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ORIGINAL RESEARCH

Variations in oxygen reserve index in different fresh gas flow rates

Fatih Sahin[1,*], Yakup Uzun[2], Burak Kaya[1], Havva Kocayigit[2], Ali Fuat Erdem[2]

[1]Anesthesiology and Reanimation, Sakarya University Training and Research Hospital, 54100 Sakarya, Turkey
[2]Anesthesiology and Reanimation, Sakarya University Faculty of Medicine, 54290 Sakarya, Turkey

***Correspondence**
fsahin@sakarya.edu.tr
(Fatih Sahin)

Abstract

Background: The Oxygen Reserve Index (ORI) is a real-time monitoring measure associated with oxygen reserve status in the moderate hyperoxic range (arterial oxygen tensionapproximately 100–200 mmHg). In this study, our primary objective was to determine whether ORI can be a reliable and sensitive indicator of hypoxia in minimal-flow anesthesia (MFA) settings. **Methods**: This randomized controlled trial included 64 patients who were randomized into two groups: Group M (minimal flow anesthesia group) and Group H (high flow anesthesia group). The subjects were American Society of Anesthesiologists (ASA) I–III patients aged 18–75 who underwent elective ear, nose and throat surgery lasting longer than 60 min under general anesthesia. In Group H, a fresh gas flow (FGF) of 4 L/min was used, while in Group M, a FGF of 0.5 L/min was administered. ORI monitoring was performed on all patients. **Results**: Both groups were comparable in terms of height, weight, ASA classification, surgery and anesthesia durations, preoperative hemoglobin and the saturation of peripheral oxygen (SpO_2) and basal ORI levels. ORI values were similar between the groups during preoxygenation, after intubation, and at 5 min post-intubation. Statistically significant differences favoring in favor of Group M were observed at 10 min, 15 min, 20 min and 35 min. End-tidal O_2 values at intubation and 5 min post-intubation were similar; however, significant differences were found at 10, 15, 20 and 35 min post-intubation, and after increasing fresh gas flow. **Conclusions**: The ORI values can help detect impending desaturation before changes in SpO_2 are evident. Our findings suggest that ORI monitoring during low-flow anesthesia application can be valuable in avoiding hypoxia, thereby supporting the application of low-flow anesthesia techniques. **Clinical Trial Registration**: Clinical trials ID: NCT06649279.

Keywords

Oxygen reserve index; Minimal flow; High flow; Hypoxia; Hyperoxia; Anesthesia

1. Introduction

During general anesthesia, the saturation of peripheral oxygen (SpO_2) is used as an indicator to adjust the fraction of inspired oxygen (FiO_2). Non-invasive monitoring of arterial blood oxygen saturation is essential in clinical practice. SpO_2 cannot increase beyond 100% (arterial oxygen tension (PaO_2) above approximately 128 mmHg), regardless of how high PaO_2 rises [1]. Therefore, while SpO_2 is crucial for indicating hypoxia, it is not sufficient on its own to indicate hyperoxia. The only way to measure hyperoxemia is through arterial blood gas analysis [2]; however, this requires arterial catheterization and does not allow continuous oxygenation monitoring. The Oxygen Reserve Index (ORI) (ORI™, Masimo Corp., Irvine, CA, USA) is a real-time monitoring measure that captures the oxygen reserve status in the moderate hyperoxic range (PaO_2 approximately 100 to 200 mmHg) [3]. ORI provides early warning of potential oxygenation disturbances before any changes occur in SpO_2 and indicates the response to oxygen therapy. ORI ranges from 1 (high reserve) to 0 (no reserve) and measures changes in mixed venous oxygen saturation (SvO_2) optically after arterial oxygen saturation (SaO_2) reaches 100% [3]. When pure oxygen is administered, SaO_2 reaches 100% at a PaO_2 of 100 mmHg. Beyond this point, as PaO_2 continues to rise, SpO_2 remains at 100%, and ORI increases in a non-linear fashion from 0.00 (at PaO_2—100 mmHg) to 1.00 (at PaO_2—200 mmHg) [3].

Traditional general anesthesia practices typically use high fresh gas flow (FGF) by contrast, in low-flow anesthesia (LFA), at least 50% of the exhaled air is rebreathed by the patient after carbon dioxide (CO_2) has been absorbed, and it is defined by an FGF rate of less than 2 L/min [4]. Although the use of LFA is increasing due to its many positive effects, one of the most feared complications is hypoxemia. To protect the patient from hypoxemia during LFA, it is essential to continuously monitor exhaled gas volume, airway pressure,

fraction of inspired oxygen (FiO_2), concentration of volatile anesthetic agents, concentration of CO_2 and SpO_2 values in accordance with the Common European Standard [5]. Recent studies have increasingly focused on evaluating the use of ORI in anesthetic practices [6, 7]. Additionally, the use of ORI to closely monitor changes in oxygenation during LFA has recently become a popular research topic [8, 9]. The most important factor limiting the use of ORI is impaired peripheral perfusion, which can occur in conditions such as shock and during high-dose vasopressor administration [3].

The primary objective of this study is to determine whether ORI can serve as a reliable and sensitive indicator for the risk of hypoxia, one of the most significant complications during LFA application.

2. Materials and methods

This study was prospectively conducted in accordance with the Helsinki Declaration and was approved by the Local Ethics Committee of Sakarya University Medical Faculty (Approval No. E16214662-050.01.04-8172-213). Clinical trials ID: NCT06649279 was obtained. This randomized controlled trial included ASA I–III patients aged 18–75 who underwent elective ear, nose and throat surgery lasting longer than 60 min under general anesthesia. Data from patients participating in the study were collected between May 2024 and August 2024.

The patients were randomly assigned to two groups using computerized randomization: Group M (minimal flow anesthesia group) and Group H (high flow anesthesia group) (Fig. 1). Patients who were excluded from the study included those who did not consent to participate, those with finger deformities preventing sensor use, severe anemia (hemoglobin <8 g/dL), alcohol or drug dependency, history of chronic obstructive pulmonary disease, decompensated diabetes mellitus, severe heart, kidney or liver failure, sensitivities to local anesthetics or opioids, those who were morbidly obese (body mass index (BMI) >40 kg/m^2) and breastfeeding women.

The patients were taken to the operating room, and anesthesia was initiated after preoxygenation with a mask (100% O_2, 8 L/min, for 2 min). All patients received 1–2 μg/kg fentanyl, 2–2.5 mg/kg propofol and 0.6–1.2 mg/kg rocuronium bromide at the start of anesthesia. The patients were ventilated using a volume-controlled mode (Dräger Perseus® A500 Anesthesia Workstation, Dräger, Germany). Medical air was used as the carrier gas. After intubation, end-tidal carbon dioxide ($EtCO_2$) was continuously measured and adjusted to remain between 30–45 mmHg by modifying tidal volume, frequency and ventilation rates. Positive end-expiratory pressure was standardized at 5 mmHg for all patients. Bispectral index monitoring was performed throughout the anesthesia duration for all patients.

The Brody formula was used for calculating oxygen consumption. According to this formula, Oxygen Consumption $= 10 \times$ Body Weight$^{3/4}$, and the estimated oxygen demand can be approximated to 3–5 mL/kg/min [10]. Therefore, in our clinic, minimal flow anesthesia is routinely administered with a fresh gas flow (FGF) of 0.5 L/min, FiO_2: 70% oxygen-medical air mixture. The cutoff value for inspiratory oxygen concentration is set at 32%. In both groups, patients were ventilated with an FGF of 4 L/min, FiO_2: 40% oxygen-medical air mixture after intubation and 2–3% sevoflurane vaporizer was adjusted to maintain a minimum alveolar concentration (MAC) of 1 for sevoflurane. All patients received an intravenous infusion of remifentanil at a dose of 0.05–0.2 mcg/kg/min during operation. After 5 min, the maintenance of anesthesia was continued with an FGF of 0.5 L/min, FiO_2: 70% oxygen-medical air mixture in Group M, and an FGF of 4 L/min, FiO_2: 40% oxygen-medical air mixture in Group H, ensuring MAC 1. At the end of the operation, the vaporizers of all patients were turned off, and a high FGF (8 L/min, FiO_2: 80%) was applied to facilitate extubation. Sugammadex (2–4 mg/kg intravenous) was administered to reverse any remaining muscle relaxation after the resumption of spontaneous breathing, and extubation was performed.

Preoperative demographic data, including patients' age, gender, body weight, height and body mass index (BMI), along with any comorbidities, were recorded. Measurements were taken at 10 time points: during preoxygenation, following intubation, at 5 min post-intubation (start of 4–0.5 L/min flow), at 10-, 15-, 20- and 35-min post-intubation and at 1, 5 and 10 min after the increase in FGF at the end of the procedure (FiO_2: 80%). Intubation duration, hemoglobin concentration, ORI values after preoxygenation, SpO_2, blood pressure, heart rate, inspiratory O_2 and expiratory O_2 values were recorded at appropriate time points. ORI values were obtained at the specified time points using a Masimo Radical 7 pulse CO-Oximeter (Masimo Corp., Irvine, CA, USA) with a light-shielded probe attached to the left index finger (RD Rainbow Lite Set ORI Probe®, Masimo Corp., Irvine, CA, USA).

Statistical analysis of the data was performed using the SPSS 20 (IBM Corp., Armonk, NY, USA) software package. Qualitative data were presented as numbers and percentages, while quantitative data were expressed as mean $\pm$ standard deviation. Qualitative data were evaluated using chi-square and Fisher's exact tests. The normality of the continuous data was tested using the Kolmogorov-Smirnov test. Comparisons of normally distributed variables were made using the Student's t-test. A p-value of < 0.05 was considered statistically significant for all tests.

Considering the mean ORI values, in a 95% confidence interval ($1 - \alpha$), at an 85% testing power ($1 - \beta$), and an effect size of $d = 0.68$, it was determined that the sample should include 64 cases in total, 32 in each group.

3. Results

In the study, 64 patients were included, with 32 in each group (Group H and Group M). The mean age of the patients in Group H was 34.9 $\pm$ 15.8 years, while in Group M it was 40.6 $\pm$ 13.3 years, with no significant difference observed between the groups. There were no significant differences found between the groups in terms of height, weight and BMI. Regarding ASA classification, Group H had 16 patients (50%) classified as ASA 1 and 16 patients (50%) classified as ASA 2, whereas in Group M, there were 13 patients (40.6%) classified as ASA 1 and 19 patients (59.4%) classified as ASA 2, with no significant difference between the groups. Preoperative

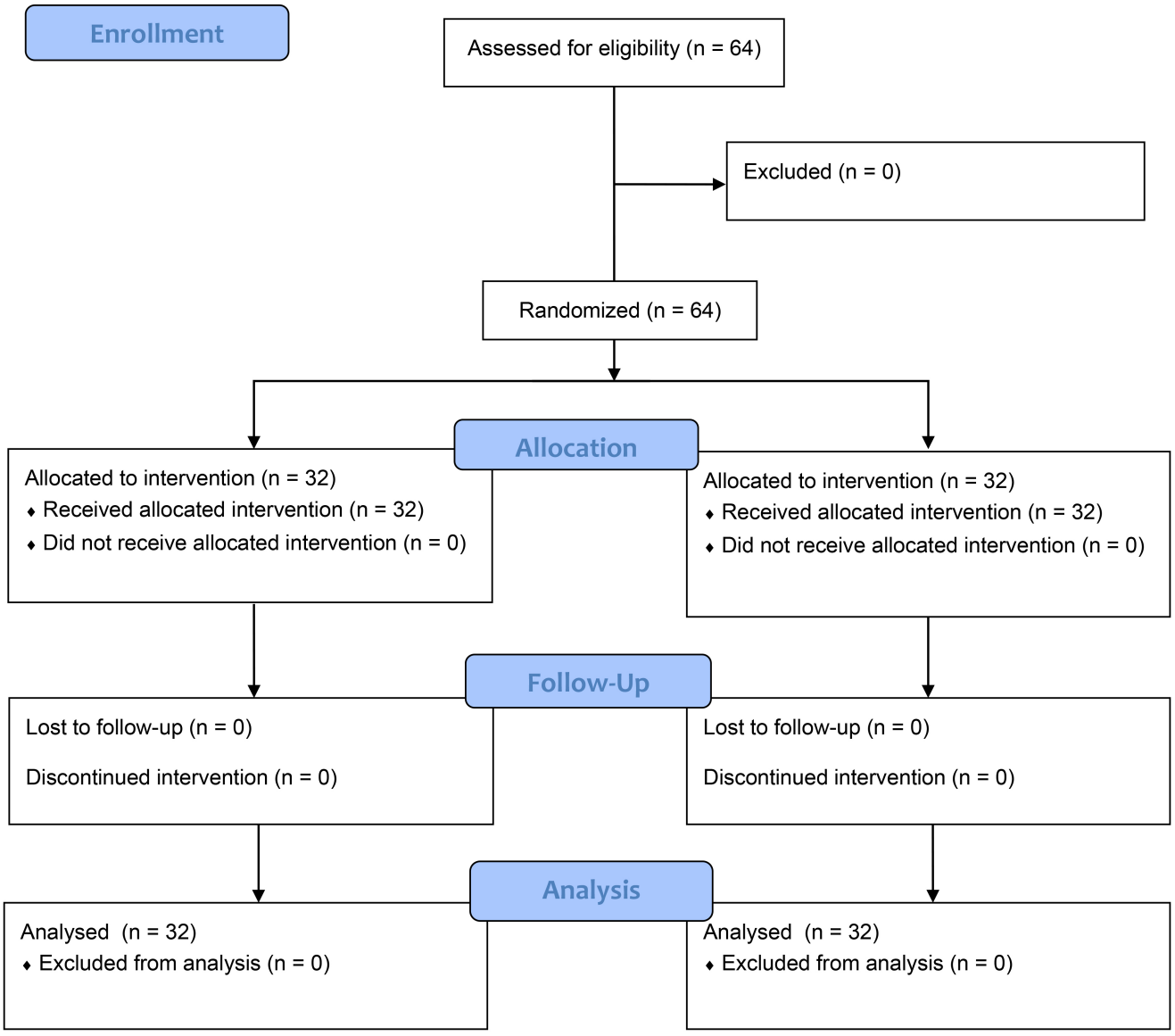

FIGURE 1. Consort diagram.

hemoglobin levels were comparable between Group H (13.2 ± 1.2 g/dL) and Group M (12.8 ± 1.4 g/dL), with no statistically significant difference noted. Similarly, there were no significant differences between the groups in terms of surgical duration, anesthesia duration and intubation duration. The extubation time was 9.31 ± 3 minutes in Group H and 6.44 ± 3.9 minutes in Group M. A statistically significant difference was observed between the two groups ($p = 0.002$). The ORI first measurement time was 61.06 ± 19.4 s in Group H and 56.1 ± 13.0 s in Group L, and there was no significant difference between the two groups (Table 1).

Comparison of ORI values between both groups revealed similar values for measurements during preoxygenation, immediately after intubation and at 5 min post-intubation. As the operation progressed, statistically significant differences favoring Group M were observed at 10 min, 15 min, 20 min and 35 min ($p = 0.014$, $p = 0.001$, $p < 0.001$ and $p < 0.001$, respectively). At the end of the operation, after increasing the fresh gas flow, no significant differences were found in ORI values at 1 min, 5 min and 10 min (Fig. 2, Table 2).

A comparison of inspiratory FiO_2 values between Group H and Group M showed that immediately after intubation, FiO_2 values were 90 ± 6 in Group H and 82 ± 11 in Group M, with a significant difference observed ($p = 0.001$). There was no significant difference in FiO_2 values at 5 min post-intubation; however, significant differences were found at 10 min, 15 min, 20 min, 35 min post-intubation and after increasing fresh gas flow ($p = 0.007$, $p < 0.001$, $p < 0.001$, $p < 0.001$, $p = 0.001$). Comparison of FiO_2 values at 5 min after increasing fresh gas flow did not show significant differences between the two groups (Fig. 3, Table 2). A comparison of end tidal O_2 values between Group H and Group M showed a significant difference between the two groups at 10 min, 15 min, 20 min, 35 min and 1 minute after increasing the FGF ($p < 0.001$, $p < 0.001$, $p < 0.001$, $p < 0.001$, $p < 0.001$) (Table 2). $EtCO_2$ was continuously measured and maintained between 30–45 mmHg. No statistically significant difference was found between the SpO_2 values of the two groups, and no hypoxia was observed in any of the patients throughout the monitoring period.

TABLE 1. Descriptive data.

	Group H n = 32	Group M n = 32	*p* value
Age	34.9 ± 15.8	40.6 ± 13.3	0.130
Height	170.0 ± 9.1	168.0 ± 8.9	0.333
Weight	72.7 ± 15.0	75.9 ± 13.4	0.379
BMI	24.7 ± 3.8	26.5 ± 3.4	0.052
ASA, n (%)			
I	16 (50.0)	13 (40.6)	0.490
II	16 (50.0)	19 (59.4)	
Hemoglobin	13.2 ± 1.2	12.8 ± 1.4	0.167
Surgery time (min)	73.2 ± 35.7	88.1 ± 43.8	0.155
Anesthesia time (min)	92.7 ± 40.6	102.1 ± 42.4	0.368
Surgery, n (%)			
FESS	3 (9.4)	5 (15.6)	0.147
Parotid	-	2 (6.3)	
Septum	25 (78.1)	17 (53.1)	
Tympanoplasty	4 (12.5)	8 (25)	
Intubation time (sec)	46.8 ± 4.7	59.5 ± 4.7	0.138
Extubation time (min)	9.3 ± 3.0	6.4 ± 3.9	0.002*
ORI first measurement time (sec)	61.1 ± 19.4	56.1 ± 13.0	0.233

*BMI: Body mass index; FESS: Functional endoscopic sinus surgery; ORI: Oxygen reserve index; ASA: American society of anesthesiologists; min: minute; sec: second. *: $p \leq 0.05$.*

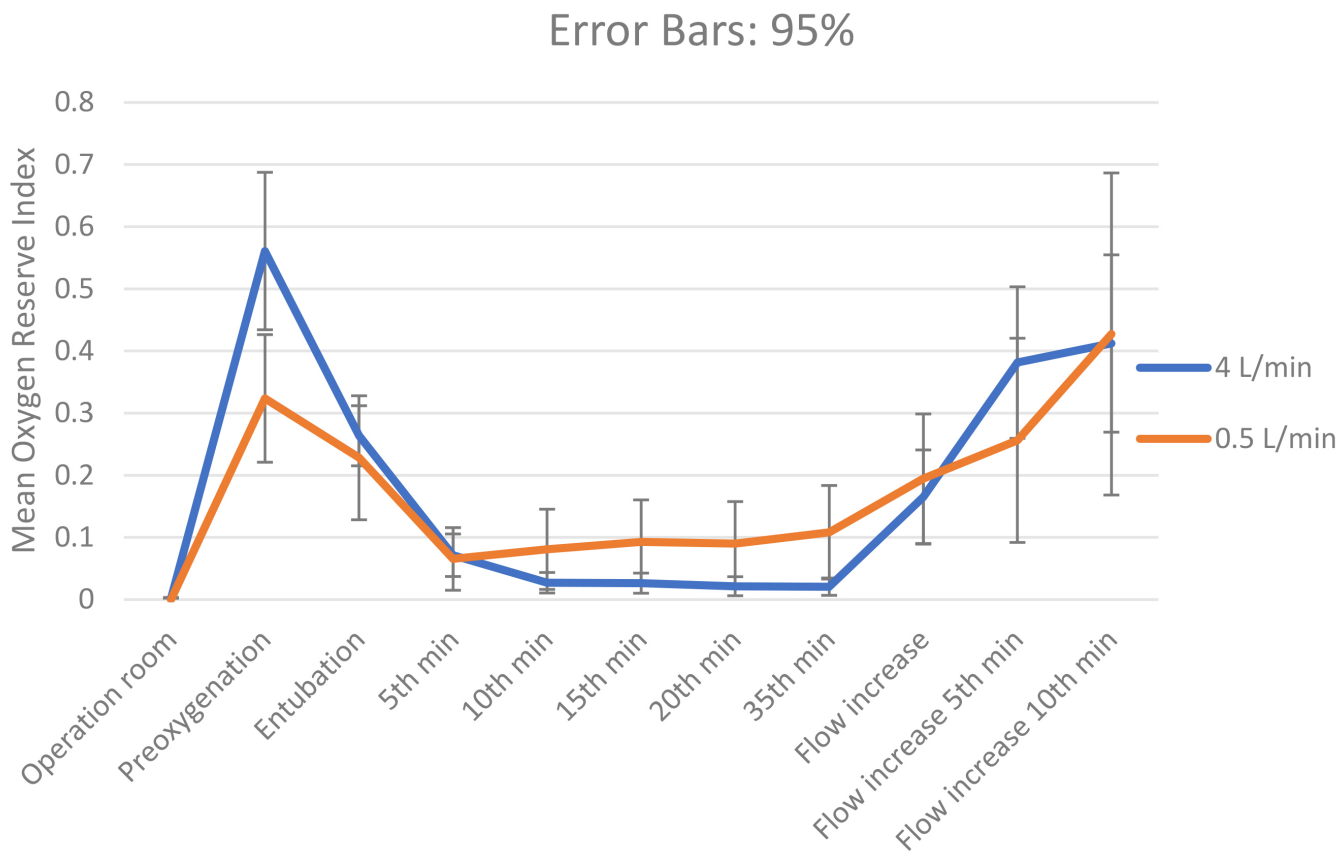

FIGURE 2. Mean oxygen reserve index.

TABLE 2. Oxygen reserve index and inspiratory FiO_2 findings.

	Oxygen Reserve Index			Inspiratory FiO_2			End-tidal O_2		
	Group H	Group M	*p* value	Group H	Group M	*p* value	Group H	Group M	*p* value
Preoxygenation	0.51 ± 0.33	0.42 ± 0.28	0.296						
Intubation	0.23 ± 0.15	0.19 ± 0.13	0.294	90 ± 6.0	82 ± 11.0	0.001*	83 ± 8.6	77 ± 8.4	0.140
5th min	0.06 ± 0.08	0.06 ± 0.07	0.838	39 ± 1.2	40 ± 3.8	0.863	35 ± 1.0	34 ± 2.9	0.690
10th min	0.02 ± 0.04	0.06 ± 0.08	0.014*	40 ± 3.5	42 ± 4.0	0.007*	32 ± 1.0	36 ± 4.0	<0.001*
15th min	0.02 ± 0.03	0.08 ± 0.08	0.001*	39 ± 4.2	44 ± 4.2	<0.001*	31 ± 1.1	38 ± 4.4	<0.001*
20th min	0.02 ± 0.03	0.08 ± 0.09	<0.001*	39 ± 4.7	45 ± 4.8	<0.001*	31 ± 0.8	39 ± 4.8	<0.001*
35th min	0.02 ± 0.03	0.10 ± 0.10	<0.001*	40 ± 5.2	46 ± 5.3	<0.001*	31 ± 0.8	40 ± 5.7	<0.001*
FGF increase 1st min	0.14 ± 0.19	0.23 ± 0.22	0.084	72 ± 3.1	75 ± 5.3	0.001*	53 ± 6.2	64 ± 5.2	<0.001*
FGF increase 5th min	0.33 ± 0.31	0.27 ± 0.29	0.450	77 ± 0.7	76 ± 3.5	0.917	70 ± 1.0	69 ± 7.4	0.364
FGF increase 10th min	0.41 ± 0.36	0.42 ± 0.38	0.917						

**: $p \leq 0.05$. FGF: fresh gas flow; min: minute; FiO_2: fraction of inspired oxygen.*

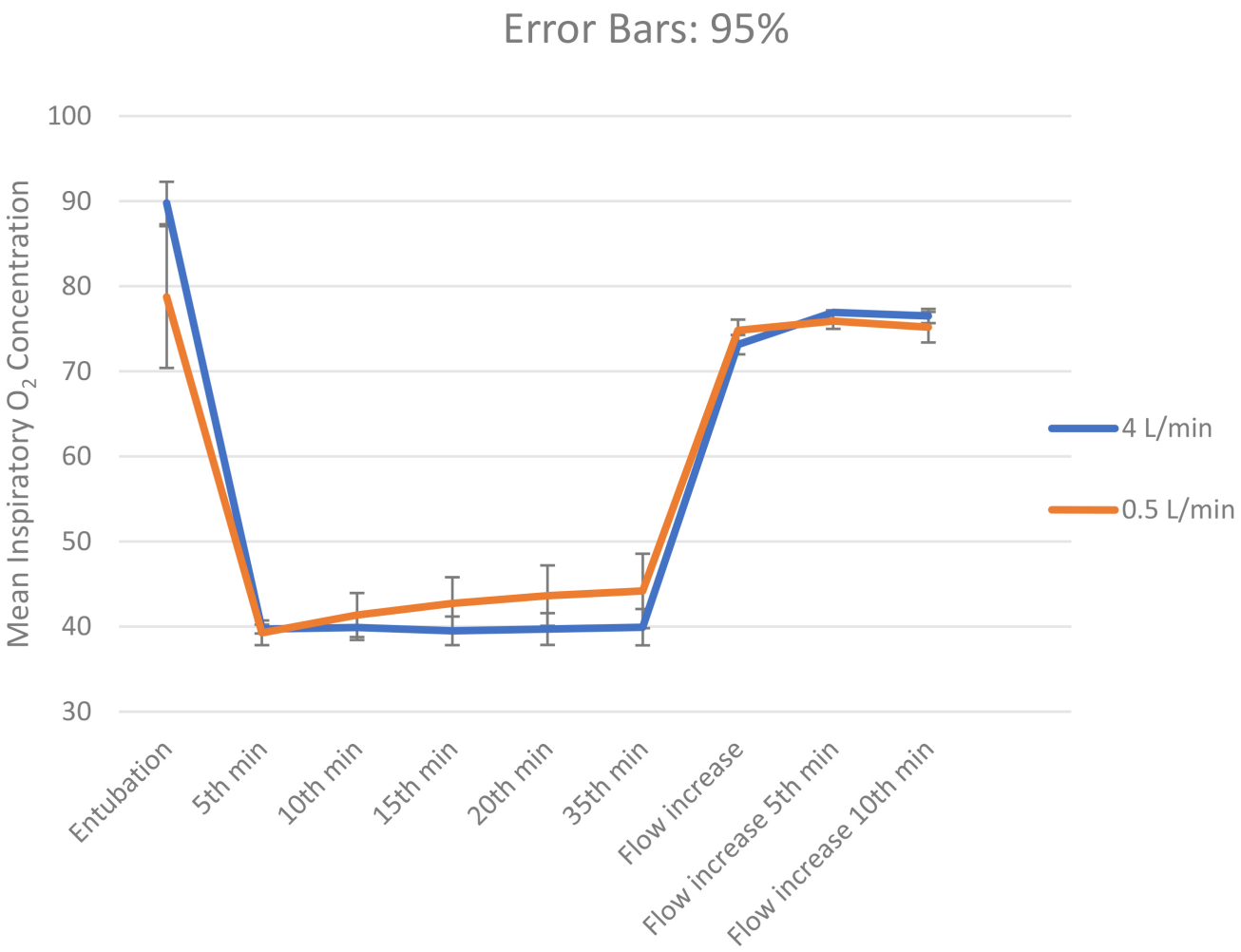

FIGURE 3. Mean inspiratory O_2 concentration.

4. Discussions

In contemporary practice, physicians mostly fear the possibility of hypoxia occurring in patients undergoing LFA techniques [11], as the harmful effects of hypoxia are well-recognized [12, 13]. This study utilized ORI monitoring to evaluate the effects of different FGF levels on oxygenation in patients undergoing otolaryngologic surgery. Although it is theoretically stated that hypoxia will not develop during LFA when adequate oxygen is provided, anesthesia providers may have some concerns in practical application. It was observed that inspiratory FiO_2 and oxygen values assessed by ORI were found to be higher in patients receiving LFA anesthesia and neither group experienced hypoxia.

In traditional general anesthesia practices, total gas flow is typically maintained between 4–6 L/min. Closed-loop anesthesia or minimal flow anesthesia (MFA) is based on the principle of returning at least 50% of exhaled gases to the patient through the respiratory system after eliminating CO_2 from the anesthetic circuit. As total gas flow decreases in MFA, the difference between the oxygen content in the gas delivered to the patient and the oxygen concentration (FiO_2) increases. This is because the recycled gas mixture, depleted of oxygen, occupies a significant volume in the rebreathing circuit, potentially increasing the risk of hypoxia [4, 14]. Although MFA reduces the consumption and cost of anesthetic gases, the concentration of oxygen delivered to the patient decreases significantly due to the large volume of the rebreathed gas mixture, thereby posing a risk of hypoxia. Studies have demonstrated that MFA, which utilizes a reduced amount of anesthetic gases, preserves mucociliary clearance and respiratory function better in the postoperative period, attributed to the use of pre-warmed and humidified gases that are largely returned to the patient [15]. Kaşıkara *et al.* [16] showed that the intraoperative use of MFA, especially in patients with comorbidities, can reduce oxidative damage and accelerate the recovery process in the postoperative period. Previous studies have also indicated that MFA does not significantly alter hemodynamic parameters [15, 17].

The ORI can help detect impending desaturation before changes in SpO_2 are evident. In the study conducted by Sagiroglu *et al.* [18], it is reported that ORI monitoring can predict impending hypoxemia and has the ability to detect changes in oxygenation 5–6 minutes earlier than changes in pulse oximetry values for the detection of hypoxemia. In a study involving pediatric patients, Szmuk *et al.* [19] reported that ORI detected desaturation approximately 31.5 s before a change in saturation was noticed. Yoshida *et al.*'s [20] study of 16 patients demonstrated a delay of about 30 s between decreases in SpO_2 and ORI. Ryu *et al.* [21] using ORI in robot-assisted prostatectomy, identified an ORI cutoff value of 0.16 for detecting hypoxia, highlighting ORI monitoring as a non-invasive approach for early detection and intervention in hypoxia. In light of this information, it is suggested that ORI could be used for the early prediction of hypoxia, one of the most feared complications in MFA. However, in the literature, we found a limited number of studies regarding the use of LFA and ORI. In a study comparing patients undergoing low-flow and high-flow anesthesia during one-lung ventilation, no statistically significant difference was observed in the ORI parameters between the groups [19]. Additionally, another study in the literature reported that an ORI value of 0.005 corresponded to a PaO_2 >100 mmHg. In major surgical procedures, it has been reported that the LFA technique can be used as an alternative to high flow anesthesia (HFA) by monitoring tissue oxygen delivery parameters, and that ORI values can be used within a safe range of 0.01 to 0.29 to protect against hyperoxia and hypoxia during anesthesia [8]. Considering this information, various ORI cut-off values for hypoxia and hypoxemia have been reported in the literature. In our study, the lowest average ORI was observed 0.02 in Group H for all time measurements, while the highest average ORI of 0.41 was recorded at the 10th minute after the increase in FGF. In Group M, the lowest average ORI was 0.06, and the highest average ORI was 0.42 at the 10th minute following the increase in FGF. Despite the different cutoff values reported in the literature, no cases of hypoxia were observed even at the lowest ORI values recorded in our study. During LFA application, the inspiratory FiO_2 should be at least 30 [22]. In our study, since both patient groups were exposed to the same oxygen therapy during pre-oxygenation and at 5 minutes after intubation, no difference in ORI values was observed between the groups. The Group M had a minimum FiO_2 value of 40 $\pm$ 3.8, and the Group H had a minimum FiO_2 value of 39 $\pm$ 4.7. Throughout the anesthesia procedure, the lowest end-tidal O_2 values were observed to be 31 in Group H and 34 in Group M. Similar to FiO_2 values, EtO_2 values were also higher in Group M at the time points of 10-, 15-, 20- and 35-min post-intubation, as well as after an increase in FGF. When comparing the average ORI values of our patients between the two groups, we observed that at the 10th, 15th, 20th and 35th min, Group M had significantly higher ORI values than Group H. We believe this difference is primarily due to the higher FiO_2 levels at these time points in Group M compared to Group H. However, despite these differences, it is important to note that no cases of hypoxia were observed in either group. Based on these results, although lower oxygen consumption was observed in Group M, we believe that the significantly higher ORI values observed at certain time points in Group M are primarily attributable to the higher FiO_2 values compared to Group H.

The most significant limitation of our study is the lack of arterial blood gas values. It also prevents you from confirming that there was indeed no significant hypoxemia as indicated by the ORI values and more importantly, prevents you from evaluating the clinical significance of the observed ORI differences. Consequently, we were unable to examine the correlation between the ORI values and PaO_2 levels.

5. Conclusions

In conclusion, while ORI monitoring can be safely used in patients undergoing general anesthesia with both HFA and LFA, our findings suggest that ORI monitoring can be effectively used in LFA, where hypoxemia is the most feared complication, thus supporting the application of LFA techniques.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

FS, HK, BK and YU—material preparation, data collection and analysis. AFE—written the first draft of the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. All authors contributed to the study conception and design.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Sakarya University (Date: 03 November 2021/No: E-16214662-050.01.04-81762-213). Informed consent was obtained from all individual participants included in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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