

ORIGINAL ARTICLE

A Qualitative Study of the Practice Preferences for Low and Minimal Fresh Gas Flow Anesthesia Using In-Depth Interviews

Tanawadee Teeratchanan MD FRCAT¹,  Kulwadee Limpanawat RN²

¹ Department of Anesthesiology, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok 10300, Thailand

² Department of Nursing, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok 10300, Thailand

Corresponding author

Tanawadee Teeratchanan
tanawadee@nmu.ac.th

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ABSTRACT

Objectives: This study primarily aimed to explore the preferences of anesthesia personnel for low (0.5–1.0 L·min⁻¹) and minimal (< 0.5 L·min⁻¹) fresh gas flow (FGF) techniques. The secondary objective was to identify factors influencing their decision-making.

Materials and Methods: After ethics approval, data were collected through in-depth interviews and nonparticipant observation over a 2-month period—from December 2022 to January 2023. This study included four anesthesiologists and six nurse anesthetists.

Results: All participants were females, and 30% were aged 31–40 years. Moreover, 40% had < 5 years of experience in anesthesiology. The duration of clinical practice ranged from 3 months to 28 years (median and mean of 6 years and 10.7 years, respectively). Additionally, 60% were not permanently assigned to a specific anesthesia service. Regarding FGF, 50% used 1.0–1.5 L·min⁻¹, only 30% used 0.5–1.0 L·min⁻¹, and none used < 500 mL·min⁻¹. Five key factors influenced decision-making: personal factors (clinical knowledge and previous hand-on experience), equipment factors (appropriate equipment and monitoring support), patient factors (patient safety concerns and characteristics of the individual patient), institutional factors (practices, policies, and norms of the department), and environmental awareness factor (climate concern).

Conclusion: Low and minimal FGF anesthesia are not yet widely favored by anesthetic personnel in Vajira Hospital. This study shows that the routine use of low and minimal FGF anesthetic technique is influenced by various factors. Although knowledge and hands-on experience are crucial, decisions are also influenced by opinions of coworkers, hospital policies, standard practices, availability of monitoring and equipment, and healthcare financing models such as impact of fix-payment system. All of the abovementioned pose significant barriers to promote the safe and sustainable use of low and minimal FGF techniques.

Keywords: in-depth interviews, low-flow anesthesia, minimal-flow anesthesia, sustainable

INTRODUCTION

The use of low fresh gas flow (FGF) has been proposed as a method for providing general anesthesia since 1995.¹ In 1997, Baxter² presented six categories of flow rates of gases through anesthetic circuits, which remains well-accepted and currently in use: metabolic flow, rate of $< 250 \text{ mL}\cdot\text{min}^{-1}$; minimal flow, rate of $250\text{--}500 \text{ mL}\cdot\text{min}^{-1}$; low flow, rate of $500\text{--}1,000 \text{ mL}\cdot\text{min}^{-1}$; medium flow, rate of $1\text{--}2 \text{ L}\cdot\text{min}^{-1}$; high flow, rate of $2\text{--}4 \text{ L}\cdot\text{min}^{-1}$; and very high flow, rate of $> 4 \text{ L}\cdot\text{min}^{-1}$.

Notably, low and minimal FGF techniques have several advantages. They decrease the amount of inhaled anesthetic agents received by the patient; are cost-effective^{3,4}; help maintain normal body temperature and humidity levels^{5,6}; decrease contamination of anesthetic gases in the operating room^{7,8}; and lower the release of these gases, many of which are greenhouse gases, into the environment.^{9,10} As mentioned above, the remarkable low blood and tissue solubility characteristic of third-generation inhaled anesthetics (e.g., desflurane and sevoflurane) together with the development of modern anesthesia machines and vaporizers promotes the adoption of low and minimal FGF as standard practice.^{11,12}

However, several drawbacks of low and minimal FGF anesthesia may obstruct its wider adoption in clinical practice. Implementing low FGF requires continuous monitoring of both oxygen and anesthetic concentrations. Moreover, flow should be frequently adjusted to ensure patient safety,¹³ and CO_2 absorbents are consumed at a higher rate, increasing the risk of hypercapnia and warranting frequent replacements.^{13,14} Additionally, unwanted or toxic gases such as trace gases (e.g., carbon monoxide, compound A, acetone, and methane) may accumulate in the breathing circuit during low FGF anesthesia.^{14,15}

However, at Faculty of Medicine Vajira Hospital, no study has been conducted on the use of low and minimal FGF in anesthetic services. Therefore, this study aimed to investigate the usage behaviors of anesthetic personnel regarding this technique to assess its popularity and identify factors influencing the decision to use it. This will provide a deeper understanding of how and why anesthetic personnel choose to adopt low and minimal FGF methods and may serve as basis for future research or policy changes.

MATERIALS AND METHODS

This study was qualitative in nature. The sample size was determined based on the case study design, that is, approximately 4–10 cases.¹⁶ The participants consisted

of 10 anesthetic personnel from Vajira Hospital: 4 anesthesiologists and 6 nurse anesthetists who were selected through purposive sampling, with varying years of work experience, age, and anesthetic service unit, and chosen based on the eligibility criterion of having given their consent to participate in the 40-minute observation and 20–40-minute interview.

Data collection was initiated in December 2022, subsequent to ethical approval from the Research Ethics Committee (COA number 170/2565 and subsequent renewal approval to extend the duration beyond the original expiration date). Comprehensive written and verbal information about the study was provided to the anesthesia personnel. For the nonparticipant observation, observers were instructed to maintain a natural and nonintrusive presence to avoid causing discomfort or altering participants' behavior. Observers were not permitted to engage in conversation, provide opinions, and influence participants in any way. The participants retained the right to withdraw from the observation at any point without consequence.

The in-depth interviews were started by an open-ended question by two interviewers who were trained in simulation-based mock interviews, scenario analysis, and rehearsals, emphasizing appropriate language, tone, and demeanor collaborated with the research team to refine their interviewing skills and ensure the credibility, accuracy, and comprehensiveness: "Can you describe your experiences using low flow or minimal FGF anesthesia in your daily clinical practice?" Then, follow-up questions were asked (Table 1). The verbatim transcripts have been analyzed in thematic framework.

Each interview and observation were immediately transcribed verbatim following its completion and was subsequently reviewed multiple times to facilitate a comprehensive understanding of the participants' perspectives. The participants' confidentiality was maintained by omitting their names from the transcribed interview data. To ensure accuracy of the transcriptions, the texts were shared with participants for verification, and their feedback was documented accordingly. An inductive qualitative content analysis (themes emerge from the data) was conducted. The verbatim transcripts were reviewed to generate initial codes, which were then clustered and condensed into overarching themes. Data, through iterative coding and pattern grouping, five main themes were identified. External supervisors with experience in qualitative research were approached for conformability of findings and coding agreement.

Table 1 Semi-Structured Guide of Open-Ended Questions

First Question	Can you describe your experiences using low flow or minimal FGF anesthesia in your daily clinical practice?
Guiding Questions	What led you to decide on that specific flow rate?
	What influenced your decision to use low flow or minimal FGF?
Exploring Questions	Can you describe a <i>recent case</i> when you decided to use low flow or minimal FGF anesthesia? What factors influenced your choice?
	Can you describe a case where your <i>past experience</i> led you to start with low flow or minimal FGF? What about that case made you trust it was appropriate?
	Could you describe a case where <i>patient characteristics</i> influenced your choice of FGF rate? How does the <i>patient's physiology</i> influence your decision between low versus traditional flow?
	How does your <i>department</i> generally view low-flow anesthesia—supportive, neutral, or resistant?
	Can you share your experiences with <i>equipment</i> limitations when attempting low-flow anesthesia?
	How do you <i>monitor inspired and expired oxygen, carbon dioxide and anesthetic agent concentrations</i> during low-flow anesthesia? Can you describe how that informs your decisions?
	Can you describe how concerns about <i>environmental impact</i> like anesthetic gas emissions influence your decisions regarding low flow or minimal FGF?

Abbreviation: FGF, fresh gas flow

RESULTS

At baseline, the characteristics of the study participants are presented in **Table 2** and reflect the initial demographic and clinical features of the enrolled population. The study findings indicate that only approximately 30% of anesthesia personnel at Vajira Hospital routinely employed low FGF anesthesia technique, consistent with findings of previous unpublished surveys among anesthetic personnel at Vajira Hospital that reported usage rates between 25% and 33%. Furthermore, the findings reveal that no personnel routinely utilized minimal FGF anesthesia technique despite the 100% use of third-generation inhalational anesthetics at Vajira Hospital (desflurane and sevoflurane, 51% and 49%, respectively). To identify the determinants of their decision-making process, interview and nonparticipant observation data were analyzed. We conducted thematic analysis: we coded all interview transcripts line by line and identified recurring concepts. Then similar codes were grouped into preliminary themes. Themes raised by participants (informants) as summarize and show in **Table 3**. After that, themes were tested against all transcripts — we looked for whether additional data *reinforced* these themes or introduced *new themes*. After around 7–10 interviews, no new themes emerged; additional interviews simply confirmed existing ones. At this stage, the thematic structure was stable — indicating saturation.

Analysis revealed five primary themes: *personal factors*, *equipment factors*, *patient factors*, *institutional factors*, and *environmental awareness factors*, as show in the **Table 4**.

After grouping the patterns into themes, deriving a hierarchical structure was performed: e.g. How themes relate conceptually. In cases with several emergent themes, which theme is most prominently influential. From the inductive analysis, we found that among these five factors influencing decision-making, certain aspects of decision-making hierarchy were observed. Interestingly, the institutional factor was the most influencing factor, and the environmental concern factor was the least influencing factor. Visualize the structure to hierarchy diagram as shown in **Figure 1**.

DISCUSSION

This study was conducted from December 2022 to January 2023. In some aspects, the information available at that time may differ from current circumstances. The anesthetic machines and monitoring systems may have been replaced with more modern equipment, or the increasing environmental awareness over time may have a greater impact on decision-making. Further research may be required to confirm the results.

The baseline characteristics of the participants, all of whom were females, reflected the reality at the

Table 2 The Baseline Characteristics and Frequency of Fresh Gas Flow Routine Used by Anesthetic Personnel

Category	Number (n)	Percentage (%)
Sex		
Male	0	0
Female	10	100
Professional group		
Physician	4	40
Nurse anesthetist	6	60
Age group		
21-30 years	2	20
31-40 years	3	30
41-50 years	3	30
51-60 years	2	20
Years of experience in anesthesiology		
Less than 5 years	4	40
5-10 years	2	20
11-15 years	1	10
16-20 years	3	30
Anesthesia service unit		
No specific unit	6	60
Cardiovascular surgery	1	10
Pediatric surgery	0	0
Urologic surgery	0	0
Neurosurgery	0	0
Orthopedic surgery	0	0
Others: ENT surgery	1	10
OBG surgery	1	10
Vascular surgery	1	10
Routine FGF rate used		
Less than 0.5 L/min	0	0
0.5 L/min	0	0
0.5–1.0 L/min	3	30
1.0–1.5 L/min	5	50
1.5–2.0 L/min	2	20
More than 2.0 L/min	0	0
Type of inhaled anesthetic used		
Desflurane	N/A	51
Isoflurane	N/A	0
Sevoflurane	N/A	49

Abbreviations: ENT, Otolaryngology; FGF, fresh gas flow; L, liter; min, minute; n, number; N/A, not applicable; OBG, obstetrics and gynecology

Table 3 Summarizes the Themes that Influenced Decision-Making as Attributed to the Informants

ID	Professional Group (experience duration)	Theme				
		Personal	Equipment	Patient	Institutional	Environmental
1	Nurse anesthetist (4 years)	✓	✓	✓	✓	
2	Nurse anesthetist (28 years)	✓	✓	✓	✓	
3	Nurse anesthetist (1 year)		✓		✓	✓
4	Nurse anesthetist (25 years)			✓	✓	✓
5	Nurse anesthetist (20 years)	✓		✓	✓	
6	Nurse anesthetist (7 years)		✓	✓		
7	Anesthesiologist (2 years)	✓			✓	
8	Anesthesiologist (3 months)		✓	✓	✓	✓
9	Anesthesiologist (15 years)	✓		✓		✓
10	Anesthesiologist (5 years)	✓	✓		✓	✓
Number of informants		6	6	7	8	5

Abbreviations: ID, identification

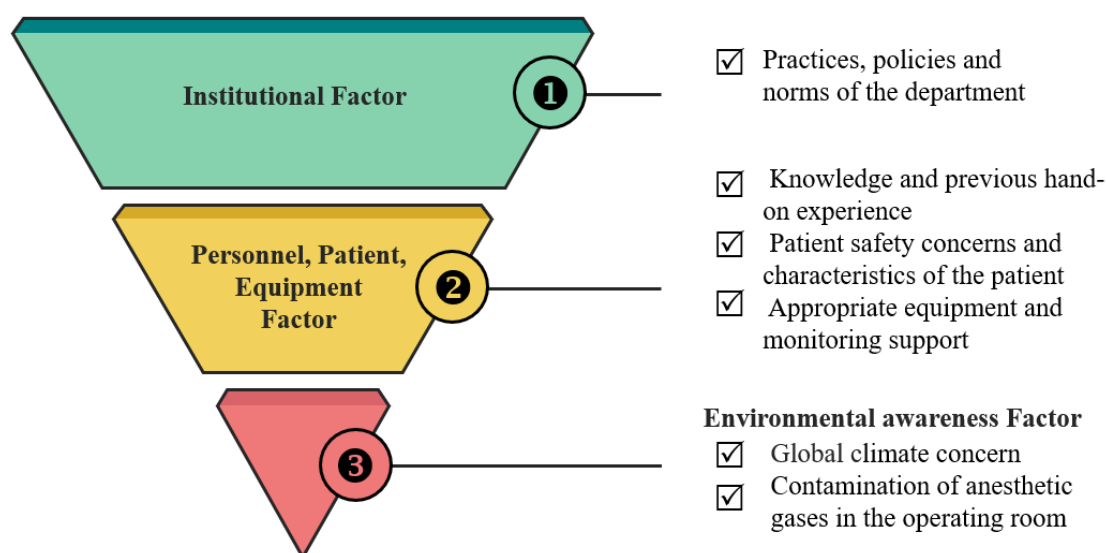
Table 4 Summarizes the Decision-Making Factors for Low-Flow and Minimal-Flow Anesthesia, Supported by Illustrative Quotes from the Interviews

Theme	Description	Illustrative Quotes
1. <i>Personal factors:</i> clinical knowledge and previous hands-on experience	Several participants (6 informants) indicated that limited exposure to low-flow anesthesia during their formal training influenced their reluctance to adopt the technique. Some reported uncertainty regarding the physiological principles and safety parameters associated with low FGF.	"I know the concept, but I was never really trained to use low-flow routinely. I'm afraid I might do something harmful if I reduce the flow too much." - A 28-year experienced nurse anesthetist
2. <i>Equipment factors:</i> appropriate equipment, monitoring support, and availability	The availability of modern anesthesia machines equipped with real-time gas analyzers was determined as a key element. Several participants (6 informants) noted that older machines in certain operating rooms and lacking of gas analyzer did not support accurate monitoring required for low-flow techniques.	"It's not that I'm against low-flow, but it requires more attention. You have to monitor end-tidal gas levels more closely, adjust the vaporizer and change soda-lime more often." - A 7-year experienced nurse anesthetist "We can't use low-flow safely without proper monitoring. In some ORs, we don't even have functioning gas analyzers." - A 3-month experienced anesthesiologist
3. <i>Patient factors:</i> patient safety concerns and characteristics of the individual patient	Concerns about patient safety were revealed, particularly the risk of hypoxia, inadequate anesthetic depth, or hypercapnia or organ-specific damage. Some clinicians (3 informants) preferred to use higher flows for higher-risk patients (e.g., patients with kidney impairment).	"If I'm going with sevoflurane for a patient in stage 3 CKD, I must keep the fresh gas flow comfortably above 1 L/min, because I'm aiming to stay safe, solid, and sure." - A 15-year experienced anesthesiologist "I get a bit uneasy using fresh gas flow below 2 L/min with some anesthetic gases — I'm just worried it might cause problems." - A 4-year experienced nurse anesthetist

Table 4 Summarizes the Decision-Making Factors for Low-Flow and Minimal-Flow Anesthesia, Supported by Illustrative Quotes from the Interviews (cont.)

Theme	Description	Illustrative Quotes
4. <i>Institutional factors:</i> practices, policies, and norms of the department	Peer opinion and departmental culture played a significant role. In settings wherein high-flow anesthesia was the norm, less-experienced staff were hesitant to deviate. Analysis of nonparticipant observation data showed the differences and decision-making hierarchy among less-experienced staff, whether they make decisions autonomously or in environments where they receive input from senior colleagues. Furthermore, many (8 informants) noted a lack of formal institutional economic policy or encouraged low-flow anesthesia practices.	"It really depends on who's leading the case. If they're confident and explain their low-flow approach, it builds our confidence too." - A 25-year-old nurse anesthetist "Even if I use low-flow and save on volatile agents, the hospital still gets the same payment per case. There's no financial motivation to be more efficient." - A 28-year-old anesthesiologist "Speaking of low flow anesthesia, a lot of colleagues feel worry about the risks if gas concentrations aren't stable. Some prefer keeping with higher flows because it feels safer and more predictable, especially in longer or more complicated cases. It's kind of the norm for us—using flow with 1.5-2." - A 5-year experienced anesthesiologist
5. <i>Environmental awareness factors:</i> climate concern and contamination of anesthetic gases in ORs	A minority of participants (5 informants) expressed awareness of the environmental benefits of low-flow anesthesia.	"I know it's good for the environment, but in our department, nobody really brings it up—or takes any action to treat it as a real issue." - A vascular nurse anesthetist "The hospital encourages 'green practices' in the institutional emphasis points, but there's no follow-up or training. There are public media about sustainability in the university, but we don't really get incentive for using low-flow techniques." - A 15-year experienced anesthesiologist "I'm worried about OR air quality, so I support low flow to cut down waste gases. But not everyone is on board yet." - An otolaryngology nurse anesthetist

Abbreviations: CKD, chronic kidney disease; FGF, fresh gas flow; L, liter; min, minute; OR, operating room

**Figure 1** Decision-Hierarchy Triangle among Five Primary Themes

time, as there were no male nurse anesthetists, and only approximately 10% of anesthesiologists were males. The participants were purposely sampled to represent diverse ages and years of work experience. As indicated in the results, 30% of the participants were aged 31–40 years, and 40% had < 5 years of experience in anesthesiology. The duration of clinical practice ranged from 3 months to 28 years (median and mean of 6 years and 10.7 years, respectively). However, the diversity was insufficient to represent each anesthesia service unit. The majority of participants were not assigned to any specific anesthesia service unit. Additionally, the following specialties each had one representative: cardiothoracic, otolaryngology, vascular, and obstetrics-gynecology anesthesia service units. Future studies should focus on each specific service. In pediatric anesthesia, there may be challenges in practicing low-flow and minimal FGF techniques, such as inadequate/imperfect airway sealing, short-term anesthesia with face mask, and slow induction and emergence due to “long time constant” while using lower flow rate.¹⁴

We acknowledge that having a colleague as the interviewer could have influenced participants' responses due to social desirability bias and relational dynamics within the workplace. The participants might be more likely to give answers that seem socially acceptable or positive rather than their completely honest thoughts—especially on sensitive issues; however, the topics covered in the interviews focus on preferences regarding anesthesia techniques as well as the reasons behind their decision and barriers related. These issues are less likely considered sensitive and are unlikely to affect workplace relationship in the future. Conversely, being familiar with the interviewer, could foster deeper trust and richer contextual insights to the study. To address this, the interviewer maintained neutral prompts, emphasized confidentiality, and reflected on positionality throughout data collection and analysis, consistent with recognized practices for managing interviewer effects in qualitative research.

According to the first question “Can you describe your experiences using low flow or minimal FGF anesthesia in your daily clinical practice?” We do not regard this open-ended question as leading or as priming participants' responses. Given its open-ended nature, participants are afforded full freedom to express their views without restriction or influence. Subsequently, participants were prompted with guiding questions designed to elicit detailed accounts of recent cases or prior experiences

in which low-flow or minimal FGF anesthesia techniques were employed. As well as the factors that influenced their choice of technique. Factors raised by participants (informants) were further examined through probing questions, allowing us to explore the underlying considerations shaping their choices.

Regarding the number of participants, data saturation was achieved when no new themes relevant to the research question emerged. A sample of 10 participants was sufficient to provide the depth needed to identify key themes; this may be because of the homogeneity of the data. Traditional qualitative research practices often utilize fixed numerical thresholds, commonly indicating sample sizes ranging from 5 to 30 participants per group.¹⁷ In contrast, current evidence-based recommendations emphasize a flexible, context-specific approach to sample size determination, based on data saturation.¹⁸

The study findings indicate that only approximately 30% of anesthesia personnel at Vajira Hospital routinely employed low FGF anesthesia techniques. These findings are comparable to those of a survey conducted in North London in September 2016, which found that only 36% of cases had a flow rate of < 1 L·min⁻¹.⁴ A global survey conducted from April 2021 to April 2022 reported that 41% of personnel do not use low-flow anesthesia (defined as <1 L·min⁻¹), and only 15% use minimal-flow techniques. However, since this is a global survey, it cannot be evaluated based solely on numerical data. Each country differs in terms of specific details and context, as noted in the same study. “*There is a correlation between higher income countries and implementation of more sustainability strategies, probably due to better access to updated technology and sustainability education programs*”.¹⁰

Analysis of interview and nonparticipant observation data revealed the decision hierarchy among the five primary themes: the institutional factor was at the most influencing factor, and environmental awareness factor was the least influencing factor (Figure 1).

For the implication, based on our study results, hospital policies should support the standardized use of low and minimal FGF anesthesia where clinically appropriate. For example, outline criteria for when to use low or minimal FGF: clear guidance reduces variability and helps clinicians feel confident applying evidence-based techniques. Integrate low and minimal FGF anesthesia into quality improvement and audit cycles, Include in the hospital policy a requirement to

regularly organize workshops, simulation sessions, and peer-sharing forums for less experienced personnel to enhance competency and confidence in relevant clinical practices, include low and minimal FGF in procurement and equipment standard: including the accurate oxygen and anesthetic gas analyzers, the circuit systems designed to minimize leaks and support rebreathing safely, the software or interface tools to assist clinicians in titrating flows. These hardware standards ensure that clinicians have the tools needed to implement low-flow and minimal FGF anesthesia effectively and safely—helping policy translate into practice. Implementation of such policies can harmonize patient safety, institutional sustainability and cost-efficiency goals. Interestingly, the interview findings indicated the need for concrete or measurable outcomes as motivation for adopting low-flow and minimal FGF anesthesia practices; for example, in a low-flow anesthesia promotion project at the Royal Free Hospital, the goals were to decrease the number of volatile agent bottles ordered per month by 20%⁴ and to decrease the volatile cost per month or the yearly carbon footprint,¹⁹ among others. Demonstrating such quantitative outcomes in clinical practice could influence decision-making and promote the use of low-flow techniques. In practice, anesthesia costs in Vajira Hospital are typically charged on a flat hourly rate. Therefore, even if anesthesia personnel reduce the use of volatile agents, the hospital's revenue remains unchanged, making the cost savings less immediately visible or impactful.

The present study is one of the first attempts to assess the practice preferences for low and minimal FGF among anesthetic personnel at Vajira Hospital and identify factors influencing the decision through in-depth interviews. This study focused not only on “what”, but also on “how” and “why.” This study had a few limitations. Participants were recruited by purposive sampling, with varying years of work experience, age, and anesthetic service unit. However, the diversity of anesthesia machines used was not considered. The sample may not be representative of anesthetic personnel who work with automated low-flow anesthesia systems, such as the AISYS® system (GE, Madison, Wisconsin), wherein the anesthesiologist sets a target alveolar concentration (FA_t) of the volatile agent and a target end-expired oxygen concentration (FaO_2). Once targets are set, the system automatically adjusts FGF and agent delivery to reach and maintain those targets efficiently without constant manual intervention.

CONCLUSION

Top-down and bottom-up policies are crucial to promote low-flow and minimal FGF anesthesia. Top-down strategies include institutional guidelines, mandatory monitoring equipment, financial incentives, and integration into routine practice. In contrast, bottom-up approaches involve empowering anesthesia providers through peer learning and environmental awareness campaigns and fostering a supportive departmental culture. Regular feedback, open conversation, and reassuring safety concerns are beneficial for reinforcing practice change. Together, these approaches enable the safe and sustainable adoption of low-flow techniques across all levels of the healthcare system. Quality improvement research is critical to clearly demonstrate the tangible benefits of using low-flow and minimal FGF anesthesia as routine practice in the hospital.

Conflict of Interest

There are no conflicts of interest.

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Author Contributions

Conceptualization: T.T.
 Data curation: T.T., K.L.
 Formal analysis: T.T., K.L.
 Funding acquisition: T.T.
 Investigation: T.T., K.L.
 Methodology: T.T.
 Project administration: T.T., K.L.
 Resources: T.T.
 Software: T.T.
 Supervision: T.T.
 Validation: -
 Visualization: T.T.
 Writing – original draft preparation: T.T.
 Writing – review & editing: T.T., K.L.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author, Tanawadee Teeratchanan. The data are not publicly available due to their containing information that could compromise the privacy of participants.

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