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Effects of automatic gas control on sevoflurane gas monitor and recovery during pancreatico-duodenectomy operation: prospective randomized study

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ABSTRACT

Background: The aim of the study was to evaluate the effect of automatic gas control (AGC) on sevoflurane gas monitoring, safety, and recovery of patients during pancreatico-duodenectomy operation.
Methods: Forty patients scheduled for the pancreatico-duodenectomy operation were allocated into group I manual gas control group (MGC, $n = 20$) and group II AGC ($n = 20$) group. In (the MGC group): The vaporizer set ranged from 3 to 5% Sevoflurane until reaching 1 MAC, fresh gas flow (FGF) 1–2 L/min, and FiO_2 of 0.4 was set. In (the AGC group): Set target FiO_2 of 0.4, end-tidal anesthetic agent (EtSev was set to 1.5–2%) with safely ventilate the patient with an FGF down to 0.3 liters per minute. Hemodynamics, anesthesia gas analysis (FiSev, EtSev, FiO_2, and EtO_2), total gas consumption, extubation time, incidence of perioperative hypercapnia, hypoxia, and accidental awareness were recorded.
Results: The volume of sevoflurane administered in the MGC group was in a mean ± standard deviation of 81.20 ± 16.47 ml which was statistically significantly greater than that administered in the AGC group (58.80 ± 10.54), $P \le 0.001$. ETSevo, FISevo, and the EtO_2 were significantly larger in the MGC group than in the AGC group. The extubation time was statistically prolonged in the MGC group than in the AGC group (14.10 ± 4.75 versus 7.70 ± 1.59 min, $P <$ 0.001). No patient developed hypoxia, hypercapnia, or awareness in both groups.
Conclusion: AGC maintained the targeted end-tidal sevoflurane concentration with the least sevoflurane consumption. It reduced the manual adjustment of delivered sevoflurane and oxygen. General anesthesia with manual and AGC is safe and maintains hemodynamic stability.

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Automatic gas control-manual gas control; pancreatico-duodenectomy

1. Introduction

Reducing the inhalational agent's consumption, utilizing minimal flow, and monitoring the depth of anesthesia all are attempts to improve patient care and enhance recovery after surgery [1].

Modern anesthesia machines became programmed with progressing software to help decrease the inhalational agent's consumption with minimal flow, adding additional value with the depth monitors for reducing the economic cost of these inhalational agents. The automatic gas control (AGC) technique of inhalational anesthetic agents has been applied for both financial and safety issues.

AGC is prepared to attain the aimed end-tidal anesthetic agent you determine, with the desired speed ranging from 3 to 15 minutes. The risk of hypoxia is also reduced as FLOW-I's unique active O_2 guard functions are designed to reduce the risk of hypoxia [2]. The need for repeated manual control of the anesthetic agent, fresh gas flow (FGF), and O_2 was reduced as AGC automatically regulates the FGF and anesthetic agent supply according to the needed end-tidal anesthetic agent (EtAA) [3].

We can all set the AGC during standby or manual ventilation. After securing the airway, we switch to AGC and set the EtAA and the speed and then the AGC automatically sets fresh gas delivery. Safe more time for making other tasks during our work. AGC automatically reduces the FGF and agent delivery to the least values as the previously sited end-tidal is reached, qualifying safe low-flow anesthesia by reducing the consumed anesthetic agent, ecological benefits, cost-savings, and improved work performance [4].

We designed this study to primarily assess the effect of AGC on sevoflurane gas monitor and consumption (ml/h) during pancreatico-duodenectomy operation compared to the manual low-flow anesthetic technique; the secondary aim was to detect the safety and effect of AGC on recovery of the patients.

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2. Materials and methods

After approval of the Institutional Review Board of the National Liver Institute, the protocol number is 0019012020, and the Clinical Trial Registry (www.pactr.org) number is PACTR202008584308152. Informed consent was taken from patients who scheduled for pancreatico-duodenectomy operations from March 2020 to December 2021. Included patients were of either sex, adult patient, with body mass index (BMI) between 20 and 30 kg/m^2. Patients were randomly allocated into two groups based on target control of sevoflurane; group I manual gas control (MGC) group, $n = 20$ and group II AGC group, $n = 20$ [Figure 1].

On arrival to the operating room and before anesthetic induction, all patients were monitored by five-lead electrocardiography, non-invasive blood pressure, pulse oximetry, and capnography. Also, a nerve stimulator for neuromuscular blockade monitoring and EEG bispectral index (BIS VIEW monitoring system, Aspect Medical System, Norwood, MA, USA) BIS (CA, USA) for anesthesia depth monitoring were applied.

A peripheral intravenous cannula of 20 gauges was inserted in a dorsal vein of the left hand for anesthetic induction. The four electrodes of the electrical cardiometry (EC) (ICON monitor; Osypka Medical Inc., La Jolla, CA 92,037, USA) were applied.

After preoxygenation, induction of general anesthesia by fentanyl 2 µg/kg and propofol 1.5–2 mg/kg. Rocuronium 0.6 mg/kg. Anesthesia was maintained with a mixture of oxygen and air. Fentanyl 1 µg/kg/h was infused for intraoperative analgesia. Maintenance doses of rocuronium 0.15 mg/kg were administered after the detection of the first response to TOF stimulation (T1). After intubation, patients were connected to the FLOW-i anesthesia machine, and sevoflurane delivery was adjusted according to the allocated group to maintain BIS between 40 and 60. Patients randomly categorized in this double-blinded study using randomization table generated by permuted block technique with variable block size into:

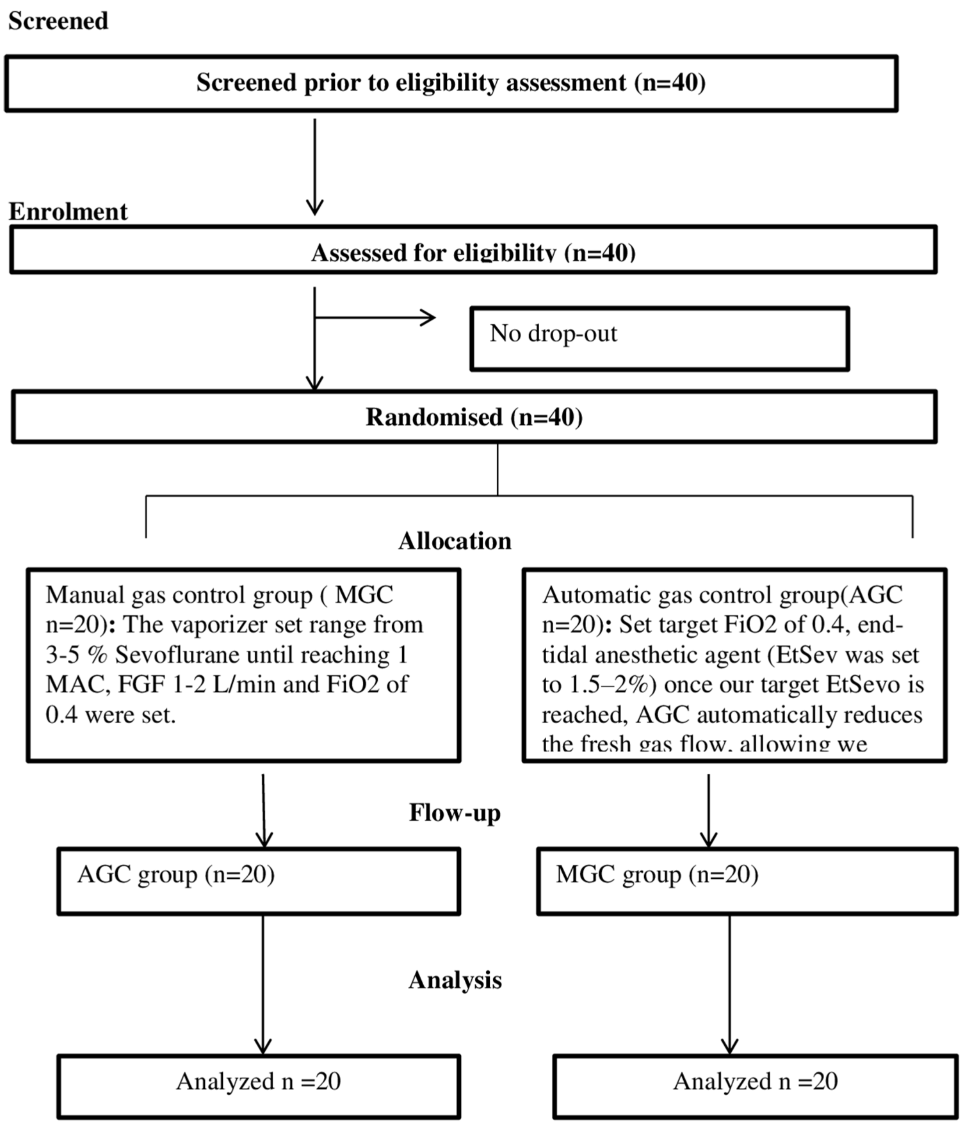

Figure 1. Flowchart of the studied groups.

MGC group (group I): The vaporizer set ranged from 3 to 5% Sevoflurane until reaching 1 MAC, free gas flow (FGF) 1–2 L/min and FiO_2 of 0.4 were set.

AGC group (group II): Set target FiO_2 of 0.4 and EtAA (EtSev was set to 1.5–2%). Once our desired EtSevo is reached, AGC automatically reduces the FGF for safe ventilation, and the patient with an FGF down to 0.3 liters per minute. Another advantage of FLOW-I is designed to reduce the risk of hypoxia with its unique active O_2GUARD™ function.

Maintenance of general anesthesia with Maquet FLOW-i in the two groups and mechanical ventilation in all patients adjusted to keep end-tidal CO_2 between 30 and 35 mmHg and SaO_2 greater than 95%. Additional rocuronium and fentanyl were administrated as appropriate in bolus doses.

A sonar-guided, right internal jugular vein triple-lumen central venous catheter was inserted. A 22-gauge angiocatheter was inserted in the left radial artery after doing the modified Allen test (for collection of arterial blood samples and measurement of invasive continuous arterial blood pressure), and a nasopharyngeal probe for core temperature measurement was applied. An indwelling urinary catheter was inserted once patients were asleep for urine collection. End-tidal fraction of oxygen (EtO_2), inspired fraction of oxygen (FiO_2), end-tidal concentration of sevoflurane (EtSev), and the fraction of inspired sevoflurane concentration (FiSev) were continuously monitored.

At the end of the surgery, all patients were planned for extubation on the table depending on recovery criteria after the complete reversal of muscle strength.

In the case of group II patients were extubated using the benefit of speed dial when surgeons remained for about 13 min to close the abdominal skin, we turned EtSevo to zero and adjust the speed bottom with a low-speed setting, resulting in a corresponding prediction of 17 minutes to reach the target ET.

In group I, sevoflurane was stopped after skin closure, and an FGF of 6 L/min was used till extubation criteria are fulfilled.

Patient's characteristics, hemodynamics (FiSev, EtSev, FiO_2, and EtO_2), and total sevoflurane used were recorded. Extubation time and interventions made by an anesthesiologist to control the target sevoflurane or FGF during surgery were recorded. The occurrence of hypoxia (SpO_2 less than 94%), hypercapnia ($EtCO_2$ more than 40 mmHg), and awareness during anesthesia assessed by Brice interview were recorded [5].

2.1. Sample size calculation

The response within each group was normally distributed with a standard deviation (SD) of 17.86. The primary outcome of this RCT was sevoflurane ml consumption between the experimental group and control group; a two-tailed analysis will be adopted. If the true difference in the experimental and control means is 20.5, we will need to study 17 subjects per group to reject the null hypothesis with a probability (power) of 0.9. The Type I error probability associated with this test of this null hypothesis is 0.05 [6,7].

2.2. Statistical analysis

The results were analyzed using SPSS-21 for windows. Using Kolmogorov–Smirnov as a test of normality by which detects that the data were normally distributed, parametric statistics were used. Data were described using mean and SD.

3. Results

Forty patients undergoing pancreatico-duodenectomy operation were randomized and equally divided into two groups. Patient characteristics in the control (MGC) group ($n = 20$) versus AGC group ($n = 20$) were comparable regarding age (61.05 ± 10.41 versus 54.95 ± 9.17 years, $P = 0.06$) and body mass index (26.35 ± 3.89 versus 26.13 ± 4.13 kg/m^2, $P = 0.86$). The male/female ratio was 16/4 in the MGC group and 13/7 in the AGC group, $P = 0.48$. Numbers of patients with DM, H, and IHD were comparable between groups without significant differences between them [Table 1]. No significant difference in operative time between MGC and AGC groups (8.28 ± 1.12 versus 8.55 ± 1.73 h, $P = 0.55$, respectively) was observed. Intraoperative values were taken automatically every 1 h. HR and MBP were similar in the two groups. Cardiometry variables denoted that no statistically significant differences between studied groups as regards cardiac output (COP) and systemic vascular resistance (SVR) (6.77 ± 1.94 versus 6.63 ± 1.30 L/min $P = 0.79$ and 907.70 ±

Table 1. Patient's characteristics.

Variable	AGC group ($n = 20$)	MGC group ($n = 20$)	P value
Age (years)	54.95 ± 9.17	61.05 ± 10.41	0.06NS
BMI (kg/m^2)	26.13 ± 4.13	26.35 ± 3.89	0.86NS
Sex (M/F)	13/7	16/4	0.48 NS
DM(Y/N)	3/17	4/16	1 NS
H (Y/N)	2/18	1/19	1NA
IHD (Y/N)	0/20	2/18	0.49NS
Duration of surgery (hrs.)	8.55 ± 1.73	8.28 ± 1.12	0.55NS

286.59 versus 892.11 ± 209.73 dynes. sec/cm^5, $P = 0.85$) in MGC and AGC groups respectively. Corrected flow time (FTc) was comparable and stable in the studied groups [Table 2]. No significant difference in the intraoperative fentanyl consumption between MGC and AGC groups (615.00 ± 98.81 versus 685.00 ± 142.44 mics, $P = 0.08$, respectively) was observed. The volume of the sevoflurane administered (Sevo) in the MGC group was in a mean ± SD (81.20 ± 16.47 ml) which was statistically significantly greater than that administered in the AGC group (58.80 ± 10.54), $P \leq 0.001$. ET Sevo was significantly larger in the MGC group than the AGC group (1.84 ± 0.05 versus 1.65 ± 0.06, $P < 0.001$) respectively [Table 3]. Both the FISevo and the EtO_2 were significantly larger in the MGC group than in the AGC group ($P < 0.001$ and $P = 0.01$, respectively). Regarding the level of consciousness, there were no statistically significant differences were detected between AGC and MGC groups in BIS readings. The extubation time was statistically significantly prolonged in the MGC than the AGC group (14.10 ± 4.75 versus 7.70 ± 1.59 min, $P < 0.001$). No patient developed hypoxia, hypercapnia, or awareness during anesthesia assessed POD1. In both groups, the mean of soda lime consumption was comparable between the studied groups with no statistically significant difference. There was a statistically significant increase in the mean of the total number of anesthetic interventions in the MGC group than AGC group (12.50 ± 1.88 versus 5.50 ± 1.19, $P < 0.001$), [Table 4].

Data expressed as mean ± SD; AGC: Automatic gas control group, MGC group: Manual gas control group, BMI: Body mass index; H: Hypertension; DM: Diabetes mellitus; IHD: Ischemic heart disease. NA: Not applicable.; SD: Standard deviation; NS: Not significant.;

Data were expressed as mean ± SD, tested by student *t*-test, *P*-value < 0.05 statistically significant. AGC: Automatic gas control group, MGC group: Manual gas control group; HR: Heart rate; MAP: Mean arterial blood pressure; SVR: Systemic vascular resistance (dyn.sec. cm^{-5}); COP: Cardiac output (Liters/min); FTC: Corrected flow time (ms); NS: Not significant.

Data expressed as mean ± SD; AGC: Automatic gas control group, MGC group: Manual gas control group, IOF: Intraoperative fentanyl; Sevo: Sevoflurane; ETSevo: End-tidal sevoflurane. FISevo: Fraction-inspired sevoflurane; EtO_2: End-tidal oxygen: FiO_2: Fraction-inspired oxygen; SD: Standard deviation; NS: Not significant; *Significance with other group ($P < 0.05$)

Data were presented as mean ± SD; tested by student t-test. AGC: Automatic gas control group, MGC group: Manual gas control group; NS: Not significant. *Significance with other group ($P < 0.05$); NS: Not significant; SD: Standard deviation.

4. Discussion

We evaluated the impact of adopting the AGC software on ETSevo compared to the manual low-flow anesthetic technique, guided by an anesthesia depth monitor; the main outcome, the mean sevoflurane consumption was significantly lower when AGC was applied with fewer interventions without harmful effect on the safety of the patients. Similar to our

Table 2. Intraoperative hemodynamics in the studied groups.

Data	AGC group (*n* = 20)	MGC group (*n* = 20)	*P* value
HR (beat/min)	92.39 ± 13.59	85.95 ± 13.75	0.15NS
MAP (mmHg)	78.01 ± 5.22	76.94 ± 6.82	0.58 NS
COP (Liters/min)	6.63 ± 1.30	6.77 ± 1.94	0.79NS
SVR (dyn.sec.cm^{-5})	892.11 ± 209.73	907.70 ± 286.59	0.85NS
FTC (msec)	328.16 ± 8.80	331.12 ± 10.04	0.33NS

Table 3. Anesthetic gas data in the studied groups.

Variable	Mean ±SD		*P value*
	AGC group (*n* = 20)	MGC group (*n* = 20)	
IOF	685.00 ± 142.44	7.70 ± 1.59	0.08NS
Sevo.	58.80 ± 10.54	81.20 ± 16.47	<0.001*
ETSevo.	1.65 ± 0.06	1.84 ± 0.05	<0.001*
FISevo.	1.88 ± 0.09	2.17 ± 0.04	<0.001*
EtO_2	43.32 ± 0.72	43.90 ± 0.67	0.01*
FiO_2	39.96 ± 0.11	39.93 ± 0.13	0.37NS
FiO_2	7.70 ± 1.59	14.10 ± 4.75	<0.001*

Table 4. BIS, soda lime consumed, and the number of interventions in the studied groups.

Variable	Mean ±SD		*P value*
	AGC group (*n* = 20)	MGC group (*n* = 20)	
BIS	56.15 ± 2.53	56.03 ± 2.11	0.87NS
Soda lime (ml)	263.00 ± 56.95	244.50 ± 41.74	0.25NS
No. of intervention	5.50 ± 1.19	12.50 ± 1.88	<0.001 *

results, Kanika Arora et al. [8], Tomasz Skalec et al. [9], and Wetz et al. [10] concluded that end-tidal control is the best method for maintaining oxygen and anesthetic gas concentrations stably and rapidly. Tomasz Skalec et al. [9] studied manual versus automatic control of anesthesia and found that both techniques are safe for patients with a reduction of the volatile agents and the number of key presses with the usage of AGC.

Agree with our results, Potdar et al. [11] and Tay et al. [2] used end-tidal control volatile agent and found a 44% lower in anesthetic gas consumption. Alrefay Kandeel et al. [12] made a study on 60 living donors undergoing right hepatectomy; they found a significant reduction in sevoflurane consumption when using AGC of EtSevo that supports our result. Lucangelo et al. [5], 2014 made a study that included 80 patients having elective abdominal surgery comparing automatic and manual control of low-flow anesthesia, and they found that both techniques provided the same clinical stability.

Disagree with our findings, de Cooman et al. [13] found that there was an increase in inhalational anesthetic consumption during anesthesia with the AGC technique. This could be explained by an increased level of end-tidal anesthetic. As well as the study did not use BIS monitoring so that the depth of anesthesia was obscure.

In our study, we also found hemodynamic stability all over the operative duration (HR and MAP) between two groups despite the significant difference between both groups in total consumption of sevoflurane; this could be explained by the high concentration of sevoflurane continued for a few minutes until the existing target value was carried out.

Similarly, studies done by Potder et al., Kandeel et al., and Lucangelo et al. reported no significant changes in hemodynamics when used AGC on their studies [5,11,12,].

In the current study, hemodynamic parameters were measured in both studied groups, including cardiac output and systemic vascular resistance by cardiometry with no statistically significant difference between them. This finding may be attributed to the added effect of BIS monitoring where there was no significant difference between both groups regarding the target level of BIS readings; therefore, deeper or lighter level of anesthesia was avoided.

In the current study, user interventions were significantly lower in the AGC group compared with the manual group. The mean number of adjustments needed to maintain the depth of anesthesia was 5.50 ± 1.19 per patient in the AGC group versus 12.50 ± 1.88 in the manual control group. Subsequently, AGC of sevoflurane substantially reduced the extra load on the anesthetist and potentially lead to increment the safety of the patients. The studies by Potdar et al., Tay et al., and Kandeel et al. reported a decrease in the number of anesthetic adjustments during the usage of end-tidal control technique [2,11,12]. Also, the study done by Singaravelu and Barclay reported a decreased number of interventions from 13.6 key presses with a manual control to 6.5 with end-tidal control [14].

In the current study, the extubation time was statistically significantly prolonged in the MGC group than in the AGC group (14.10 ± 4.75 versus 7.70 ± 1.59 min, $P < 0.001$). The speed button was useful in our study in extubation time as we adjusted it to MAC zero according to the remaining time in the surgery that have a beneficial effect on consuming the inhalational agent as well as rapid recovery and early extubation.

In our study, soda-lime consumption was similar between both groups. Disagree with our finding, Tay et al. [2] reported that the cause may be due to different canister designs that were used in each technique.

In the present study, we monitored depth of anesthesia; in addition, the BIS values were recorded over the period of the study and we found that there were no statistically significant changes in the BIS readings in both groups. Other studies used entropy monitor throughout their studies [15–17] and maintained it between 40 and 60 at all times. Locher et al. [18] evaluated the effectiveness of AGC using isoflurane on the depth of anesthesia by BIS monitoring, and they found that AGC using isoflurane with BIS monitoring can be safely used with better performance than manual control.

Our study found that there was no different in the amount of fentanyl used that may indicate that, convenient saturation and steadiness of the depth of anesthesia with sevoflurane adding the beneficial effects of CNS monitoring by BIS. Similar to our finding, Kennedy et al. [19] and Lortat et al. [20] used remifentanil target-controlled infusions in their study.

Our study revealed that there were no incidences of perioperative hypoxia, hypercapnia, and over- or underdosage of anesthetic in both groups. Our study revealed that no patient developed awareness in either group which was coincided with continues CNS monitoring using BIS. Kandeel et al and Tay et al. [12,13] coincide with our finding and approved this also.

There are many risks with manual adjustment of the vaporizer, for controlling the concentration of anesthetic and FGF rates [21]. For economic issues, anesthetists use low-flow anesthetic techniques to reduce the cost of volatile agents [14]. All these factors encourage the usage of AGC adding the ecological benefits to it.

In conclusion: AGC maintained the targeted end-tidal sevoflurane concentration with the least sevoflurane consumption. It reduced the manual adjustment of delivered sevoflurane and oxygen, which led to reducing the burden on the anesthetist. General anesthesia with manual and AGC is safe and maintains hemodynamic stability and adequate depth of anesthesia.

The limitation: more studies need to be designed among a larger population to investigate AGC and its effect on cost-saving without affecting hemodynamics.

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