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Oxygen reserve index guided fraction of inspired oxygen titration to reduce hyperoxemia during laparoscopic gastrectomy

A randomized controlled trial

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Abstract

Background: The usefulness of the oxygen reserve index (ORi) in reducing hyperoxemia remains unclear. We designed this study to investigate whether fraction of inspired oxygen (FiO_2) adjustment under a combination of ORi and peripheral oxygen saturation (SpO_2) guidance can reduce intraoperative hyperoxemia compared to SpO_2 alone.

Methods: In this prospective, double-blind, randomized controlled study, we allocated patients scheduled for laparoscopic gastrectomy to the SpO_2 group (FiO_2 adjusted to target $SpO_2 \geq 98\%$) or the ORi-SpO_2 group (FiO_2 adjusted to target $0 < 0$ ORi $< .3$ and $SpO_2 \geq 98\%$). The ORi, SpO_2, FiO_2, arterial partial pressure of oxygen (PaO_2), and incidence of severe hyperoxemia ($PaO_2 \geq 200$ mm Hg) were recorded before and 1, 2, and 3 hours after surgical incision. Data from 32 and 30 subjects in the SpO_2 and ORi-SpO_2 groups, respectively, were analyzed.

Results: PaO_2 was higher in the SpO_2 group (250.31 ± 57.39 mm Hg) than in the ORi-SpO_2 group (170.07 ± 49.39 mm Hg) 1 hour after incision ($P < .001$). PaO_2 was consistently higher in the SpO_2 group than in the ORi-SpO_2 group, over time ($P = .045$). The incidence of severe hyperoxemia was higher in the SpO_2 group (84.4%) than in the ORi-SpO_2 group (16.7%, $P < .001$) 1 hour after incision. Higher FiO_2 was administered to the SpO_2 group [52.5 (50–60)] than the ORi-SpO_2 group [40 (35–50), $P < .001$] 1 hour after incision. SpO_2 was not different between the 2 groups.

Conclusion: The combination of ORi and SpO_2 guided FiO_2 adjustment reduced hyperoxemia compared to SpO_2 alone during laparoscopic gastrectomy.

Abbreviations: FiO_2 = fraction of inspired oxygen, ORi = oxygen reserve index, PaO_2 = arterial partial pressure of oxygen, SpO_2 = peripheral oxygen saturation.

Keywords: fraction of inspired oxygen, hyperoxemia, hyperoxia, oxygen reserve index, severe hyperoxemia

1. Introduction

Oxygen supplementation is a standard practice in general anesthesia.[1–3] Although oxygen may prevent hypoxic events, it may put patients at risk of hyperoxemia.[3] Excessive oxygen generates reactive oxygen species in the body and promotes oxidative stress.[1,4–6] It can also increase peripheral vascular resistance and decrease cardiac output.[7,8] Previous reports have warned that excessive oxygen is related to atelectasis,[9,10] elevated mortality in intensive care units,[11,12] and acute lung injury.[13,14] However, intraoperative hyperoxemia is frequent during routine general anesthesia.[6]

Adequate oxygen supplementation during general anesthesia can be monitored with peripheral oxygen saturation (SpO_2), or arterial blood gas analysis.[15,16] However, because SpO_2 plateaus at 100% and cannot increase beyond this, hyperoxemia cannot be monitored adequately with SpO_2.[15,17,18] In addition, arterial blood gas analysis has disadvantages of discontinuity and invasiveness.[15,16,19]

The Masimo SET rainbow pulse oximeter (Masimo Corp., Irvine, CA) uses multi-wavelength light to noninvasively and continuously monitor various parameters, such as oxygen reserve index (ORi™), or methemoglobin.[17,20] ORi is a unitless parameter representing the mild hyperoxaemic status of arterial

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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partial pressure of oxygen (PaO_2).[21] It ranges from 0.00 to 1.00, and it depicts moderate hyperoxemic status of PaO_2 ranging from about 100 mm Hg to about 200 mm Hg.[21] It has been primarily investigated for early detection of hypoxemia.[22,23] Although a few studies have investigated its efficacy in the management of hyperoxemia, its usefulness in actual clinical practice remains inconclusive.[16,18]

This study aimed to investigate whether intraoperative hyperoxemia could be reduced by adjusting the fraction of inspired oxygen (FiO_2) guided by the combination of SpO_2 and ORi, compared to SpO_2 alone.

2. Materials and Methods

This prospective, double-blind, randomized controlled study was approved by the Ethics Board of Kangbuk Samsung Hospital, Seoul, Korea (Institutional Review Board approval number: KBSMC 2019-12-027, approval date: January 21, 2020) and registered at ClinicalTrials.gov (NCT04211246, principal investigator: Eunah Cho, registration date: December 26, 2019) prior to patient enrollment. Written informed consent was obtained from all participants. The inclusion criteria were patients scheduled for elective laparoscopic gastrectomy expected to last >2 hours, patients scheduled for invasive arterial cannulation, ages between 18 and 65 years, and American Society of Anesthesiologists physical class I or II. The exclusion criteria were abnormal findings in the preoperative pulmonary function test, pregnancy, SpO_2 below 92% in room air or a history of pulmonary disease, conditions where sensor application is unavailable (e.g., finger deformity), anemia associated with haemoglobinopathies, or any major changes in the surgical plan that might affect study outcomes.

2.1. Randomization and blinding

The study subjects were assigned to each of the 2 groups (the SpO_2 or ORi-SpO_2 group) in a 1:1 ratio. A randomization table was produced by the investigator prior to patient recruitment using an interactive internet-based response system generated by the randomly permuted block randomization algorithm (http://www.randomization.com). The allocation groups were enclosed in opaque envelopes numbered according to the randomization table and kept in a closed box after sealing. The second investigator, after being informed about the allocation by the first investigator, administered general anesthesia and adjusted the FiO_2 according to the allocated group. Blinded to the group allocation, the third investigator performed all outcome assessments and the fourth investigator conducted the data analysis.

2.2. Anesthetic technique

After entering the operating room, they were monitored using standard monitoring methods, including electrocardiography, pulse oximetry, and noninvasive blood pressure measurements. A pulse oximeter was applied to the left thumb, while a noninvasive blood pressure cuff was wrapped around the right upper arm. The depth of neuromuscular relaxation was monitored at the adductor pollicis muscle of the right hand using a TOF Watch® SX monitor (Essex Pharma GmbH, Munich, Germany). A disposable adhesive pulse oximeter sensor (Rainbow® sensor, Revision O, Masimo Corp.) was applied to the fourth fingertip of the left hand according to the manufacturer's instructions. The finger was covered with a black opaque finger shield to block ambient light. The sensor was connected to Radical-7® (software: v1.6.3.5, Tech board:7c07, Masimo Corp.). ORi was monitored to guide oxygen administration in the ORi-SpO_2 group. The pleth variability index was used for goal-directed fluid management, and the perfusion index was monitored to confirm the quality of the signal. A detailed algorithm, such as the calculation basics for ORi, was stated in a previous study.[21]

For pre-oxygenation, 100% oxygen was administered for 3 minutes via a facial mask. General anesthesia was induced with propofol 1.5 mg/kg and remifentanil 1 μg/kg. After confirming loss of consciousness, rocuronium 0.8 mg/kg was administered. Mask ventilation was performed with 100% oxygen and 5% sevoflurane. After a train-of-four count reached zero, the airway was secured with endotracheal tube. Mechanical ventilation was performed using a volume-guaranteed pressure-controlled mode with the following settings: tidal volume, 6 to 8 mL/kg; positive end-expiratory pressure, 5 cm H_2O; respiratory rate, 10 to 20 bpm; end-tidal carbon dioxide, 35 to 45 mm Hg; inspiration: expiration ratio, 1:2; and fresh gas flow, 4 L/min. The radial artery was cannulated with a 20-gauge catheter, and continuous invasive arterial blood pressure was monitored. An additional intravenous route was established using an 18-gauge catheter. A 12-French nasopharyngeal temperature sensor (Lucky Medical Co., Ltd., Seoul, South Korea) was inserted through the subject's nostril to monitor core body temperature and maintain normothermia. The ambient temperature of the operating room was maintained at 23℃ to 24℃.

General anesthesia was maintained with 1.8% to 2.4% sevoflurane and remifentanil 0.05 to 0.15 μg/kg/min. During general anesthesia, treatment of hypotension was done with 4 mg ephedrine or 50 μg phenylephrine, hypertension with esmolol 30 mg or nicardipine 400 μg, and bradycardia (heart rate < 45 bpm) with atropine 0.5 mg. Intravenous fluid was administered to maintain euvolemia, targeting a pleth variability index <14%.[24]

After surgery, 100% oxygen was delivered at a flow rate of 6 L/min, and the lungs were ventilated by manual bagging. Sugammadex 2 mg/kg was administered when the train-of-four ratio exceeded 0.9. The subjects were extubated once they were fully awake and able to spontaneously breathe adequately. Following surgery, all subjects were transferred to the post-anesthetic care unit, where they were observed for 1 hour and administered 5 L/min oxygen via a facial mask.

2.3. Study protocol

The study protocol for each group is shown in Figure S1, http://links.lww.com/MD/H841. In both groups, the initial FiO_2 was set to 0.5 when mechanical ventilation was initiated after intubation.

In the SPO_2 group, the Radical-7® monitor was covered, and the FiO_2 was adjusted based on the SpO_2 measured by the pulse oximeter. The FiO_2 was adjusted to maintain an $SpO_2 \geq 98\%$, which was evaluated every 2 to 3 minutes throughout the surgery. If, $SpO_2 < 98\%$, FiO_2 was increased by 0.05, and SpO_2 was reevaluated after 2 minutes. This process was repeated every 2 to 3 minutes.

In the ORi-SpO_2 group, FiO_2 was adjusted to maintain $0 < ORi < 0.3$, and this was evaluated every 2 to 3 minutes throughout the surgery. If ORi was 0 and $SpO_2 < 98\%$, FiO_2 was increased by 0.1. If ORi was 0 and $SpO_2 \geq 98\%$, FiO_2 was increased by 0.05. If $0 < ORi < 0.3$, FiO_2 was maintained. If ORi was ≥ 0.3, and $SpO_2 < 98\%$, FiO_2 was decreased by 0.05. If ORi was ≥ 0.3, and $SpO_2 \geq 98\%$, FiO_2 was decreased by 0.1. After adjusting the FiO_2, ORi was reevaluated after 2 minutes. This process was repeated every 2 to 3 minutes.

2.4. Outcome assessments

All outcomes were recorded after achieving a stable state for 5 minutes with no change in fluid infusion rate, heart rate, patient position, and blood pressure, without administration of vasoactive drugs. ORi, SpO_2, FiO_2, and PaO_2 were recorded before surgical incision and 1, 2, and 3 hours after surgical incision.

To measure PaO_2, 1 mL of arterial blood was retrieved from the arterial catheter, and arterial blood gas analysis was performed by arterial blood gas co-oximetry (ABL-90 FLEX Plus; Radiometer Medical ApS, Copenhagen, Denmark).

Hyperoxemia was defined as $PaO_2 \geq 100$ mm Hg, and depending on severity, it was divided into mild (100 mm Hg ≤ PaO_2 < 200 mm Hg) and severe (200 mm Hg ≤ PaO_2). The incidence of severe hyperoxemia was recorded.

2.5. Statistical analysis

2.5.1. Sample size estimation. The primary outcome of our study was PaO_2 1 hours after surgical incision. The mean PaO_2 1 hour after surgical incision in the most recent 16 consecutive patients who underwent major abdominal surgery under general anesthesia in our hospital was 210 ± 76 mm Hg at an FiO_2 of 0.48. Assuming that the difference in mean PaO_2 of 60 mm Hg is clinically significant between the 2 groups, 32 subjects in each group were needed at a significance level of 0.05, power of 80%, and a dropout rate of 20%.

2.5.2. Data analyses for outcomes. Data analyses for this study were conducted using SPSS Statistics software (release 24.0; IBM Corp., Armonk, NY). Continuous variables were tested for normal distribution using the Kolmogorov-Smirnov test. Data are presented as mean ± standard deviation for normally distributed continuous variables, median (interquartile range) for non-normally distributed continuous variables, and numbers (percentage) for categorical variables. Student *t* test or Mann-Whitney *U* test was used to compare continuous variables according to their distribution. Pearson's chi-square test or Fisher's exact test was used to compare categorical variables, as appropriate.

FiO_2, PaO_2, ORi, SpO_2, and incidence of severe hyperoxemia were compared between the 2 groups at the time before surgical incision and 1, 2, and 3 hours after incision. Normally distributed data (PaO_2) were compared using a parametric method (linear mixed model). For comparison of the non-normally distributed data (FiO_2, ORi, and SPO_2), a nonparametric method (Brunner & Lange's method) was used.[25] A categorical variable (incidence of severe hyperoxemia) was compared using the generalized estimating equations. For post hoc analysis of multiple comparisons, Mann-Whitney *U* test, Wilcoxon-signed rank test, and Mann-Whitney *U* test were used for group post hoc, time post hoc, and group × time post hoc analyses, respectively. Statistical significance was set at $P < .05$. Simple linear regression was used to determine the correlation between ORi and PaO_2.

3. Results

3.1. Participant characteristics

Between October 2020 and April 2022, 206 patients were assessed for eligibility. Among these patients, 123 were excluded because they did not meet the inclusion criteria, and 19 declined to participate. Therefore, 64 patients were randomly allocated to the SpO_2 group and the ORi-SpO_2 groups. In the ORi-SpO_2 group, 1 subject was excluded from the analysis because ORi could not be obtained owing to technical failure, and another subject was excluded because further surgery was contraindicated because of peritoneal metastasis. Therefore, 32 subjects in the SpO_2 group and 30 subjects in the ORi-SpO_2 group were included in the final analysis (Fig. 1). Baseline characteristics of the study participants are shown in Table 1. There was no statistical difference in the baseline characteristics between the 2 groups.

3.2. Primary outcome: PaO_2 1 hour after surgical incision

PaO_2 1 hour after surgical incision in the ORi-SpO_2 group (170.07 ± 49.39) was lower than the SpO_2 group [250.31 ± 57.39; mean difference: 80.25; 95% confidence intervals: (52.96–107.53); $P < .001$, Table 2]. PaO_2 was significantly higher in the SpO_2 group than in the ORi-SpO_2 group in the comparison between groups ignoring the effect of time. PaO_2 was higher in the SpO_2 group than in the ORi-SpO_2 group, both in the post hoc analysis conducted for each time point ($P < .001$) when comparing the groups over time ($P = .045$, Fig. 2A).

3.3. Secondary outcomes

The incidence of severe hyperoxemia was higher in the SpO_2 group than in the ORi-SpO_2 group ($P < .001$), when the difference between the 2 groups was compared, ignoring the effect of time. Based on post hoc analysis, the incidence of severe hyperoxemia was higher in the SpO_2 group than in the ORi-SpO_2 group ($P < .001$) at all time points. However, there was no time × group difference in the incidence of severe hyperoxemia between the groups ($P = .450$, Fig. 2B).

FiO_2, when compared between groups, ignoring the effect of time, was significantly higher in the SpO_2 group than in the ORi-SpO_2 group ($P < .001$). In the post hoc analysis, the FiO_2 was higher in the SpO_2 group than in the ORi-SpO_2 group at all measurement time points ($P < .001$). FiO_2 was higher in the SpO_2 group than in the ORi-SpO_2 group when comparing the difference between the 2 groups over time ($P < .001$, Fig. 2C).

ORi was higher in the ORi-SpO_2 group compared to the SpO_2 group at 1 hour ($P = .005$), 2 hour ($P = .003$), and 3 hour ($P = .008$) after surgical incision, ignoring the effect of time. According to the post hoc analysis, the ORi maintained lower in the SpO_2 group than in the ORi-SpO_2 group, considering the effect of time ($P = .002$, Fig. 2D).

A total of 231 datasets of ORi and PaO_2 were collected, and these were compared for correlation using linear regression. There were no correlations between ORi and PaO_2, at all PaO_2 values ($r^2 = 0.008$), and at a PaO_2 < 240 mm Hg ($r^2 = 0.015$, Fig. S2, http://links.lww.com/MD/H842).

The postoperative outcomes regarding the length of hospital stay, incidence of atelectasis, intensive care unit stay, acute lung injury, and surgical site infection are listed in Table 3. There were no significant differences between the 2 groups.

4. Discussion

ORi is a noninvasive continuous parameter that displays the trend of PaO_2 changes after SpO_2 rises beyond 98% and reaches a plateau.[16] Therefore, we hypothesized that ORi could help reduce unnecessary oxygen supplementation in cases of mild to severe hyperoxemia, which SpO_2 cannot detect. In our study, we demonstrated that when FiO_2 was adjusted and guided by SpO_2 and ORi, FiO_2 could be lowered, resulting in lower PaO_2 and lower incidences of severe hyperoxemia compared to using SpO_2 alone.

In general, oxygen is routinely administered in almost all cases of general anesthesia to prevent or treat hypoxemia.[1,3] However, it can also expose patients to the risk of hyperoxemia.[1] Hyperoxemia generates reactive oxygen species causing oxygen toxicity and can increase complications after surgery.[1] However, the exact threshold of PaO_2, which increases postoperative complications, is unclear. In addition, the clinical risk-benefit of reducing hyperoxemia during general anesthesia remains inconclusive. We believe that our study is meaningful in that it focuses on the reduction of unnecessary oxygen administration and a reduction in the incidence of severe hyperoxemia by applying a new parameter, ORi, to clinical anesthesia.

In a standard clinical setting, hyperoxemia is generally defined as PaO_2 of 100 mm Hg or more.[17] According to previous studies, the mean PaO_2 during general anesthesia was 206 mm Hg;[1] however, in some cases, PaO_2 was as high as 500 mm Hg.[16] Although the amount of PaO_2 that is considered to cause hyperoxemia during general anesthesia is not well understood,

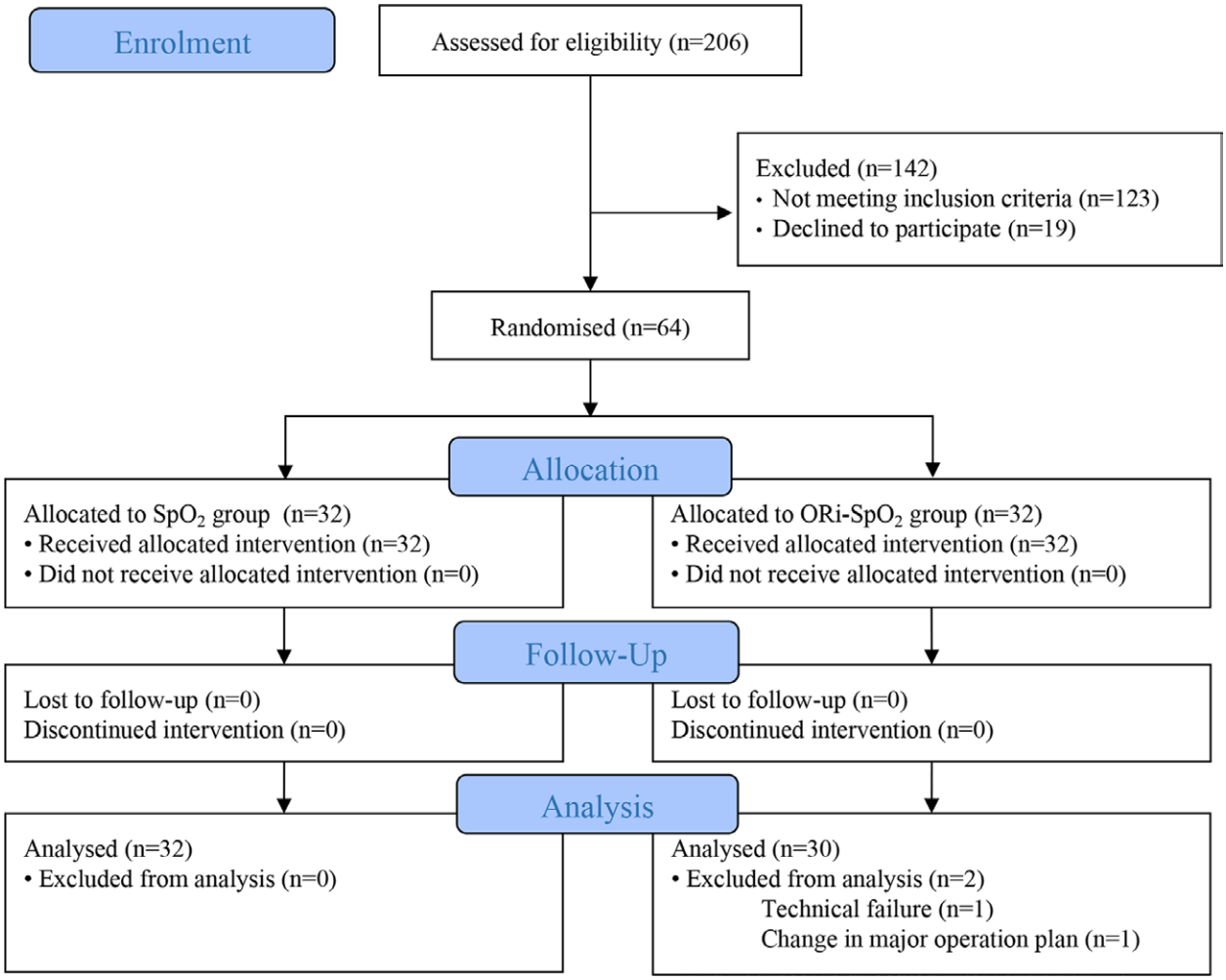

Figure 1. CONSORT diagram of the present study.

Table 1

Baseline characteristics of study subjects.

	SpO_2 group (n = 32)	ORi-SpO_2 group (n = 30)	*P* value
Sex, male/female	23/9 (71.9/28.1)	20/10 (66.7/33.3)	.657
Age, yrs	52.3 ± 7.9	53.0 ± 9.8	.739
Height, cm	167.5 ± 6.3	168.2 ± 8.3	.688
Weight, kg	68.5 ± 10.7	65.5 ± 11.6	.292
Body mass index, kg/m^2	24.3 ± 2.9	23.0 ± 2.9	.084
ASA physical status, I/II	20/12 (62.5/37.5)	21/9 (70.0/30.3)	.533
Smoking, ex-smoker/ smoker/nonsmoker	2/6/24 (6.3/18.8/75.0)	5/5/20 (16.7/16.7/66.7)	.432
Hypertension	8 (25.0)	3 (10.0)	.185
Diabetes mellitus	3 (9.4)	5 (16.7)	.467
Pulmonary function test			
FEV1, liters	3.2 ± 0.6	3.1 ± 0.7	.484
FVC, liters	5.5 ± 8.8	3.9 ± 0.9	.361
FEV1/FVC, %	81.8 ± 6.6	81.2 ± 6.6	.751
Operation type, total gastrectomy/ subtotal gastrectomy	7/25 (21.9/78.1)	7/23 (23.3/76.7)	.891
Operation duration, min	183.8 ± 48.0	190.0 ± 52.5	.626
Intraoperative fluid, mL	1567.8 ± 469.3	1633.3 ± 539.8	.611

Data are presented as numbers (%) for nominal data and mean ± SD for continuous data.
ASA = American society of anesthesiologists; FEV1, forced expiratory volume in 1 s, FVC = forced vital capacity.

the hyperoxaemic cutoff of PaO_2 in critically ill patients was reported to be as low as 150 mm Hg.[26,27] According to our study results, when FiO_2 was controlled with only SpO_2 as in the conventional method, PaO_2 was approximately 250 mm Hg and the maximum value recorded was 390 mm Hg. However, when an effort was made to maintain ORi at 0 to 0.3, PaO_2 was lowered to 170 mm Hg, which was 80 mm Hg lower than that in the SpO_2 group. Therefore, it is expected that if ORi is used as a guide to control FiO_2, unnecessary oxygen supplementation can be avoided, and the risk of severe hyperoxemia can be lowered.

ORi should detect PaO_2 values ranging from 100 to 200 mm Hg according to the algorithm presented by the manufacturer.[16] However, in clinical practice, the PaO_2 corresponding to an ORi between 0 and 1 is often over 200 mm Hg, and can be as high as 534 mm Hg.[16] Therefore, the linearity between ORi and PaO_2, and whether ORi can predict PaO_2 at each time point have been studied in previous studies.[16,18,21,28] One study demonstrated that ORi showed a strong relationship with PaO_2 ($r^2 = 0.536$) at a PaO_2 below 240 mm Hg.[16] Yoshida and colleagues analyzed 69 datasets of ORi and PaO_2, and showed a strong positive correlation between ORi and PaO_2 below 240 mm Hg ($r^2 = 0.706$).[18] The other study also showed a strong correlation between ORi and PaO_2, after analyzing 101 datasets, including PaO_2 above 240 mm Hg.[28] We performed correlation analysis of ORi and PaO_2 with our 231 datasets; however, our data showed no linearity at all PaO_2 levels ($r^2 = 0.008$), including PaO_2 below 240 mm Hg ($r^2 = 0.015$). We believe that this difference is due to the different versions of the Rainbow® sensors used. Our study

Table 2

Demographic table of partial pressure of arterial oxygen, incidence of severe hyperoxemia, fraction of inspired oxygen, and oxygen reserve index before, and 1 h, 2 h, and 3 h after surgical incision.

	SpO_2 group (n = 32)	ORi-SpO_2 group (n = 30)	Difference (95% CI)	*P* value
PaO_2				
Before surgical incision	265.66 ± 53.17	209.23 ± 41.89	56.42 (32.00–80.85)	<.001*
1 h after incision	250.31 ± 57.39	170.07 ± 49.39	80.25 (52.96–107.53)	<.001*
2 h after incision	244.47 ± 48.63	173.73 ± 46.62	70.73 (46.11–95.36)	<.001*
3 h after incision	246.91 ± 53.08	171.06 ± 50.06	75.85 (41.96–109.74)	<.001*
Severe hyperoxemia				
Before surgical incision	30 (93.8)	16 (53.3)	40.50 (14.72–63.55)	<.001†
1 h after incision	27 (84.4)	5 (16.7)	67.70 (21.17–84.51)	<.001†
2 h after incision	26 (83.9)	6 (20)	63.90 (20.56–82.43)	<.001†
3 h after incision	19 (86.4)	1 (5.9)	80.50 (1.73–91.39)	<.001†
FiO_2				
Before surgical incision	50 (50–60)	50 (45–50)	5 (0–10)	<.001‡
1 h after incision	52.5 (50–60)	40 (35–50)	15 (10–15)	<.001‡
2 h after incision	55 (50–60)	42.5 (35–50)	15 (10–15)	<.001‡
3 h after incision	52.5 (50–60)	40 (35–45)	15 (10–20)	<.001‡
ORi				
Before surgical incision	0.33 (0.27–0.44)	0.3 (0.27–0.41)	0.03 (0.03–0.11)	.301
1 h after incision	0.32 (0.24–0.67)	0.25 (0.15–0.29)	0.13 (0.04–0.27)	.005‡
2 h after incision	0.42 (0.28–0.65)	0.27 (0.19–0.31)	0.13 (0.04–0.23)	.003‡
3 h after incision	0.49 (0.38–0.65)	0.27 (0.22–0.42)	0.20 (0.06–0.35)	.008‡

Severe hyperoxemia defined by PaO2 ≥ 200.

PaO2 = partial pressure of arterial oxygen, FiO2 = fraction of inspired oxygen, ORi = oxygen reserve index.

**P* < .05, compared with Student *t* test.

†*P* < .05, compared with Pearson's chi-square test.

‡*P* < .05, compared using the Mann–Whitney *U* test.

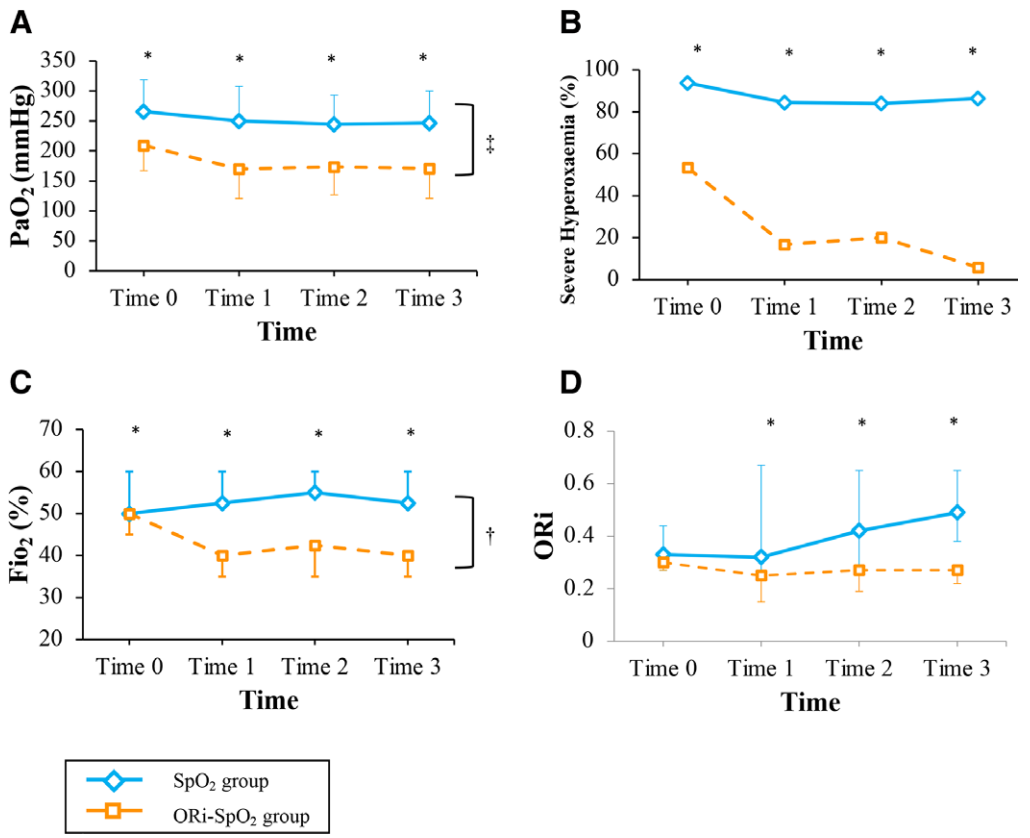

Figure 2. Diagram describing the change of incidence of severe hyperoxemia (A), fraction of inspired oxygen (B), partial pressure of arterial oxygen (C), and oxygen reserve index (D) before surgical incision (time 0) and 1 h (time 1), 2 h (time 2), and 3 h (time 3) after surgical incision in each group. **P* < .05, post hoc test at each time point. †*P* < .05 by Brunner & Langer's method. ‡*P* < .05 by linear mixed model.

Table 3

Postoperative outcomes.

	SpO_2 group (n = 32)	ORi-SpO_2 group (n = 30)	*P* value
Length of hospital stay, d	11 ± 1.7	12 ± 3.1	.230
Atelectasis, at postoperative d 1	7 (21.9)	10 (33.3)	.312
Sent to intensive care unit	0	0	N/A
Acute lung injury	0	0	N/A
Surgical site infection	0	0	N/A

Data are presented as numbers (%) for nominal data and mean ± SD for continuous data.
N/A = not available.

used an updated version of the sensor (Revision O) compared to previous studies (Revision L). Therefore, we suggest that the updated version of the ORi can be used as a guide for the adjustment of FiO_2; however, its predictability for PaO_2 seems inferior.

Several studies have suggested that hyperoxemia may adversely affect postoperative outcomes.[2,29] However, in our study, there was no difference in postoperative outcomes between the 2 groups. It is well understood that high FiO_2 is potentially harmful in critically ill patients, especially when they receive long-term high oxygen therapy.[30] The difference between FiO_2 of 40% and 50% in both groups seems to be insufficient to affect the postoperative course, when exposed during 3 hours of surgery, in patients with relatively good physical status that can withstand the surgery.

Our study has some limitations. First, our study was limited to patients who underwent elective gastrectomy. We chose elective gastrectomy because there was relatively less hemodynamic variability and vital signs were hemodynamically stable during surgery. Considering that the ORi algorithm uses the difference in light absorption according to mixed venous oxygen saturation, ORi is less reliable when it is hemodynamically unstable.[19] For example, according to our experience, ORi may suddenly rise to 1.0 with acute volume replacement, without any change in FiO_2 or ventilator settings. Thus, we collected data only when the patients were hemodynamically stable and the fluid rate was constant. Therefore, our study cannot be applied to hemodynamically unstable patients who require volume replacement.

Second, we did not collect oxidative stress indicators.[31] In 1 study, oxidative stress markers between an FiO_2 of 40% and 80% were compared in elective abdominal surgery, and malondialdehyde was lower in the low FiO_2 group.[2] In the study, the investigators suggested malondialdehyde as the main end product of peroxidation and the best oxidative stress marker. In our study, although the FiO_2 was different between the 2 groups, the difference was 10%. Therefore, even when we investigated oxidative stress markers, we did not observe any significant differences.

In conclusion, intraoperative hyperoxemia was reduced when FiO_2 was adjusted based on the combination of SpO_2 and ORi compared with SpO_2 alone in patients undergoing laparoscopic gastrectomy.

Author contributions

JA contributed to the data acquisition, designation of the study. JS contributed to the data analysis, and data interpretation. JP contributed to the manuscript drafting. SL contributed to the manuscript drafting and revision. KR contributed to the conception and designation and revision of the study. EC contributed to the conception and designation of the study, manuscript drafting.
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Investigation: Sung Hyun Lee, Eun-Ah Cho.
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Supervision: Kyoung-Ho Ryu, Eun-Ah Cho.
Writing – original draft: Jiyeon Park, Sung Hyun Lee, Kyoung-Ho Ryu, Eun-Ah Cho.

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