Comparison of Effectiveness between Gas Flow 1 And 2 L.Min^{-1} for General Anesthesia in Infants and Children

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Objectives : *To determine 1) Success rate of using fresh gas flow (FGF) 1 l.min^{-1} compared to 2 l.min^{-1} in pediatric patients 2) Necessity of using anesthetic agent analyzer 3) predicting volatile anesthetic concentration 4) cost difference*

Method : *Seventy-seven patients (age 10 days to 8 years) who underwent general anesthesia were randomly allocated into 2 groups: the control group (FGF 2 l.min^{-1}) and the study group (FGF 1 l.min^{-1}). Outcome measures included system leakage, SaO_2, P_ECO_2, FiO_2, Fi and FeN_2O, isoflurane dial setting, Fi and Fe isoflurane, isoflurane mass consumed and sodalime used.*

Results : *There was no difference between the groups regarding demographic data, duration of surgery and anesthesia. Success rate in using FGF 2 l.min^{-1} was 100% and FGF 1 l.min^{-1} was 92%. All failure cases (8%) were due to system leakage. The necessity of using a capnometer was similar at 5.3-7.7% in both groups. FiO_2 was $\geq$ 0.3 at any time. FiN_2O and FeN_2O were not different. Fi isoflurane was 13-15% lower than dial setting. Overall savings from using FGF 1 l/min was 37.8%.*

Conclusion : *FGF 1 l.min^{-1} could be safely used in most pediatric patients with lower cost. Capnometer was recommended, whereas FiO_2 and Fi isoflurane could be clinically adjusted.*

Keywords : *Low flow anesthesia, Infant, Children*

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Economic crises and the national health policy have induced cost constraints which health care providers are increasingly forced to deal with. As a result, there has been a revival of interest in the use of low-flow anesthetic techniques with circle absorber breathing systems in adult practice in order to minimize waste of expensive volatile anesthetic agents, to reduce atmospheric pollution and to conserve humidity and body temperature[1,2]. Even though, Perkins and Meakin (1996) found that this technique could save 58% of the isoflurane and 54% of fresh gas flow[3], there have been doubts and concerns over the safety of adopting the low-flow method in children.

Low flow anesthesia in pediatric patients was reported to be safe with additional monitoring of anesthetic gas and agent analyzer. Inspired oxygen concentration and inspired-expired concentration of inhaled anesthetics are not similar to the dial setting[5].

In developing countries where anesthetic and agent analyzers including capnometer, are not available country-wide, the savings of low flow anesthesia in infants and children might not outweigh the expensive monitoring required. This study aimed to determine 1) The success rate of using fresh gas flow 1 l/min (study group) compared to 2 l/min (control group) in pediatric patients 2) The necessity of using anesthetic gas and agent analyzer 3) Predicting volatile anesthetic concentration during low- flow anesthesia in children 4) Cost comparison of the 2 flow rates.

Material and Method

After approval from the Institutional Research Ethic Committee and parental consent, infants and children (age 1 month to 8 years, ASA physical status I or II) who underwent surgery that lasted at least 1 hr

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were enrolled in this study. Chloral hydrate 50mg/kg or diazepam 0.1 $mg.kg^{-1}$ was given orally for premedication in children. No premedication was given in infants. Patients were randomly allocated into 2 groups by using a random number table and concealed envelopes. The controlled group received fresh gas flow (FGF) 2 $l.min^{-1}$ and the study group received FGF 1 $l.min^{-1}$. Each group was stratified into 3 strata according to 1) age group being infants (< 1 year) and children (1-8 year) 2) Type of anesthesia (general anesthesia alone or combined with regional anesthesia and 3) type of ventilator used (pressure or volume limited).

Ohmeda EXCEL 210 or ULCO anesthesia machine with a complete leak test and pediatric circle system with minimal dead space connector and a 15-mm flexible light weight plastic tube were used. Upward operating bellows were used in all types of ventilators. All patients were continuously monitored with automated blood pressure, electrocardiography, precordial stethoscope and esophageal temperature probe. Warming blankets, heated mattresses, covers and evaporative heat loss prevention techniques were used in all patients. Inspired and expired concentration of anesthetic gases and volatile agents including end tidal carbon dioxide (side stream) were continuously monitored by using Datex-Ohmeda ULTIMA gas analyzer and recorded by an independent observer at 15, 30, 45, 60, 90, 120, 150 and 180 min from initial flow reduction. Sampling gas for analysis was then returned to the anesthetic circuit. This equipment was not visible to the anesthetists who took care of the patients.

Anesthesia was induced with either sevoflurane inhalation or intravenous thiopentone, the trachea was then intubated under succinyl choline 1.5 $mg.kg^{-1}$ or atracurium 0.6 $mg.kg^{-1}$. Uncuffed tracheal tube of appropriate size with minimal leak in the usual working range of 20-25 cmH_2O was used. Anesthesia was maintained with nitrous oxide or air and isoflurane. Inspired oxygen concentration was adjusted at 50%. Balanced anesthesia was supplemented with muscle relaxant (atracurium) and regional block or narcotics (fentanyl) as appropriate. Artificial ventilation was started with peak airway pressure 15-20 cmH_2O or tidal volume 7 $ml.kg^{-1}$ and respiratory rate as appropriate to age group, and adjusted until end tidal CO_2 partial pressure (P_ECO_2) of 30-35 mmHg.

All patients received high flow gas of 6 $l.min^{-1}$ for 15 min, then total flow was reduced to 2 $l.min^{-1}$ in the control group and to 1 $l.min^{-1}$ in the study group. Isoflurane was adjusted according to the clinical depth of anesthesia and turned off 10-15 min before the operation was finished. A low flow rate was maintained until the operation was finished, then oxygen 6 $l.min^{-1}$ was turned on.

Failure of using each flow rate was defined as 1) leakage in the system detected by inadequate bellow filling, 2) $SpO_2 \leq 95\%$ 3) $P_ECO_2 \geq 46$ mmHg in spite of the correction of hypoventilation. If failure occurred, then the low flow rate would be increased another 1 $l.min^{-1}$. Patients with $P_ECO_2 \geq 46$ mmHg without any abnormal signs were recorded as necessity of using capnometer monitoring.

Savings from each group were studied by comparing the sum of average cost of isoflurane mass consumed per min, the average cost of soda lime used per min and the average cost of fresh gas flow. Before a new case started, the vaporizer was drained until empty. Then the vaporizer was filled with isoflurane before use and drained after use. The mass of isoflurane consumed was calculated by subtracting the weight of isoflurane left after first filling from the weight of isoflurane left after use at the conclusion of the operation session. The duration of using a canister of sodalime until all granules' color changed was recorded. Each canister was used for each flow. Predicting volatile anesthetic concentration during low- flow anesthesia was calculated by subtracting the average difference between the dial setting and inspired concentration of isoflurane from the dial setting of isoflurane.

Sample size was estimated based on equivalent trial. From world-wide practice[4] and a pilot study, the success rate of using FGF 2 l/min flow rate was 100%. By using an equivalent limit difference of 10%, one sided test with α error of 0.05 and power 90%, sample calculated from nQuery Advisor program was 24 per group. Independent continuous data was analyzed by using an unpaired Student t-test for parametric data and Mann Whitney U test for non parametric data. Independent categorical data was analyzed by using Chi square or Fisher Exact test. P value of less than 0.05 was considered statistically significant.

Results

Seventy-seven infants and children (aged 4 months to 7 years, body weight ranging from 3 to 20 kg) were enrolled in the present study. There was no difference between the study and control groups regarding age, ratio of infants and children, body weight, anesthetic technique, type of ventilator used, type of surgery, anesthetic time, operation time and low flow duration (Table 1,2). Success rate in using FGF 2 l/min in the control group was 100%(39/39) com-

Table 1. Demographic data

Demographic data	Controlled gr (2 l.min^{-1}) n = 39	Study gr (1 l.min^{-1}) n = 38	p-value
Age [year,median (IQR)]	1.5 (0.83-2)	2 (0.775-3.5)	0.195**
Infants n(%)	14 (35.9)	12 (31.6)	0.810#
BW (kg, mean ± SD)	10.6718±4.1820	11.3132±3.9281	0.490*
Type of surgery n (%)			
-Head-neck n (%)	13 (33.3)	11 (28.9)	0.902#
-Abdomen n (%)	10 (25.6)	10 (26.3)	
-Urogenital surgery n (%)	1 (2.6)	2 (5.3)	
-Groin-perineum n (%)	10 (25.6)	11 (28.9)	
-Extremity n (%)	3 (7.7)	3 (7.9)	
-Superficial n (%)	2 (5.1)	1 (2.6)	
Operation time [min, median (IQR)]	130 (90-197)	126 (85-219)	0.702**

* Unpaired t-test, # Chi square, ** Mann Whitney U test
IQR = Inter Quartile Range

Table 2. Anaesthetic data

Anaesthetic data	Controlled gr (2 l.min^{-1}) n = 39	Study gr (1 l.min^{-1}) n = 38	p-value
Anaesthetic technique			
General: General + regional	18:21	17:21	0.999#
Type of ventilator			
Pressure:Volume limit	17:22	19:19	0.650#
Anaesthetic time [min, median (IQR)]	165(120-241)	175(115-285)	0.498**

Chi square ** Mann Whitney U test

pared to 92%(35/38) in the study group, but this was not statistically different. The reason for failure in all 3 patients of the study group was an inadequate volume in the circuit. Endotracheal tube size was appropriate in 1 patient and was bigger than calculated in 2 patients (calculated size of uncuffed tube = [age(yr) /

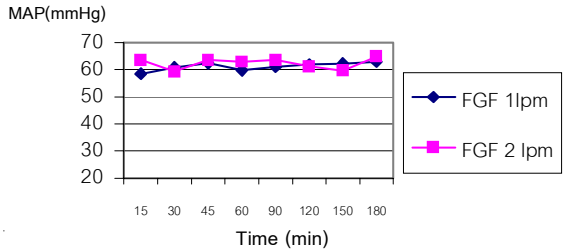

Fig. 1 Mean arterial pressure change during flow reduction

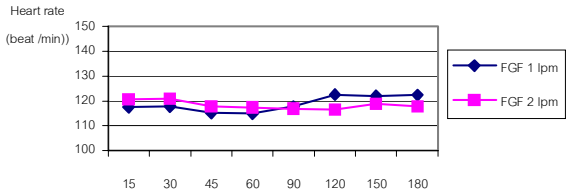

Fig. 2 Heart rate change during flow reduction

4] + 4). The necessity of using a capnometer and the need to use a bigger size endotracheal tube in order to minimize leakage was not different between the two groups. Duration from isoflurane termination until recovery was significantly longer in the study group, but duration from low flow termination until recovery was not different (Table 3).

Mean arterial pressure, heart rate, arterial oxygen saturation and $PECO_2$ were not different at any time recorded (Fig. 1-4). Body temperature rose from the initial period in both groups. Better heat conservation was noticed in the study group, but without statistical significance (Fig. 5). Inspired oxygen concentration (FiO_2) was not different between the two groups and not less than 0.3 at any time (Fig. 6). Inspired and expired N_2O concentration were not different in each pair at any time or between groups (Fig. 7). Inspired isoflurane concentration was about 13-15% lower than the dial setting in both groups (Fig.

Table 3. Outcome regarding low flow anaesthesia

Outcome	Controlled gr (2 l.min^{-1}) n = 39	Study gr (1 l.min^{-1}) n = 38	p-value
Success rate of using each flow n (%)	39(100)	35(92.1)	0.115$
Necessity of using capnometer n (%)	3(7.7)	2(5.3)	1.000$
Need of bigger size endotracheal tube n (%)	10(25.6)	10(26.3)	1.000#
Duration from isoflurane ceased until recovery [min, median (IQR)]	5(4-13)	12(7.5-18.5)	0.010**
Duration from low flow ceased until recovery [min, median (IQR)]	5(2-10)	5(2.5-10)	0.120**
Low flow duration [min, median (IQR)]	138(86.5-195.5)	120(87-220)	0.907**

$ Fisher's exact test # Chi square test ** Mann Whitney U test

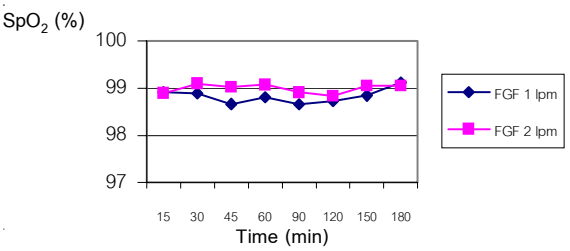

Fig. 3 Change of arterial oxygen saturation during flow reduction

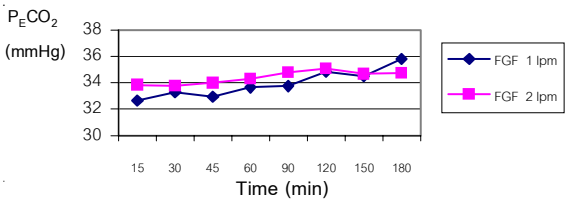

Fig. 4 Change of end tidal carbon dioxide during flow reduction

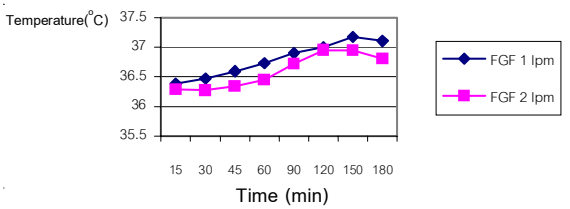

Fig. 5 Change of temperature during flow reduction

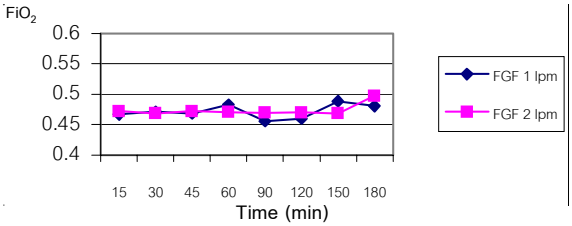

Fig. 6 Change of inspired O_2 concentration during flow reduction

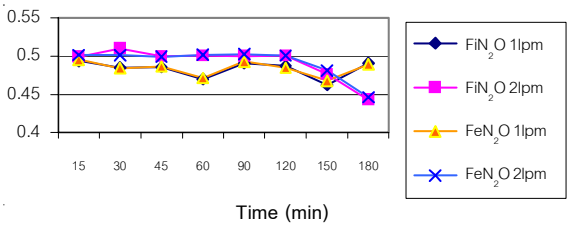

Fig. 7 Change of inspired and expired concentration of nitrous oxide during flow reduction

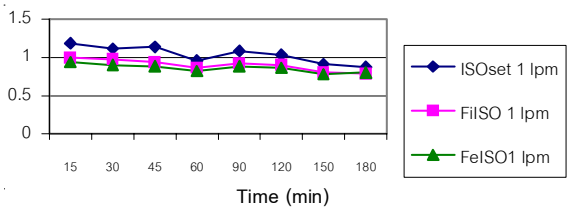

Fig. 8a Change of isoflurane dial setting, inspired and expired concentration during FGF 1 l/min

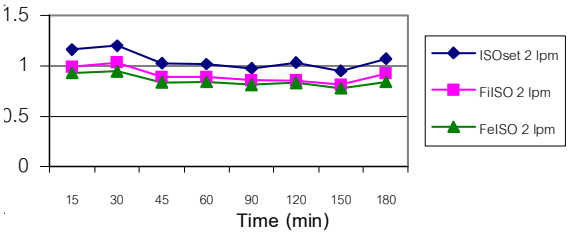

Fig. 8 b Change of isoflurane dial setting, inspired and expired concentration during FGF 2 l/min

8). A body temperature higher than 38 C was detected in a patient from the study group but responded to termination of warming devices. A patient in the control group developed hoarseness after surgery which was relieved by intravenous dexamethasone. In addition, using FGF 1 l/min could save 39.6% of isoflurane and 50% of FGF, but spent 78.4% more on sodalime cost. Nevertheless, the overall savings from using FGF 1 l/min was 37.8% (Table 4).

Discussion

Lower FGF as 1 $l.min^{-1}$ did not result in hypoxic FGF mixture nor did it lead to significant rebreathing of CO_2 compared to higher FGF as 2 $l.min^{-1}$. Pediatric circle system with minimal dead space connector and 15 mm flexible light weight plastic tube could be safely used in infants and children[5]. The success rate of using FGF 1 and 2 $l.min^{-1}$ was determined to be equivalent

Table 4. Comparison of average cost in using flow rate 2 and 1 $l.min^{-1}$

Average cost	Control gr (2 $l.min^{-1}$) (Baht)	Study gr (1 $l.min^{-1}$) (Baht)
-Average cost of isoflurane mass consumed/min	2.405	1.4526
-Average cost of soda lime used/min	0.0124	0.0575
-Average cost of fresh gas flow/min N_2O: O_2 1:1	0.06245	0.03122
Total	2.4799	1.5418

based on difference < 10% and sufficient power > 90%. Three patients aged 10 months, 4 years and 5 years in the study group were not able to maintain sufficient volume in system by FGF 1 $l.min^{-1}$. The reason might be related to a leak around the tracheal tube which might have developed later due to higher positive ventilatory pressure, more relaxed vocal cord (not completely paralyzed during intubation). An increase of FGF to $l.min^{-1}$ could completely compensate for the leakage in all 3 cases. Previously, the use of a lower FGF of 600 $ml.min^{-1}$ was reported to be successful, used with safety and efficacy[6]. In that trial, semi-closed circle ventilation of the Drager anesthesia ventilator (Cicero, Cato) that had a built-in safety mechanism for insufficient system volume by automatically adding air to the breathing system was used. Therefore, in general practice where a special ventilator is not available, lower FGF of 1 $l.min^{-1}$ was safe in most cases with both pressure and volume limited ventilators. Should system leakage occur, it is readily corrected by increasing the FGF to 2 $l.min^{-1}$.

Risk of decreasing FiO_2 in the circuit during low flow anesthesia was reported in adults[7]. This could be explained by the fact that the initial calculated FiO_2 did not entirely compensate for the patient's oxygen consumption. In infants, oxygen consumption per kilo body weight (6-8 ml/kg/min) is higher than adults (3.3 $ml.kg^{-1}.min^{-1}$)[6]. As the total oxygen consumption of infants is low, slight inadequacies between added FiO_2 and the consumption will affect the circuit gas composition less than in adults. In the present study, the oldest child was 7 years old, weighed 19.7 kg, and the oxygen consumption was 150 $ml.min^{-1}$ [8]. In the lower flow group with FGF 1 $l.min^{-1}$, the lowest initial calculated FiO_2 was 0.4 (dial setting O_2: N_2O = 400:600 ml, O_2: air = 250: 750 ml) which would lead to sufficient FiO_2 of at least 0.25. The present study has justified this simplification of infants' and children's oxygen need by using initial calculated FiO_2 of 0.5, since the FiO_2 as well as the SaO_2 readings remained in the safe range and were relatively constant.

Retention of CO_2 ($PECO_2 \geq 46$ mmHg) was found in 3 cases(7.7%) from the control group (FGF 2 $l.min^{-1}$) and in 2 cases(5.3%) from the study group (1 $l.min^{-1}$). The authors presumed that the P_ECO_2 values found provided an accurate approximation of the arterial CO_2 tension since the gas mixture was sampled at the tracheal tube by the use of neonatal adapter[9]. In some children, precalculated preset ventilation volumes proved inadequate during the course of anesthesia. One patient had an increased body temperature which might increase metabolism. Further studies are needed to investigate these mechanisms. Therefore, a capnometer is necessary not only for low flow but also for medium flow anesthesia in infants and children.

In adults, low flow anesthesia with moderate soluble anesthetic agents such as halothane, enflurane, isoflurane requires significant increase in the vaporizer setting after flow reduction (60-130%)[10]. According to Lin CY's formula, the dial setting to achieve 1% isoflurane in FGF 1 $l.min^{-1}$ is derived from uptake of isoflurane 1% (12 $ml.min^{-1}$) times 100 divided by 1000 $ml.min^{-1}$, equals to 1.2%[11]. The difference from inspired concentration and dial setting was about 20%. In the present study inspired isoflurane concentration was about 13-15% lower than the dial setting.

Low-flow anesthesia could conserve heat effectively during anesthesia as well as medium flow and did not prolong recovery after high flow was restarted. Postintubation croup was found in a patient using an endotracheal tube that was larger than the precalculated size. However, it was reported that actual endotracheal tubes used varied from the calculated size in 35% of children under than 6 years[12]. There might be reasons for croup other than the use of a large endotracheal tube such as trauma during intubation, coughing on tube, change of head position and prolonged surgery[13].

Cost in using FGF 1 $l.min^{-1}$ was 37.8% less than FGF 2 $l.min^{-1}$ based on the cost of isoflurane, sodalime, N_2O and oxygen in the authors' hospital. The cost of the anesthetic gas and agent analyzer including the capnometer were not included since the anesthetic gas and agent analyzer could be safely adjusted by clinical prediction and a capnometer was necessary in both groups.

In summary, FGF 1 $l.min^{-1}$ could be safely used if there is no system leakage at a lower cost compared to FGF 2 $l.min^{-1}$. Should system leakage occur, it is readily corrected by increasing FGF to 2 $l.min^{-1}$. A capnometer was recommended in both types of FGF, whereas FiO_2 and inspired isoflurane concentration could be clinically adjusted.

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การเปรียบเทียบประสิทธิภาพของการใช้อัตราการไหลของก๊าซ 1 และ 2 ลิตร/นาที ในการดมยาสลบสำหรับผู้ป่วยเด็กและทารก

สุวรรณี สุรเศรณีวงศ์, สุมิตรา เชาวนโยธิน, แสงโสม ปิรยะวราภรณ์, ทรงยศ วลัยฤาชา, นัยนา อรุณพฤกษากุล, สมศักดิ์ อารีวัฒนา

วัตถุประสงค์ *: เพื่อเปรียบเทียบ 1) ความสำเร็จในการดมยาสลบโดยการใช้อัตราการไหลของก๊าซต่ำ 2) ความจำเป็นในการใช้เครื่องวิเคราะห์ความเข้มข้นของก๊าซและยาดมสลบ 3) ความเข้มข้นของยาดมสลบที่ผู้ป่วยได้รับเมื่อเทียบกับที่ตั้งไว้ในเครื่อง 4) ความแตกต่างของต้นทุน เมื่อใช้อัตราการไหลของก๊าซ (FGF) 1 ลิตร/นาที และ 2 ลิตร/นาที สำหรับดมยาสลบในผู้ป่วยเด็กและทารก*

วิธีการศึกษา*: ผู้ป่วยเด็กและทารกจำนวน 77 ราย (อายุ 10 วัน ถึง 8 ปี) ที่มารับการดมยาสลบ ได้รับการแบ่งเป็น 2 กลุ่มแบบสุ่ม กลุ่มควบคุมได้รับ FGF 2 ลิตร/นาที และ กลุ่มทดลองได้รับ FGF 1 ลิตร/นาที บันทึกการรั่วในวงจรดมยาสลบ, SaO_2, P_ECO_2, FiO_2, Fi และ FeN_2O, isoflurane dial setting, Fi และ Fe isoflurane, ปริมาณ isoflurane และ sodalime ที่ใช้*

ผลการศึกษา *: ไม่พบความแตกต่างในข้อมูลพื้นฐาน, ระยะเวลาผ่าตัดและได้รับยาสลบ ความสำเร็จในการใช้ FGF 2 ลิตร/นาที เท่ากับ 100% และ FGF 1 ลิตร/นาที เท่ากับ 92% รายที่ไม่สำเร็จเกิดจากการรั่วในวงจรให้ยาสลบ ความจำเป็นในการใช้ capnometer ไม่แตกต่างในทั้ง 2 กลุ่ม (5.3 - 7.7%) ค่า FiO_2 ไม่น้อยกว่า 0.3 ในทั้ง 2 กลุ่ม Fi N_2O และ FeN_2O ไม่แตกต่างกัน Fi isoflurane มีค่า 13-15% ต่ำกว่าค่าที่ตั้งจากเครื่องดมยาสลบ ต้นทุนของกลุ่มทดลองต่ำกว่ากลุ่มควบคุม 37.8%*

สรุป *: FGF 1 ลิตร/นาที สามารถใช้ได้อย่างปลอดภัยในผู้ป่วยเด็กและทารก โดยมีต้นทุนถูกกว่า capnometer เป็นเครื่องเฝ้าระวังที่จำเป็น ขณะที่ FiO_2 และ Fi isoflurane สามารถปรับโดยอาศัยอาการอาการทางคลินิค*