetic. Additionally, the frequency of changes in the gas flow and anaesthetic concentrations performed by an anaesthetist and the supply of fentanyl boluses were recorded. For the purpose of the study, all those activities were defined as interventions. The above data were recorded at 5-minute intervals. Additional elements analysed included: time required to achieve the desired concentration of sevoflurane (EtAA), time between the discontinuation of gas delivery and eye opening as well as extubation, total duration of the procedure and anaesthesia. Furthermore, the consumption of fresh gases (oxygen, air) and the inhalational anaesthetic was recorded.

The data were quantified using Statistica 10.0 (StatSoft, Tulsa, USA). Analysis of the study strength showed that the sample size was sufficient. Given that the normality of quantitative variables was not demonstrated (Shapiro-Wilk W test), a nonparametric Mann-Whitney U test was used. The distribution of qualitative variables was tested with contingency tables and the χ^2 test.

RESULTS

The course of study is presented in Fig. 1. Both patient populations were comparable in terms of demographic profile and ASA classification (Table 1).

The medians of anaesthesia time were 105 minutes in the AUTO-ET group and 125 minutes in the MANUAL-ET group and were not significantly different. Moreover, no significant differences were noted in times to achieve the desired EtAA. Similarly, no significant differences were observed in times of recovery from anaesthesia. The medians of times to eye opening and extubation after cessation of anaesthetic delivery were not significantly different in both groups — 15 min and 15 min in the MANUAL-ET group versus 15 min and 20 min in the AUTO-ET group, respectively. The comparisons of time intervals recorded in both groups are presented in Table 2.

The study findings did not demonstrate significant differences in the stability of anaesthesia in both groups.

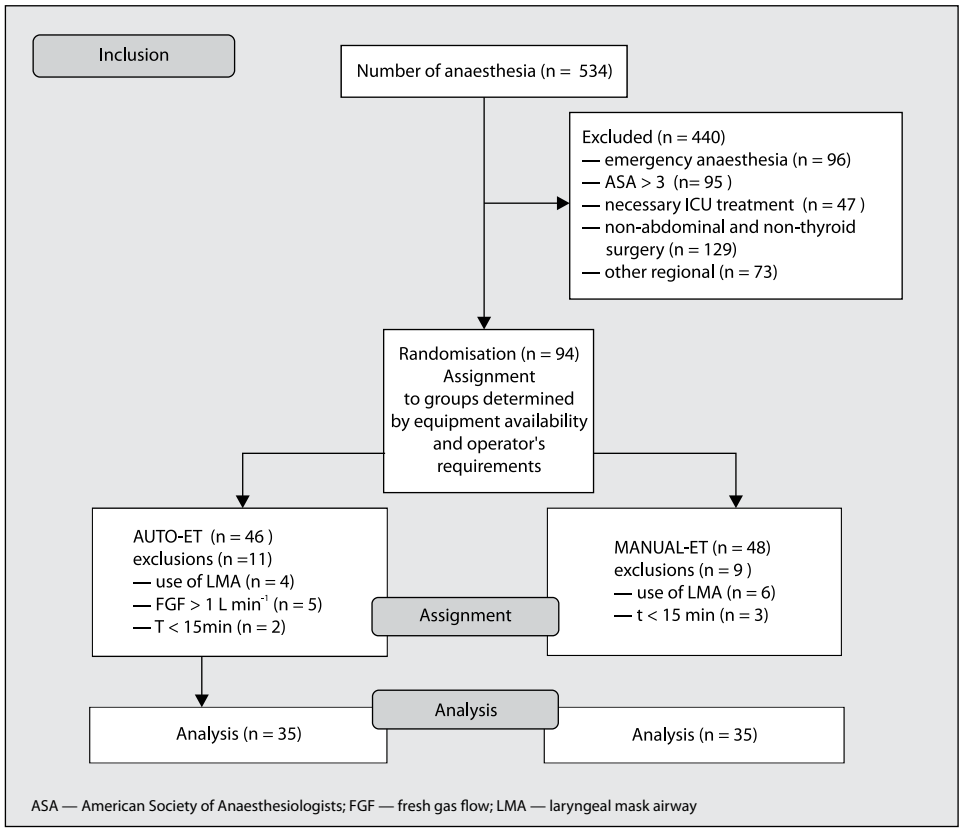

Figure 1. The course of study

Table 1. American Society of Anesthesiologists (ASA) classification and demographic characteristics of both groups; n (%) or medians (IQR) are provided

	MANUAL-ET	AUTO-ET
Females	28 (73.68%)	27 (77.14%)
Males	10 (26.32%)	8 (22.86%)
ASA 1	8 (20.51%)	12 (34.29%)
ASA 2	27 (69.23%)	15 (42.86%)
ASA 3	3 (10.26%)	8 (22.86%)
Age (years)	61 (24)	57 (28)
Body mass (kg)	75 (24)	65 (18)

Both the haemodynamic parameters in the form of systolic arterial pressure and its variability index and the depth of anaesthesia measured with BIS were comparable in both groups. Furthermore, no significant differences were observed in end-expiratory anaesthetic concentrations during anaesthesia and the frequency of administration of fentanyl boluses. The results are presented in Table 3.

In the AUTO-ET group of patients, the number of interventions (changes in gas flow and concentrations of inhalational anaesthetic) was reduced compared with that in the MANUAL-ET group. Similarly, significantly fewer interventions were required in the AUTO-ET group per

Table 2. The recorded times in both study groups

	MANUAL-ET Median (IQR)	AUTO-ET Median (IQR)	*P*
Duration of anaesthesia (min)	125 (65)	105 (60)	0.199
Duration of surgery (min)	80 (60)	65 (65)	0.321
Time to obtain MAC of 1.0 for sevoflurane (min)	10 (3)	10 (5)	0.074
Time from cessation of sevoflurane delivery to eye opening (min)	15 (10)	15 (5)	0.107
Time from cessation of sevoflurane delivery to extubation (min)	15 (10)	20 (10)	0.056

Table 3. Haemodynamic parameters, BIS and end-tidal anaesthetic concentrations

	MANUAL-ET Median (IQR)	AUTO-ET Median (IQR)	*P*
Systolic arterial pressure (SAP)	117 (15)	114 (20)	0.491
SAP variability	0.1587 (0.0670)	0.1378 (0.0736)	0.278
Bispectral index (BIS)	48 (13)	48 (5)	0.144
BIS variability	0.4367 (0.1156)	0.4782 (0.1276)	0.198
Level of EtAA	1.3043 (0.3587)	1.4095 (0.5928)	0.218
EtAA variability	0.4739 (0.1769)	0.5246 (0.4728)	0.685
Fentanyl supply	3 (2)	3 (1)	0.470

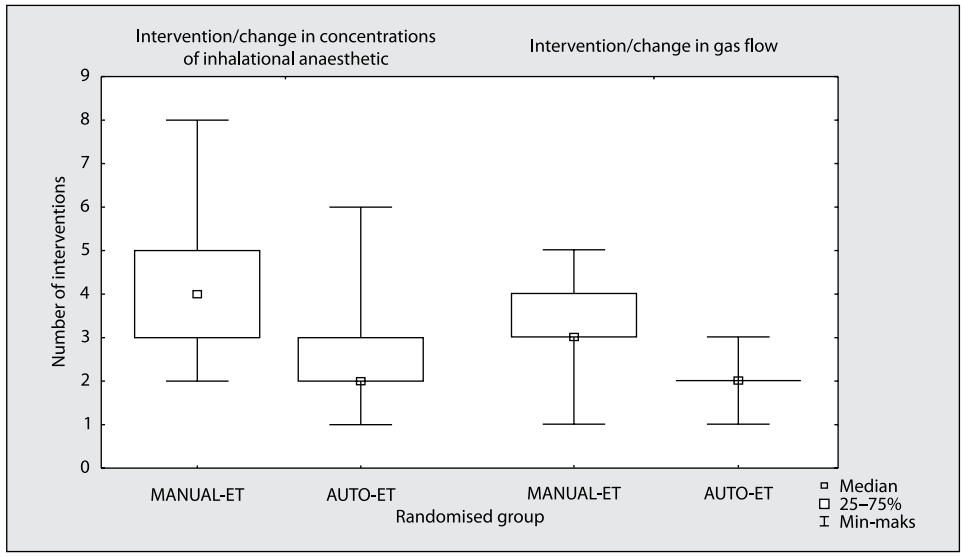

Figure 2. Number of interventions (changes in gas flow and concentrations of inhalational anaesthetic) in both groups

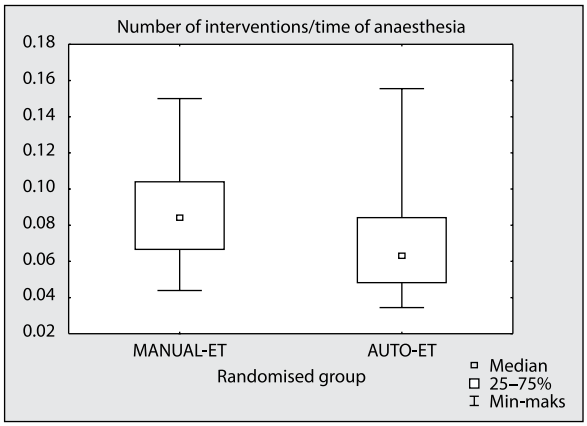

Figure 3. Number of interventions per total time of anaesthesia

total time of anaesthesia. The results are provided in the Figures 2 and 3.

The observations in the AUTO-ET group demonstrated higher total consumption of oxygen and inhalational anaesthetic compared with those in the MANUAL-ET group; however, the differences observed were not statistically significant with regard to the time of anaesthesia. On the other hand, the AUTO-ET patients consumed less air compared with the MANUAL–ET patients; however, the difference was not significant. The results are presented in Tables 4 and 5.

DISCUSSION

This study demonstrated that the methods using automated and manual control of anaesthetic gases were comparable in terms of stability. No differences in haemodynamic parameters or bispectral index were noted, which suggests a similar level for the depth of anaesthesia in both groups. However, the data published in the literature to date are ambiguous regarding the time of anaesthetic saturation and recovery from anaesthesia. The results presented by Lortat-Jacob, who used the Zeus device, are similar to our findings [6]. The analysis of both groups revealed no differences in the times required to achieve the desired level of anaesthetic saturation and recovery from anaesthesia. A suitably chosen mode of anaesthetic delivery in the ini-

Table 4. Total consumption of anaesthetic gases and the number of interventions during anaesthesia

	MANUAL-ET Median (IQR)	AUTO-ET Median (IQR)	*P*
Consumption of sevoflurane (mL)	11.0 (7.0)	11.0 (11.0)	0.354
Consumption of oxygen (L)	165.0 (47.0)	209.0 (96.0)	0.014
Consumption of air (L)	96.0 (43.0)	77.00 (51.0)	0.239
Number of gas flow changes	3 (1)	2 (0)	< 0.0001
Number of anaesthetic concentration changes	4 (2)	2 (1)	< 0.0001
Number of interventions	10 (3)	7 (2)	< 0.0001

Table 5. Consumption of inhalational anaesthetic and gases and the number of interventions per duration of anaesthesia

	MANUAL-ET Median (IQR)	AUTO-ET Median (IQR)	*P*
Consumption of sevoflurane (mL)/time of anaesthesia (min)	0.0824 (0.0305)	0.1171 (0.0503)	0.003
Consumption of oxygen (L)/time of anaesthesia (min)	1.2880 (0.6517)	1.8286 (1.3752)	0,017
Consumption of air (L)/time of anaesthesia (min)	0.7579 (0.3081)	0.6615 (0.4)	0.348
Number of interventions/time of anaesthesia (min)	0.0842 (0.0373)	0.0632 (0.0359)	0.001

tial phase of manually controlled anaesthesia is equally as effective as the algorithm for automated anaesthesia. The study results by Lortat-Jacob *et al.* [6] confirm our findings. Moreover, the authors demonstrated no differences in the time to eye opening and extubation between automated and manual methods. Otherwise, the results published by Lucangelo *et al.* [8] are contrary to our data. Lucangelo et al. demonstrated that the required concentration of inhalational anaesthetic was achieved more rapidly in the group with manual control. These findings resulted from different methods used. In their study, the automated control module abruptly adjusted the desired flows, which increased the saturation time. Otherwise, the study by Struysa *et al.* [10] revealed that the desired level of anaesthetic was achieved more rapidly in the group with automated measurements of EtAA. However, the study was performed with an in vitro model confined to the respiratory system, which did not consider the phase of anaesthetic redistribution. Lucangelo obtained the same times for recovery from general anaesthesia in the automated and manual groups, which confirms our findings.

Moreover, the results of studies regarding the consumption of oxygen, air and sevoflurane in the group anaesthetised with the EtC module are also ambiguous. Our observations did not exhibit reduced consumption of these gases, which stands in contradiction to the other study results regarding automated control modules [6, 7, 9]. In the study by Lortat-Jacob *et al.* [6], desflurane was used in the mixture with nitrogen peroxide, which potentially resulted in reduced consumption of desflurane. Additionally, the authors excluded patients in whom the duration of surgery was less than 1 hour, i.e., the period with the highest consumption of anaesthetic due to the phase of saturation. The range of anaesthesia times accepted by the researchers from Liverpool was definitely wider [7]. In their study, only patients with anaesthesia times less than 10 minutes were excluded. However, they did not use a uniform method of induction and maintenance of manually controlled anaesthesia, leaving choices to attending anaesthetists. Additionally, anaesthetists chose inhalational anaesthetics; both desflurane and sevoflurane were used. Therefore, in this case, the method of manual control anaesthesia cannot be considered a standard. In our study, a more standardized algorithm of manual control was applied, which clearly affected our findings. The results presented by De Cooman [11] are comparable to our data. The author demonstrated increased consumption of inhalational anaesthetic during anaesthesia with the automated control module of end tidal concentration of inhalational anaesthetic. However, the protocol of his study assumed an increased level of end tidal anaesthetic in the automated control group, which could have affected the findings. Moreover, the study did not consider BIS monitoring; hence, the depth and adequacy of anaesthesia were unknown. In our study, in which we used the same gas flows and assumed concentrations of inhalational anaesthetic in both groups, the results were comparable to those published by De Cooman. Increased anaesthetic consumptions using ETC are likely to be caused by the algorithm controlling the module in the AISYS. However, objective verification of the above is not possible given that the procedures for automated control of inhalational anaesthetic are not available.

Our observations demonstrated that the use of the automated control module considerably reduced the number of anaesthetist interventions during general anaesthesia. Similar results have been presented by other researchers [6–9]. In his 10-year observation, Kennedy *et al.* [9] found that automated control of inhalational anaesthetic substantially decreased the additional burden on the anaesthetist and potentially increased the safety of anaesthetised patients. However, the automated control module does not change the amount of opioid anaesthetics delivered during the procedure, which suggests suitable saturation with inhalational anaesthetic and stability of the depth of anaesthesia. Similar conclusions were presented by Lortat [6]; in his study, however, target-controlled infusions (TCIs) of remifentanil were used.

CONCLUSIONS

1. General anaesthesia with manual and automated control (EtC) are equally stable and safe for patients, assuring an adequate depth of anaesthesia and haemodynamic stability.
2. The consumption of anaesthetic and oxygen was significantly increased in the EtC module group.
3. EtC substantially reduces the number of anaesthetist interventions during anaesthesia.

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2. Conflicts of interest — none.
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