Original Article

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Evaluation of Oxygenation in Low- and High-Flow Anesthesia Applications by Oxygen Reserve Index: A Randomized Prospective Study

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Abstract

Aim: While arterial blood gas (ABG) analysis is invasive, intermittent, and costly, the oxygen reserve index (ORI) is a new method that can be non-invasive and continuous measurement aimed at providing information about the patient's O_2 status in the moderately hyperoxic range. In our study, the ORI to PaO_2 relationship in different fresh gas flows was evaluated.

Methods: This randomized prospective study was conducted between November 2018 and November 2019. All patients were ventilated for the first 10 min after intubation with 50% O_2/air and 6 L/min fresh gas flow. Then, the flow rate was randomly set to 4 L/min for high-flow anesthesia (group H) or 1 L/min for low-flow anesthesia (group L). ABG's were taken before preoxygenation, intraoperative 60th min, and at the end of surgery, and simultaneous ORI and SpO_2 were recorded.

Results: The study was completed with 70 patients. Mean PaO_2 values were higher in group H, apart from before preoxygenation ($p<0.05$). Mean ORI values differed between groups except before preoxygenation and the intraoperative 10th min ($p<0.05$). A statistically significant, positive and weak correlation was identified between ORI and PaO_2. According to the regression analysis, the ORI value was approximately 0.2 when the PaO_2 value was ≥100 mmHg at the intraoperative 60th min and at the end of the surgery, and 0.3 when the PaO_2 was ≥150 mmHg.

Conclusion: ORI may be an alternative to PaO_2 in monitoring the oxygen status of intraoperative patients.

Keywords: General anesthesia, hyperoxia, low flow anesthesia, oxygen reserve index

Introduction

Low-flow anesthesia is based on the principle of returning at least 50% of the exhaled gases to the patient via a breathing system after the elimination of carbon dioxide in the anesthesia circuit (1). In low-flow anesthesia applications, the difference between the amount of oxygen (O_2) and the O_2 centration in the gas composition provided to the patient increases as the fresh gas flow decreases. Because the oxygen-depleted gas mixture takes up a large amount of space in the rebreathing volume, the O_2 concentration delivered to the patient may drop significantly, increasing the risk of hypoxia (1,2).

Peripheral O_2 saturation (SpO_2) and arterial partial oxygen pressure (PaO_2) are monitored to detect hypoxia during anesthesia applications. Oxygen reserve index (ORI) is a measurement technique derived from hemoglobin sensors, which shows the O_2 reserve in arterial blood and can instantly evaluate tissue oxygenation. It is an index with a unitless scale between 0 and 1, which is a relative indicator of changes in PaO_2, especially in the mild hyperoxic range (PaO_2 100-200 mmHg) (3). The ORI reportedly gives an early warning during a possible oxygenation impairment-before any change in SpO_2 occurs-and shows the response to the oxygen administration (4,5). Recently, it has been reported that ORI can be used to prevent hyperoxia during general anesthesia and after surgery (6,7). This study evaluates the ORI-PaO_2 relationship in different fresh gas flows.

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Methods

Compliance with Ethical Standards and Study Design

The study was conducted at the Zonguldak Bulent Ecevit University between November 2018 and November 2019, with the approval of the Zonguldak Bulent Ecevit University Clinical Research Ethics Committee (date: 07.11.2018, protocol no: 2018-221-07/11) and the written consent of the patients. The trial was registered before subject enrollment at ClinicalTrials.gov (Ref: NCT04698863; principal investigator: G.K.; date of registration: January 6, 2021). The flow diagram of the study according to the Consolidated Standards of Reporting Trials (CONSORT) 2010 is presented in Figure 1 (8).

Patient Population

In this prospective study, randomization was performed using the sealed-envelope method. Patients between the ages of 18 and 65 who were in the ASA I-II risk group and who were scheduled for a tympanomastoidectomy under elective conditions, with a minimum operation time of 1.5 h, were included in the study. Patients with morbid obesity, a history of malignant hyperthermia, opioid sensitivity, alcohol or drug abuse problems, congestive heart failure, coronary artery disease, significant anemia, liver and kidney disease, pregnant or lactating women, and patients allergic to the drugs used in the study were excluded.

Before each patient, the seal of the anesthesia circuits was checked, the gas monitors were calibrated, and the lower limit of the inspired O_2 fraction (FiO_2) was set to 30%. The carbon dioxide (CO_2) absorbent was replaced after each patient.

Oxygen Reserve Index and Arterial Blood Gas Measurements

Routine hemodynamic monitoring was performed on patients in the operating room. Additionally, the ORI sensor (ORi™, Masimo Corp., Irvine, CA, USA) was placed on the fourth finger of the arm without a blood pressure cuff. The sensor was covered to avoid light exposure, and it was connected to the oximeter device (Root® platform Pulse CO-Oximetre, Masimo Corp., Irvine, CA, USA) and monitored. The vascular access of all patients without premedication was opened with an 18 gauge (G) granule and the saline infusion was started at a 10 mL/kg/h rate. The Allen test was performed for arterial blood gas (ABG) analysis, and

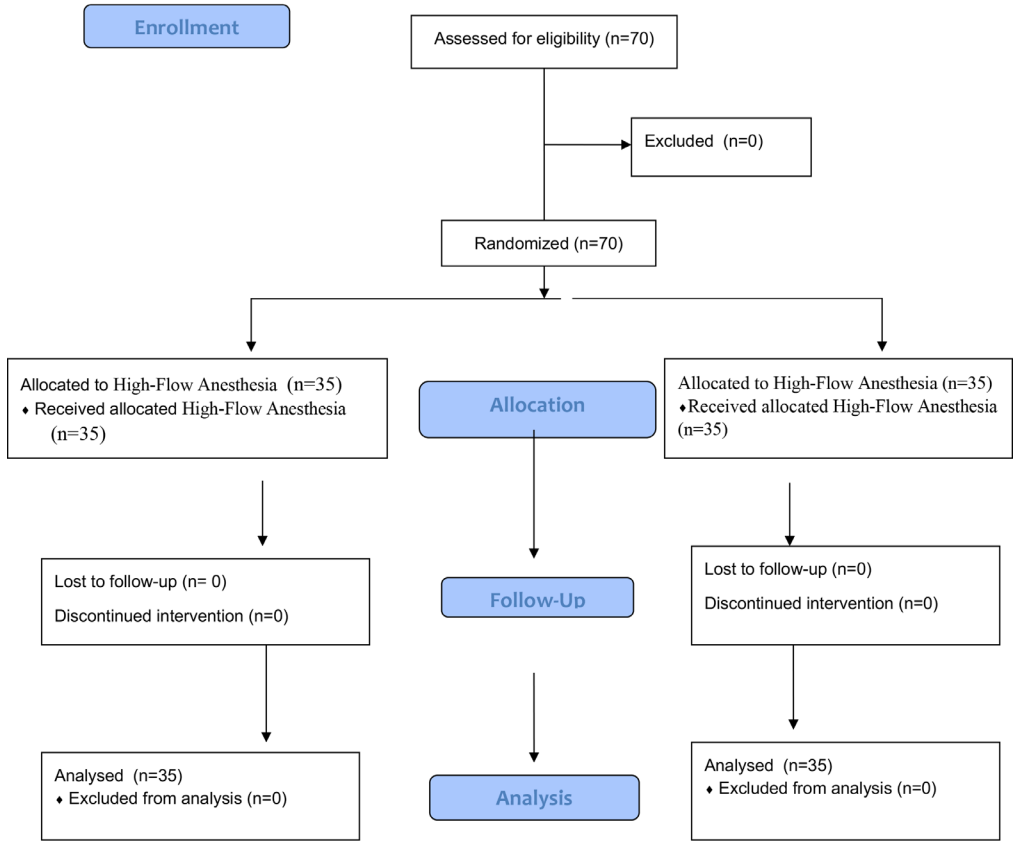

Figure 1. CONSORT flow diagram

20 G granules were placed in the radial artery in the non-dominant hand, if possible. Hemodynamic parameters before preoxygenation, ORI values, and ABG samples were taken, and the PaO_2 values in the blood gas device (I-STAT®1 Analyzer, Abbott, California, USA) were recorded.

Anesthesia Management

The patients were preoxygenated by administering 100% O_2 with a face mask for 5 min. Standard anesthesia induction was applied. Afterwards, a remifentanil infusion was started. All patients were ventilated with the same anesthesia device. The respiratory rate was adjusted so that the tidal volume was 8 mL/kg and the end-tidal carbon dioxide ($EtCO_2$) was between 35 and 45 mmHg.

In terms of the maintenance of anesthesia, the patients were divided into two groups: high-flow anesthesia (group H, n=35) and low-flow anesthesia (group L, n=35). For all patients, the fresh gas flow was provided with 50%/50% O_2/air (3/3L/min) and 6% desflurane for the first 10 minutes after intubation. After the first 10 min, the anesthesia was maintained with flow rates of 4 L/min in group H and 1 L/min in group L.

It was planned to increase the fresh gas flow to 4 L/min if the FiO_2 fell below 30%, the $EtCO_2$ above 45 mmHg, or the SpO_2 fell below 92%. It was planned to change the remifentanil dosage if the mean arterial pressure (MAP) increased more than 20% compared to the control value, administer 5 mg of ephedrine iv if it decreased more than 20%, and administer 0.5 mg of atropine iv if the heart rate (HR) value fell below 50 beats/min.

Ten minutes before the end of the operation, the fresh gas flow was increased to 6 L/min. Anesthetic agents were discontinued at the end of the surgery. Patients with routine wake-up protocols were extubated and taken to the recovery unit.

HR, MAP, SpO_2 and ORI values of all patients were recorded before preoxygenation and intraoperatively at 10., 15., 30., 45., 60 minute (min), and then at 30-min intervals until the end of surgery. Also, three ABG samples were taken from all patients before preoxygenation, intraoperative 60 min, and at the end of the surgery, just before starting ventilation with 6 L min, 100% O_2, and the PaO_2 values and simultaneous ORI and SpO_2 values were recorded. In the study, PaO_2 of more than 100 mmHg was determined as hyperoxia, and <60 mmHg as hypoxia.

All patients were administered 1 mg/kg tramadol iv and 10 mg/kg acetaminophen infusion intravenously for postoperative pain control 15 min before the end of the operation, and 10 mg/kg metoclopramide iv for nausea and vomiting prophylaxis.

Statistical Analysis

Data was analyzed using the Statistical Package for the Social Sciences version 23.0 (IBM SPSS Inc. Chicago, IL, USA) program. Considering the mean ORI values, it was determined that there should be a minimum of 35 patients in each group, with 95% confidence and 99.99% test power (9). The normality of data distribution was analyzed with the Kolmogorov-Smirnov test. An independent sample t-test was used for the normally distributed data. A paired samples t-test was used for normally distributed data to examine two time-dependent changes. Repeated measures variance analysis was used to examine three or more time-dependent changes. Pearson's correlation coefficient was used to measure the relationships between normally distributed quantitative variables. The effect of the PaO_2 parameter on ORI was analyzed by linear regression. For quantitative data, the results were presented as mean and standard deviation, and for categorical data, as frequency (percentage).The significance level was determined as $p<0.05$.

Results

The study was completed with 70 patients. The groups were similar in terms of demographic characteristics, ASA risk groups, and duration of surgery ($p>0.05$) (Table 1).

A comparison of PaO_2 values between and within groups is presented in Table 2. It was observed that PaO_2 values increased in both groups in the intraoperative period (Table 2).

A comparison of mean values of ORI between and within groups is presented in Table 3. Intraoperative ORI values increased during surgery in both groups (Table 3).

There was a statistically significant, positive weak correlation found with the correlation analysis performed between the mean ORI and PaO_2 values obtained at the intraoperative 60^{th} minute and at the end of the surgery, excluding the preoxygenation values between the groups (Table 4).

When the effect of the independent PaO_2 variable on the ORI value measured at the 60^{th} min intraoperative and at the end of surgery was examined by linear regression analysis, the regression models established by the time were found to be statistically significant (fintraoperative 60^{th} min=5,326, $p_{intraoperative\ 60^{th}\ min}$=0.024, F_{End}= 6,084, p_{End}=0.016). With the regression model established for the 60^{th} min after intubation, it was found that when PaO_2 increased by one unit, the ORI value increased by 0.002 units, and with the regression model established for the time measured at the end of the surgery, there was an increase of 0.002 units in the ORI value for one unit increase in PaO_2 value (Table 5).

If PaO_2 was 100 mmHg, the ORI value at the intraoperative 60th minute was 0.244 (~0.2), and the ORI at the end of the surgery was 0.205 (~0.2), according to the linear regression analysis in which PaO_2 was determined as the independent variable and ORI as the dependent variable. Accordingly, when PaO_2 was ≥100 mmHg, ORI >0.20 was found in 62.8% of patients at the intraoperative 60th min and in 72.8% at the end of surgery (Figures 2 and 3).

According to the regression analysis, when PaO_2 was 150 mmHg, ORI was 0.344 (~0.3) at the intraoperative 60th minute and was 0.305 (~0.3) at the end of surgeries. Similarly, when PaO_2 was ≥150 mmHg, ORI >0.30 was found in 63.3% of patients at the intraoperative 60th min and in 75.7% at the end of surgery (Figures 4 and 5).

Discussion

In this study, in which the effectiveness of ORI in oxygenation monitoring in low- and high-flow anesthesia applications was evaluated, it was concluded that ORI could be used as a non-invasive method, especially in determining hyperoxia due to its positive correlation with PaO_2 and because hyperoxia, which is a feared situation in low-flow anesthesia applications, can also be seen in addition to hypoxia.

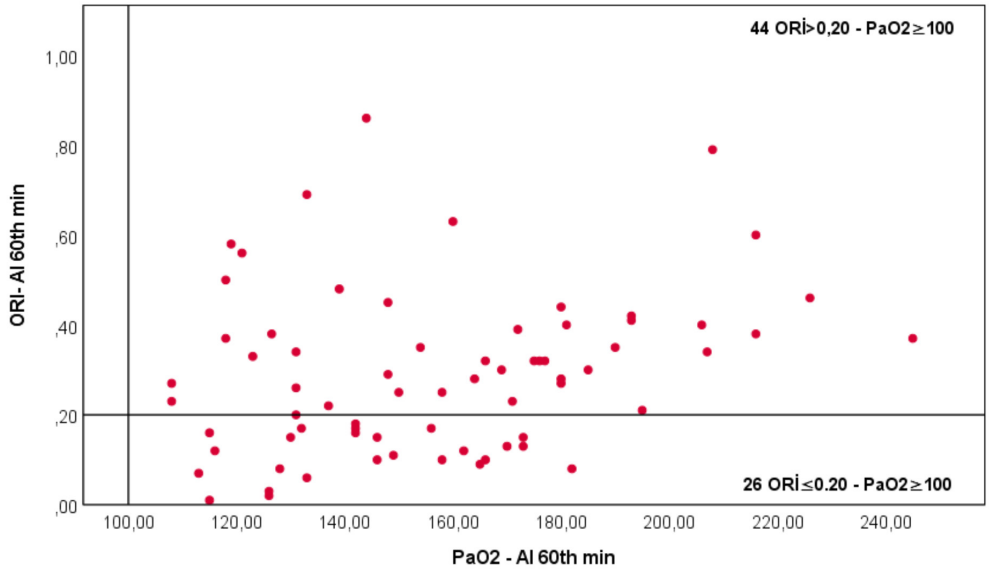

Figure 2. ORI values that in 100 mmHg of PaO_2 measured at AI 60th min
AI: After Intubation, ORI: Oxygen reserve index

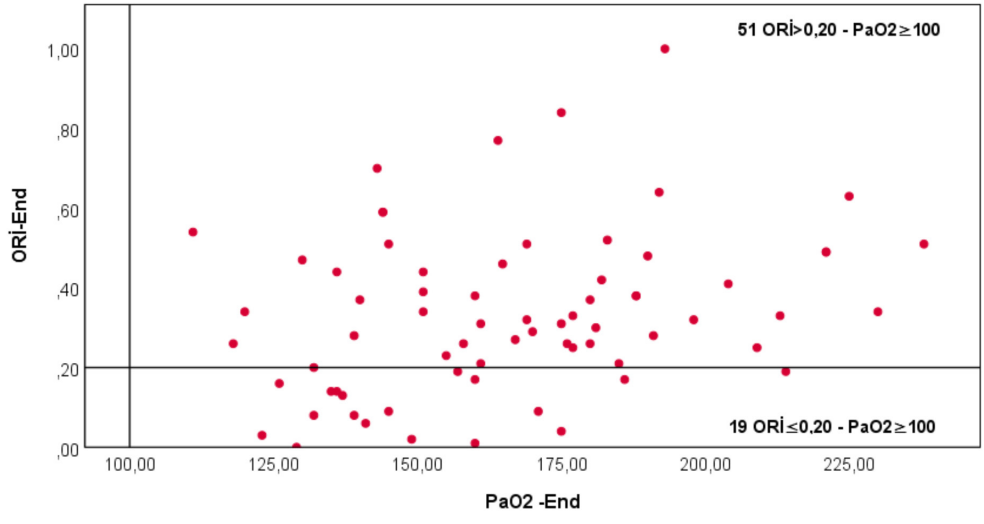

Figure 3. ORI values that in 100 mmHg of PaO_2 measured at the end of surgery
End: End of surgery, ORI: Oxygen reserve index

There are concerns, especially among anesthetists using low-flow techniques, that oxygen cannot reach the tissues in sufficient amounts (10,11). In the study of Çukdar et al. (12), in which low-flow [1 L/min (O_2/N_2O=0.5/0.5)] and high-flow [4.4 L/min (O_2/N_2O=1.4/3)] desflurane anesthesia with FiO_2 greater than 30% was compared, it was reported that in none of the cases, FiO_2 fell below 30% and SpO_2 below 97%. Similarly, the fact that the SpO_2 value did not fall below 97% in any of the patients in this study and that hypoxia findings were not found in the ABG analysis suggests that this study is compatible with the literature.

Although oxidative stress caused by hypoxia has been a well-known fact for many years, interest in the negative effects of hyperoxia has been increasing recently (13). There have been studies suggesting pathological changes in alveolar cells subjected to hyperoxia (FiO_2: 80-90%) for 48 h (14). In the animal study by Clerch and Massaro (15) it was reported that pleural effusion and pulmonary edema appeared in the 48th-60th hours with exposure to intense oxygen (FiO_2: >95%). Animals started to die at the 60th hour, and most of them were dead at the 72nd. It is common practice to use 100% O_2 in general anesthesia

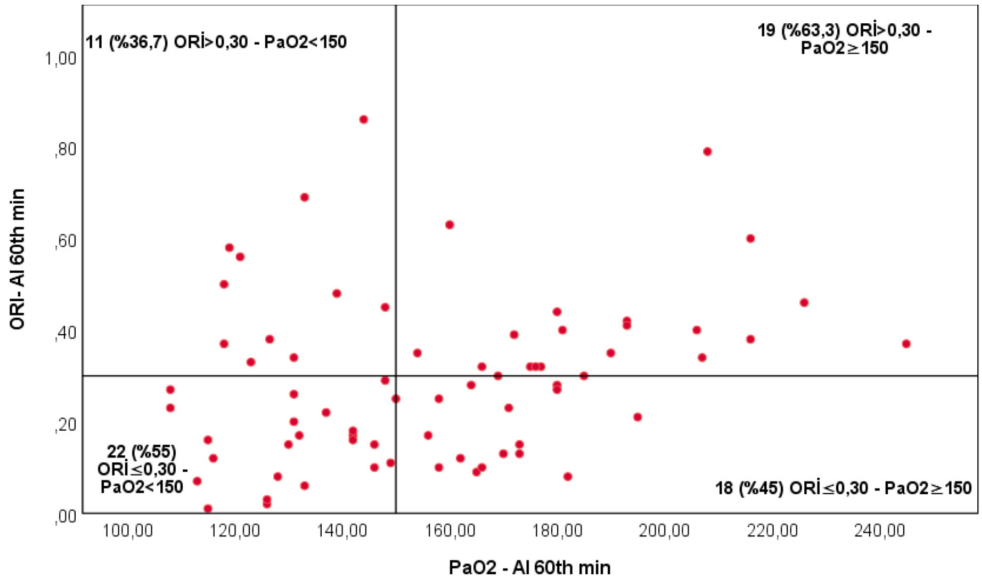

Figure 4. ORI values that in 150 mmHg of PaO_2 measured at AI 60th min
AI: After Intubation, ORI: Oxygen reserve index

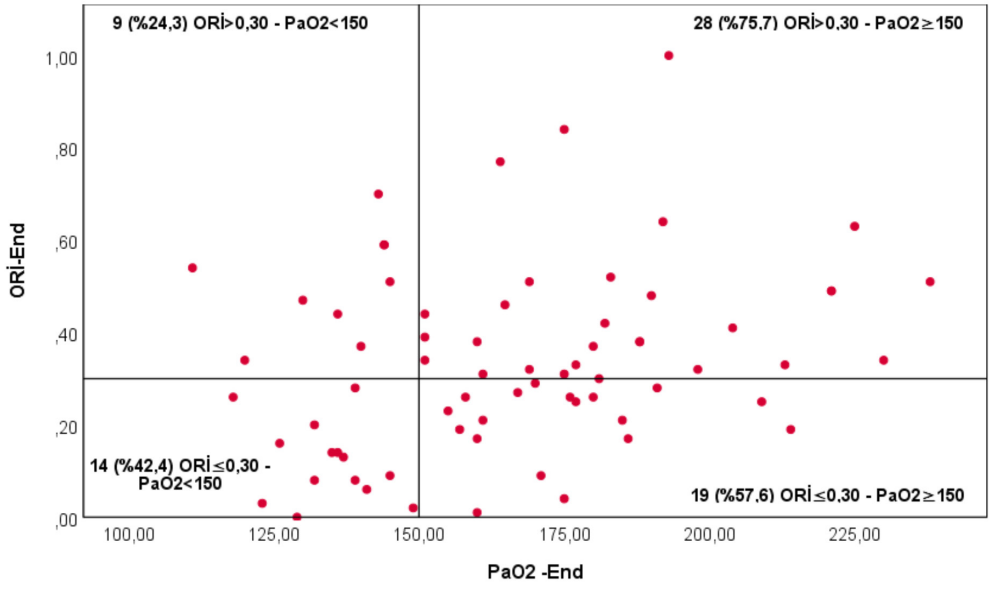

Figure 5. ORI values that in 150 mmHg of PaO_2 measured at the end of surgery
End: End of surgery, ORI: Oxygen reserve index

induction and before extubation. However, studies have shown that even a short time (~20-30 minutes) of high O_2 use causes atelectasis (16-18). Using computed tomography, Benoit et al. (16) reported that using 100% O_2 at the end of general anesthesia (<2.5 h) triggers the formation of atelectasis and low FiO_2 levels prevent it. Rothen et al. (19) reported that after the "recruitment" maneuver they applied during general anesthesia, it took 40 min for atelectasis to occur in the group ventilated with low FiO_2 (0,4), while atelectasis occurred in the 5th minute in the group getting high FiO_2 (1,0) (19). In a multicenter study with 14,441 intensive care patients, it was reported that severe hyperoxia (PaO_2>200 mmHg) was associated with higher mortality rates, and weaning

Table 1. Comparison of demographic characteristics, ASA risk class and duration of surgery

	Group L (n: 35)	Group H (n: 35)	p-value
Age (year)	37.1±11.4	40.2±11.7	0.259
Body weight (kg)	75.9 12	75.1±12.7	0.788
Height (cm)	164.6±5.3	165.1±5.1	0.445
Male/Female	18/17	22/13	0.334
ASA risk class (I/II)	14/21	15/20	1.000
Surgery time (min)	285.6±122.1	256.9±112.3	0.309

Group L: Low-flow anesthesia, Group H: High-flow anesthesia, Independent Sample t-test, chi-square test
ASA: The American Society of Anesthesiologists, min: Minute

Table 2. Comparison of mean PaO_2 values within and between groups (mmHg)

Time	Group L (n: 35)	Group H (n: 35)	p*
Before preoxygenation	84.35±7.96[a]	81.73±8.08[a]	0.178
Intraoperative 60th min	145.71±24.81[b]	168.07±33.36[b]	**0.002**
End of surgery	155.37±23.51[c]	177.22±30.98[c]	**0.001**
P**	**<0.001**	**<0.001**	

Group L: Low-flow anesthesia, Group H: High-flow anesthesia
*Independent Sample t-test, **Anova test,
*Comparing between groups,
**Compared within groups,
a-c: There is no difference between times with the same letter in a group

Table 3. Comparison of mean ORI values within and between groups

Time	Group L (n: 35)	Group H (n: 35)	p*
Before preoxygenation	0.018±0.05[a]	0.030±0.10[c]	0.402
Intraoperative 10th min	0.252±0.169[b]	0.317±0.166[b]	0.110
Intraoperative 15th min	0.224±0.110[b]	0.370±0.144[ab]	**<0.001**
Intraoperative 30th min	0.211±0.133[b]	0.376±0.189[ab]	**<0.001**
Intraoperative 45th min	0.230±0.178[b]	0.355±0.188[ab]	**0.005**
Intraoperative 60th min	0.185±0.125[b]	0.392±0.168[ab]	**<0.001**
Intraoperative 90th min	0.197±0.134[b]	0.375±0.153[ab]	**<0.001**
Intraoperative 120th min	0.219±0.117[b]	0.465±0.378[ab]	**0.001**
Intraoperative 180th min	0.250±0.146[b]	0.420±0.214[ab]	**0.002**
Intraoperative 210th min	0.240±0.147[b]	0.427±0.185[a]	**0.001**
Intraoperative 240th min	0.259±0.160[b]	0.437±0.198[a]	**0.004**
End of surgery	0.245±0.180[b]	0.419±0.187[a]	**<0.001**
P**	**<0.001**	**<0.001**	

Group L: Low-flow anesthesia, Group H: High-flow anesthesia
*Independent Sample t-test, **ANOVA test,
*Comparing between groups,
**Compared within groups,
a-c: There is no difference between times with the same letter in a group
ORI: Oxygen reserve index

Table 4. Correlation analysis between ORI and PaO2			
Time			**PaO_2**
Before preoxygenation	ORI	r	0.024
		p	0.843
Intraoperative 60th min	ORI	r	**0.270**
		p	**0.024**
End of surgery	ORI	r	**0.287**
		p	**0.016**
r: Pearson's correlation coefficient, ORI: Oxygen reserve index			

was more difficult than both mild hyperoxia (PaO_2: 120-200 mmHg) and normoxia (PaO_2<100) (20). The optimal PaO_2 level is not yet clearly defined (3,21-23). Elmer et al. (22) define hypoxia as a PaO_2 of 60 mmHg, normoxia as a PaO_2 of 60-100 mmHg, moderate hyperoxia as a PaO_2 of 101-299 mmHg, and severe hyperoxia as a PaO_2 of >300 mmHg (21). In this study, in which PaO_2<60 mmHg was determined as hypoxia and PaO_2>100 mmHg as hyperoxia, all the patients were at a normoxic level before preoxygenation, but it was found that PaO_2 values at the intraoperative 60th minute and at the end of surgery were PaO_2>100 mmHg for all patients. This suggests that hyperoxia rather than hypoxia should be considered in low-flow anesthesia.

Supplying high concentrations of oxygen (>50%) for more than 48 h is reported to possibly cause O_2 toxicity. Therefore, O_2 application of more than 50% should be limited to 48 h (24). In this study, O_2 was used at a concentration of 50% during an average of 5 hours of surgery in both groups.

The most common method for monitoring oxygenation under anesthesia is the pulse oximeter, which has become a universal standard of care and can be measured continuously (25). Reports of respiratory complications during anesthesia have decreased significantly since the use of the pulse oximeter (26). SpO_2 has a major limitation when it comes to evaluating hypoxia or hyperoxia in patients receiving oxygen therapy. That is, due to the sigmoid shape of the Oxyhemoglobin dissociation curve, a small change in PaO_2 in the vertical part of the curve causes a large difference in SpO_2. Consequently, when SpO_2 is ≥97%, the PaO_2 level can be anywhere between 90 and 600 mmHg. Therefore, monitoring SpO_2 alone cannot exclude unwanted hyperoxia in patients receiving O_2 treatment. In the impending hypoxia state, the SpO_2 decrease is slower than the PaO_2 decrease. SpO_2 may not decrease before PaO_2 is <70 mmHg and SpO_2 may be insufficient for the impending danger (27). In cases where SpO_2 is insufficient in oxygenation, PaO_2 gives precise information, but being costly and invasive, waiting for results, and causing blood loss are the weaknesses of this method (28). In this study, no clinical findings of hypoxia or any decrease in SpO_2 and PaO_2 values were detected in either group. However, when SpO_2 was more than 97%, PaO_2 was found to be in a wide range, such as 70-240 mmHg. According to the literature on the subject, the researchers of this study believe that SpO_2 cannot be used as a guide in intraoperative O_2 management and hyperoxia prevention. Because hyperoxia in ABG increased gradually in both fresh gas flows during the prolonged surgical period and SpO_2 remained limited in this regard, it is necessary to be more careful with O_2 applications, especially at high currents, and routine ASA monitoring may be insufficient for intraoperative hyperoxia detection.

Studies have reported that ORI can provide an early warning when arterial oxygenation is impaired without any change in peripheral O_2 saturation (9,29,30). In the study by Szmuk et al. (29) with 25 healthy children, it was found that during the induction of anesthesia, ORI detected the approaching desaturation (on mean) 31.5 seconds before any change in SpO_2 and that this represents a clinically important warning period. This can give clinicians enough time to intervene. Tsymbal et al. (31) also showed that the added warning time provided by the ORI was 46.5 s in obese and 87.0 s in normal BMI patients. Fleming et al. (32) found that the ORI allowed an added warning time of 48.4 s compared to the SpO_2 in cardiac surgical patients. In the study of Applegate et al. (9), where they examined the relationship between the intraoperatively measured 1594 ORI value in 106 patients and PaO_2 values in the ABG samples taken when clinically necessary, PaO_2

Table 5. Linear regression analysis of the relationship between ORI and PaO2					
		Beta coefficient *	**95.0% confidence interval**		**p**
Time			**Lower limit**	**Upper limit**	
Intraoperative 60th min	Constant	0.044	-0.171	0.260	0.682
	PaO_2	0.002	0.000	0.003	**0.024**
End	Constant	0.005	-0.265	0.274	0.973
	PaO_2	0.002	0.000	0.004	**0.016**
End: End of surgery, *Not standardized, dependent variable: ORI, R^2intraoperatif 60th min=0.073, R^2End=0.082, adjusted R^2 intraoperatif 60th min=0.059, adjusted R^2End=0.069 ORI: Oxygen reserve index					

was found to be 100 mmHg in all measurements for ORI >0.24, while when ORI>0.55, SpO_2 was >96% and PaO_2 was ≥150 mmHg (3). In the same study, during the decrease of PaO_2 from 500 mmHg to 100 mmHg in 30 min, ORI also decreased, but the response of SpO_2 to such various O_2 changes was monitored only as from 99% to 96%. Saraçoğlu et al. (33) showed in their study investigating the effect of ORI-guided oxygen titration on morbidity in one lung ventilation with low fresh gas flow, that adjusting ORI with SpO_2 and blood gas analysis can prevent hyperoxemia in patients under low-flow or high-flow anesthesia. In this study, SpO_2 did not fall below 97% in any patient, and no decrease was observed in ORI values. As reported in the literature, the researchers of this study also believe that ORI can be used as a guide in determining the hyperoxia that may occur at different gas flows, in addition to its role of providing an early warning when arterial oxygenation is impaired without any change in SpO_2. According to the linear regression analysis, ORI was 0.244 (~0.2) at the intraoperative 60th min, when PaO_2 was 100 mmHg, and ORI was determined to be 0.344 (~0.3) when PaO_2 was 150 mmHg.

Accordingly, considering the values at the intraoperative 60th minute, it was observed that although PaO_2 was ≥100 in all patients, while the ORI values were >0.244 in 62.8% of them, this rate increased to 72.8% at the end of the surgery. Similar rates were found for the ORI values determined for ≥150 mmHg of PaO_2. This suggests that the relationship between ORI and PaO_2 gets stronger with the duration of surgery.

Study Limitations

There are some limitations in our study. The limitations of this study can be listed as the inclusion of only the patients who were in the ASA I-II risk group without any problems with their lung mechanics and not being able to evaluate the effectiveness of ORI for situations that may be affected by peripheral perfusion, due to the absence of a condition (such as severe hypotension, etc.). Despite these limitations, our study is valuable as it is one of the few studies showing that ORI is effective in detecting hyperoxia in different fresh gas streams and contributes to the literature.

Conclusion

It is the strong belief of the researchers of this study that ORI, which can be useful in every stage of monitoring oxygenation starting from preoxygenation, can be a guide in terms of titrating the O_2 levels in long operations with its relationship with PaO_2. Considering the defining power of the model designed in the study (R2=0.059, R2=0.069), it can be evaluated whether the identification power of the model increases by increasing the number of participants. By evaluating variables other than PaO_2 that affect the ORI value, regression models with higher definition powers can be developed with the inclusion of these variables. The usefulness of the ORI values determined for Pa100 mmHg and 150≥mmHg of PaO_2 should be tested with different clinical studies.

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Ethics

Ethics Committee Approval: This study approved by the Zonguldak Bulent Ecevit University Clinical Research Ethics Committee (date: 07.11.2018, protocol no: 2018-221-07/11).

Informed Consent: Written informed consent was obtained from the patients.

Authorship Contributions

Concept: H.O., G.K., B.G.A., R.D.O., O.P., H.A., Design: H.O., G.K., B.G.A., R.D.O., O.P., H.A., Data Collection and/or Processing: H.O., G.K., B.G.A., O.P., H.A., Analysis and/or Interpretation: H.O., G.K., B.G.A., O.P., H.A., Literature Research: H.O., G.K., H.A., Writing: H.O., G.K., B.G.A., H.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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