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Assessing the incidence of hyperoxia and the effectiveness of Oxygen Reserve Index-guided FiO2 titration in hyperoxia prevention

Pelin Uzun Sarıtaş[1], Aykut Sarıtaş[2*], Merve Çetin Poyraz[2] and Gaye Aydın[2]

Abstract

Background Although pulse oximetry technology, which is considered the standard of care to ensure optimum oxygenation, is indispensable in clinical practice, especially in the detection of hypoxemia, it has some limitations in the detection of hyperoxemia. Oxygen Reserve Index can provide clinicians with a crucial pathway in detecting and preventing hyperoxia, noninvasively. Our aim in this study is to determine the hyperoxia detection ability of ORi and to investigate the effectiveness of ORi and SpO_2-guided FiO_2 titration in preventing hyperoxia.

Methods This prospective randomized study was conducted in the operating theater of Health Sciences University İzmir Tepecik Training and Research Hospital from September 1, 2020, to December 1, 2022. Patients undergoing major abdominal surgery were divided into two groups: the control group and the SpO2 + ORi group. FiO2 titration was performed in the SpO2 + ORi group to maintain the ORi between 0.00 and 95% < SpO2 ≤ 98%. Parameters were recorded before induction, 10 min after intubation, and every hour during the operation.

Results A positive linear relationship of 75.8% ($r = 0.758$) was found between PaO2 and ORi in the ORi + SpO2 group ($p < 0.001$). Moderate hyperoxemia was observed in 31.6% of patients in the control group, while it was not observed in the ORi + SpO2 group at the 3rd hour. PaO2 values decreased significantly over time in the ORi + SpO2 group with FiO2 titration ($p < 0.001$).

Conclusion The combined use of SpO2 and ORi has been demonstrated to successfully guide FiO2 titration for optimal oxygenation and reduce hyperoxemia.

Keywords Arterial partial pressure of oxygen, Fraction of inspired oxygen, Hyperoxemia, Oxygen Reserve Index, Oxygen therapy, Pulse oxymetry

*Correspondence:
Aykut Sarıtaş
aykut26tr@hotmail.com
[1] Department of Anesthesiology and Reanimation İzmir, İzmir City Hospital, İzmir, Türkiye
[2] Department of Anesthesiology and Reanimation İzmir, Health Sciences University İzmir Faculty of Medicine Tepecik Training and Research Hospital, İzmir, Türkiye

Introduction

Oxygen therapy is universally used in patients under anesthesia and in intensive care. Oxygenation optimization is typically guided by peripheral oxygen saturation (SpO2). Generally, practices aim to avoid hypoxemia and protect against its harmful effects, leading to a tendency to use more liberal oxygen (Pala Cifci et al. 2020; Mach et al. 2011). Consequently, iatrogenic hyperoxemia is a prevalent condition (Karalapillai et al. 2020). Hyperoxia, or elevated levels of oxygen in the blood, has been increasingly recognized as a condition with potential adverse effects, comparable to those of hypoxia. The physiological impact of hyperoxia includes oxidative stress, inflammation, and potential cellular damage, which have been documented in various studies. For instance, studies have shown that excessive oxygen can lead to harmful outcomes, including ventilation/perfusion mismatch, hypercapnia, and even increased mortality in critically ill patients (Mach et al. 2011; Karalapillai et al. 2020). Although many side effects related to hyperoxemia have been reported and linked to poor outcomes, hyperoxemia remains common in clinical practice (Pala Cifci et al. 2020; Mach et al. 2011; Karalapillai et al. 2020).

In this study, we chose specific oxygenation thresholds (hypoxemia, normoxia, and hyperoxemia) based on existing literature that indicates a signal of harm associated with higher PaO2 levels (Vos et al. 2019). These thresholds were selected to provide a clear stratification of oxygenation levels, allowing for a detailed analysis of the effectiveness of the Oxygen Reserve Index (ORi) in preventing hyperoxia. By understanding the potential risks associated with different levels of oxygenation, our study aims to contribute to the broader discussion on optimal oxygen management in clinical settings.

While pulse oximetry technology, considered the standard of care for ensuring optimum oxygenation and vital for detecting hypoxemia noninvasively, has limitations in detecting hyperoxemia because it measures blood oxygen saturation but cannot distinguish between normoxia and hyperoxia, potentially leading to unrecognized hyperoxemia in clinical settings. The oxyhemoglobin dissociation curve is sigmoidal, and as SpO2 approaches 100%, there is no further increase in saturation, regardless of how high the arterial oxygen partial pressure (PaO2) is. Hence, relying solely on SpO2 may overlook hyperoxemia. To achieve optimal oxygenation, tools capable of detecting hyperoxemia noninvasively should complement pulse oximetry (Vos et al. 2019; Yoshida et al. 2020).

Oxygen Reserve Index (ORi™, Masimo Corp., Irvine, CA, USA) is a novel, noninvasive, continuous variable that offers clinicians a crucial tool for detecting moderate hyperoxemia (*PaO2* 100–200 mmHg [13.3–26.7 kPa]). ORi is a dimensionless index measurable noninvasively with a multi-wavelength pulse co-oximeter, ranging between 0.00 (no oxygen reserve) and 1.00 (maximum reserve) (Vos et al. 2019; Yoshida et al. 2020; Applegate et al. 2016; Szmuk et al. 2016; Koishi et al. 2018; Scheeren et al. 2018; Saugel and Belda 2018).

Continuous, noninvasive monitoring of ORi can effectively detect and prevent hyperoxemia. ORi-guided FiO2 titration can mitigate hyperoxemia's harmful effects by maintaining lower PaO2 values, applicable to both patients under anesthesia and in intensive care units.

This study aims to investigate ORi's ability to detect hyperoxemia, determine its incidence, and evaluate the effectiveness of ORi-guided FiO2 titration in preventing hyperoxemia in patients undergoing major abdominal surgery.

Material and methods

This study was approved by the Institutional Review Board and Ethics Committee of the Health Sciences University İzmir Tepecik Training and Research Hospital (No.: 01 12/08/2020), and written informed consent was obtained directly from patients who were capable of providing it. For those unable to consent due to medical or cognitive reasons, consent was obtained from their next of kin. The clinical trials (ClinicalTrials.gov) registration number is NCT05770583.

This prospective randomized study was carried out in Health Sciences University İzmir Tepecik Training and Research Hospital operating theater where elective surgery was planned for major abdominal surgery patients in the risk groups I, II, and III according to the American Society of Anesthesiologists (ASA) from 01/09/2020 to 01/12/2022.

Major abdominal surgery was defined as surgical procedures involving significant operative time, extensive tissue dissection, and a potential for considerable physiological impact, such as notable blood loss or the requirement for extensive postoperative care.

The selection of patients was conducted as follows:

The inclusion criteria were as follows: (1) Patients older than 18 years, (2) patients scheduled for major abdominal surgery that are expected to last longer than 2 h, (3) patients that have invasive arterial monitorization, and the (4) American Society of Anesthesiologists physical classes I, II, or III.

The exclusion criteria were as follows: (1) Patients younger than 18 years, (2) hemodynamically unstable patients, (3) patients with hemoglobinopathy, (4) pregnancy, (5) morbid obesity (BMI > 40 kg/m^2), (6) patients with arrythmia that can result in hemodynamic

instability and patients with acute coronary syndrome, and (7) acute respiratory failure or ARDS.

Anesthesia management

The anesthesia management was carried out as follows: after the patients were admitted to the operating rooms, patients were monitored using routine monitoring methods, including electrocardiogram (ECG), pulse oximetry, and noninvasive blood pressure measurements. To minimize any potential impact on the initial post-intubation data, preoxygenation with FiO2 1.0 was intentionally avoided.

General anesthesia was induced with 2–3 mg/kg propofol intravenous (IV) and 1–2 µg /kg fentanyl IV with skeletal muscle relaxation induced with 0.6 mg/kg rocuronium bromide. The airway was secured with endotracheal tube.

Mechanic ventilator parameters after intubation routinely will be set as TV: 6–8 ml/kg, PEEP: 4–7 mmHg, FiO_2: 50% (50% oxygen + 50% air mixture), and 4 lt/min fresh gas flow. In both groups, the initial FiO_2 was set to 50%, and only FiO_2 settings were modified.

20-G radial artery catheterization was applied to the patients for arterial blood gas analysis and continuous invasive hemodynamic monitoring. General anesthesia was maintained with sevoflurane or desflurane and remifentanil 0.05 to 0.15 µg/kg/min, using the Mindray A9 Anesthesia Machine, as specified.

The study protocol for each group is shown in CONSORT flow diagram. Patients who would undergo major abdominal surgery were divided into two groups as the control group and the SpO_2 + ORi group. The randomization of the patients in the groups was performed with the closed envelope method.

Settings

In the control group, FiO2 titration was performed by an independent anesthesiologist who was not involved in the study and was not following any specific protocol. The hemodynamic data, including SpO2, ORi, PaO2, PaCO2, PEEP, and FiO2, were recorded by a different anesthesiologist or assistant who was part of the study. The independent anesthesiologist, not involved in the study, was blinded with respect to data recording.

In the SpO_2 + ORi group, it was aimed to maintain $95\% < SpO_2 \leq 98\%$ and ORi 0.00. Lower limits were determined as $SpO_2 > 95\%$ and $FiO_2 \geq 25\%$. Accordingly, as follows:

- If $ORi \geq 0.01$ and $SpO_2 \geq 98\%$, FiO_2 was reduced by 10% titrations (until FiO_2 was 30%) until ORi was 0.00. Titration was carried out up to 25%, which is the FiO_2 lower limit, so that the titration would be 5% after FiO_2 was 30%.
- As long as $ORi \geq 0.01$ and $95\% < SpO_2 \leq 98\%$, FiO_2 was reduced by 10% titrations (until FiO_2 was 30%) until ORi was 0.00. Titration was carried out up to 25%, which is the FiO_2 lower limit, so that the titration would be 5% after FiO_2 was 30%.
- If ORi is 0.00 and $95\% < SpO_2 \leq 98\%$, FiO_2 is not changed.
- If ORi is 0.00 and $SpO_2 \leq 95\%$, FiO_2 is increased by 10%.

Monitoring and data collection

In addition to routine monitoring methods, PaO_2-$PaCO_2$ monitoring was performed with ORi and blood gas analyses. ORi values were measured by connecting Rainbow R1 25-L probe (Irvine, CA, USA) and Radical-7® (Masimo Corp., Irvine, CA, USA).

In both groups, patients' SpO_2, ORi, PaO_2, $PaCO_2$, PEEP, FiO_2, and hemodynamic parameter (blood pressure, arterial, and pulse) values were recorded before induction, 10 min after intubation, and every hour during the operation. When data were categorized, normoxemia was defined as PaO2: 80–100 mmHg (10.7–13.3 kPa), moderate hyperoxemia as 100–200 mmHg (13.3–26.7 kPa), and severe hyperoxemia as > 200 mmHg (> 26.7 kPa) (Vos et al. 2019; Applegate et al. 2016; Shen 2023).

Sample size

In calculating the required sample size, Cohen's effect size (d) was used. The minimum sample size is to be used in the study for the analysis, which gives the maximum sample size in all analyses; in simple linear regression analysis, in order to test the significance of the model, with independent variable 1 to be included in the model 1, $f2 = 0.35^*$, it was calculated as a minimum of 50 patients with n: 25 patients in each group to ensure 80% test power at 95% confidence level.

Statistical analysis

In the study, mean and standard deviation were used as descriptive statistics. In the study, whether there is a significant difference in terms of the parameters examined in the control and ORi + SpO_2 groups was analyzed with the independent sample *t*-test, since the parametric test assumptions were met. Repeated measures ANOVA test was used to evaluate the difference between the times only in the Ori + SpO_2 group. In order to estimate PaO_2 with ORi, a single variable regression equation was set up for each time period separately, and the explanatory coefficient was given together with the equation.

Table 1 Comparison of data classified according to PaO_2 values between groups

	Control	ORi + SpO_2	*p**
Normoxia	13 (68.4)	18 (100)	**0.020**
Moderate hyperoxia	6 (31.6)	0 (0)	
Severe hyperoxia	-	-	

* Fisher's exact test, *n* (%)

Table 2 Change of PaO_2 data over time in the ORi + SpO_2 group

ORi + SpO2	10 min[a]	1 h[b]	2 h[c]
	177,688 ± 51,617[b,c*]	151,344 ± 39,757[a*]	131,067 ± 25,268[a*]
	***p* < 0.001**		

* a, b, c indicate statistically significant differences between time points ($p < 0.05$, repeated measures ANOVA, mean ± standard deviation)

Pearson chi-square coefficient and coefficient significance test were used to examine the correlation between variables separately in each group. In the analysis of the study, $p < 0.05$ was considered statistically significant. The analyses of the study were made using the IBM SPSS v22 program.

Results

According to the demographic data analysis, out of the 62 patients enrolled in the study, 30 were allocated to the control group and 32 to the ORi + SpO2 group. The mean age of the control group was 59.47 ± 16.292, whereas the mean age of the ORi + SpO2 group was 57.813 ± 14.634. There were no significant differences observed between the groups regarding age ($p = 0.675$) and gender ($p = 0.450$). In the control group, there were 14 (46.7%) female and 16 (53.3%) male patients, while in the ORi + SpO2 group, there were 18 (56.3%) female and 14 (43.8%) male patients.

When examining the correlation between ORi and PaO2, a high level of linear relationship was found with a correlation coefficient (r) of 0.758 ($p < 0.001$) when all times and groups were included. When analyzed according to the groups, a positive linear relationship with $r = 0.717$ ($p < 0.001$) was found in the control group and $r = 0.758$ ($p < 0.001$) in the ORi + SpO2 group. The relationship between ORi and PaO2 at all times is detailed in Supplemental Fig. 1.

While no statistical differences were found between the groups during the 1st and 2nd hours, by the 3rd hour, moderate hyperoxemia was observed in 31.6% of patients in the control group. In contrast, none of the patients in the ORi + SpO2 group exhibited moderate hyperoxemia (Table 1). We would like to emphasize that the data at the 3rd hour decreased in relation to the duration of the operation.

A significant difference was found between the times in the ORi + SpO2 group ($p < 0.001$). PaO2 values decreased significantly over time ($p < 0.001$) with FiO2 titration in the ORi + SpO2 group (Table 2).

In the regression equations obtained to predict the ORi and PaO2 variables, the regression model was found to be significant for the 1st, 2nd, and 3rd hours (Supplemental Table 1). The coefficient of determination R-squared was approximately 46% (R^2 = 0.459) at the 2nd hour.

According to the examination of hemodynamic and other parameters, there was no significant difference between the control and ORi + SpO2 groups in terms of the parameters examined ($p > 0.05$) (Supplemental Table 2).

Changes in PaO2, FiO2, and Oxygen Reserve Index in all time periods for both groups are shown in Fig. 1a. In the ORi + SpO2 group, changes with FiO2 titration over time are shown in Fig. 1b. Comparison of changes in PaO2, FiO2, and ORi of both groups over time is given in Fig. 1c.

Discussion

In this study, we demonstrated that (I) ORi and PaO2 exhibit a high level of correlation, (II) ORi may provide valuable insights for clinicians in evaluating hyperoxemia, and (III) under the guidance of ORi and SpO2 together, FiO2 titration can be performed, contributing to achieving optimum oxygenation by obtaining lower PaO2 values and reducing the incidence of hyperoxemia.

Unlike studies that solely investigated the correlation between ORi and PaO2 or the success of ORi in detecting hyperoxemia, our study also suggests that FiO2 titration can be effectively performed noninvasively with ORi.

Almost all clinicians use SpO2 as an indicator for adjusting FiO2, both during general anesthesia and in the intensive care unit. Currently, the clinical use of SpO2 as a noninvasive oxygenation monitor is indispensable and serves as a standard monitoring method for providing optimum oxygenation (Yoshida et al. 2020; Scheeren et al. 2018; Chen and Min 2020).

When SpO2, crucial for detecting hypoxemia, reaches 100%, PaO2 may be at elevated values, and its level becomes unpredictable (Yoshida et al. 2020; Courson et al. 2022). The disadvantages of arterial blood gas analysis, the gold standard in hyperoxemia detection and oxygen monitoring, such as invasiveness, extra cost, time delay, blood loss during repeated measures, complications related to puncture, and inability to provide continuous data, limit its use and may lead to overlooking hyperoxemia (Vos et al. 2019; Cousins and O'Donnell 2004).

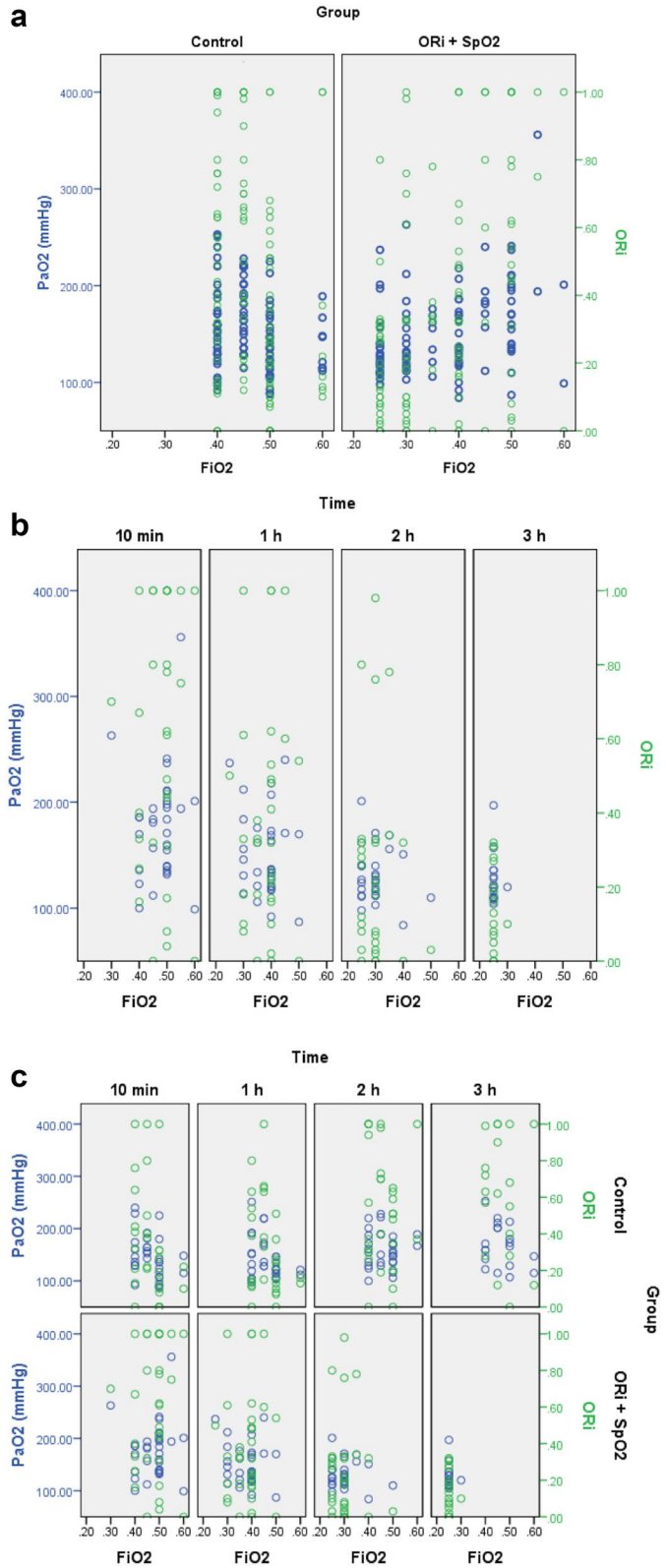

Fig. 1 **a** Changes in PaO2, FiO2, and ORi. **b** In the ORi + SpO2 group, changes in PaO2, FiO2, and Oxygen Reserve Index overtime. **c** Comparison of changes in PaO2, FiO2, and ORi overtime in both groups

The damage caused by hyperoxemia in the body is significant. Studies indicate that hyperoxemia has physiopathological harmful effects akin to hypoxia. Potential effects of hyperoxemia include ventilation/perfusion disequilibrium, hypercapnia, atelectasis, acute tracheobronchitis, diffuse alveolar damage, acute respiratory distress syndrome (ARDS), systemic vasoconstriction, cardiac output depression, and increased mortality (Horncastle 2019; Hafner et al. 2015). Furthermore, excessive medical gas usage rates have detrimental effects economically and environmentally (Gómez-Chaparro et al. 2018). Oxygen, while essential, has side effects when applied excessively, necessitating accurate monitoring for oxygen optimization.

Due to the limitations of SpO2 in detecting hyperoxemia, the use of ORi, which provides continuous and noninvasive measurements, may be more effective in preventing hyperoxemia. Using SpO2 and ORi together can complement each other and ensure effective oxygenation monitoring.

Reviewing studies on the relationship between ORi and PaO2, Applegate et al. reported a positive correlation between PaO2 and ORi ($r^2 = 0.536$) when PaO2 was < 240 mmHg, while Yoshida et al. found a relatively high positive correlation between ORi and PaO2 ($r^2 = 0.706$) (Yoshida et al. 2020; Applegate et al. 2016). Koishi et al. reported a positive correlation between PaO2 and ORi ($r^2 = 0.671$), including some data with $PaO2 \geq 240$ mmHg (Koishi et al. 2018). Similarly, Vos et al. reported a strong positive correlation between PaO2 and ORi in the ORi-sensitive range (*PaO2*: 100–200 mmHg), and that ORi had a good trend ability according to PaO2 changes in this range (Karalapillai et al. 2020). In our study, including all times and both groups, we found a high level of positive linear correlation of 73.8% between PaO2 and ORi ($p < 0.001$). In the ORi + SpO2 group, this relationship was highly positive and linear at a rate of 75.8% ($p < 0.001$).

Additionally, the regression equations obtained to estimate ORi and PaO2 variables for the 1st, 2nd, and 3rd hours were significant in our study.

These data suggest that ORi monitoring offers a reasonable estimate of PaO2 and can serve as a potential noninvasive tool in evaluating hyperoxemia in patients receiving oxygen. However, Jin Hee Ahn et al. (Ahn et al. 2022) mentioned that they did not find any linearity, including $PaO2 < 240$ mmHg values, in the PaO2 and ORi correlation analysis they conducted with 231 data sets. They suggested that differences in studies might result from using different versions of the rainbow sensors (updated versions Revision O/ and Revision L). Although a high level of PaO2-ORi correlation has been demonstrated in many studies, including ours, improvements to ORi with necessary updates might reduce variations.

These characteristics of ORi are crucial for preventing hyperoxemia due to unnecessary and excessive oxygen use and associated complications. Hyperoxemia is as harmful as hypoxia, with a U-shaped relationship between oxygenation and harm. Hence, using SpO2 and ORi together is essential to prevent complications and mortality (Vos et al. 2019; Jonge et al. 2008; Martin and Grocott 2013; Asfar et al. 2015).

De Jonge et al., in their study examining the relationship between PaO2 and mortality, found the lowest mean mortality rate at a PaO2 of 113–150 mmHg (15–20 kPa) and indicated that the mortality rate increased when PaO2 < 68 mmHg (9 kPa) and > 225 mmHg (30 kPa) (Jonge et al. 2008). Rincon et al. (Rincon et al. 2014) reported that hyperoxemia ($PaO2 > 300$ mmHg/40 kPa) independently increases mortality in patients with traumatic brain injury (TBI) and advised against unnecessary oxygen administration.

Although the European Society of Intensive Care Medicine consensus specified that there is enough data to recommend that both hypoxemia and hyperoxemia should be avoided in TBI patients and agreed on a general normoxia recommendation with optimal PaO2 of 80–120 mmHg (10–16 kPa) in TBI patients with or without increased intracranial pressure, specific PaO2 targets need to be individualized (Courson et al. 2022; Robba et al. 2020).

Oxygen is a double-edged sword. While hyperoxemia has numerous harmful effects on the pulmonary, cardiac, metabolic, vascular, and cerebral systems and increases morbidity and mortality, studies have reported average PaO2 levels during general anesthesia to be 206 mmHg (Robba et al. 2020) and even exceeding 500 mmHg in some case groups (Yoshida et al. 2020; Ahn et al. 2022). Therefore, achieving optimum oxygenation within a narrow therapeutic range is vital (Courson et al. 2022).

Various classifications based on PaO2 values have been proposed for oxygen status. Although no definitive classification exists, it is generally defined as hypoxemia ($PaO2 < 80$ mmHg [< 10.7 kPa]), normoxia (81–100 mmHg [10.7–13.3 kPa]), moderate hyperoxemia (100–200 mmHg [13.3–26.7 kPa]), and severe hyperoxemia (PaO2 > 200 mmHg [> 26.7 kPa]) (Scheeren et al. 2018; Chen and Min 2020). In our study, using this classification, we investigated the effectiveness of ORi-guided FiO2 titration to achieve optimum oxygenation and avoid hyperoxemia. Normoxia (*PaO2* 80–100 mmHg [10.7–13.3 kPa]) was observed in more patients in the ORi + SpO2 group, and moderate hyperoxemia was not observed in any patient in the ORi + SpO2 group, with a significant statistical difference found between the

groups. Moreover, the decreasing trend of PaO2 values over time in the ORi + SpO2 group and the statistically significant difference between PaO2 values in each time period demonstrate the effective application of FiO2 titration guided by ORi. Consistent with our study, Ahn et al. reported that adjusting FiO2 under the guidance of ORi and SpO2 resulted in a lower incidence of hyperoxemia with lower PaO2 levels (Ahn et al. 2022). In another study evaluating 50 patients undergoing breast surgery, lower oxygen requirements were obtained in the group using ORi to determine additional postoperative oxygen amounts. The beneficial effect of ORi on postoperative oxygen titration was demonstrated in this study (Martin et al. 2016; Kumagai et al. 2020). Another study investigating the effects of ORi-guided oxygen titration and hyperoxemia-mediated morbidity in one-lung ventilation reported lower mean FiO2 and PaO2 values with ORi monitoring. They concluded that ORi-guided oxygen titration can protect against hyperoxia, reduce hospital stay duration, and increase patient safety (Saraçoğlu et al. 2021). Consistent with our study, these studies indicated that ORi has a beneficial role in preventing hyperoxia and achieving optimum oxygenation through its guiding effect on FiO2 titration.

In our study, we believe that the lack of significant differences in detectable hyperoxaemia until the third hour may be due to the patients' physiological reserve and stable oxygenation in the early phases of surgery. Additionally, the delay in detecting differences may be influenced by the combination of hourly monitoring and cumulative FiO2 titrations. As these adjustments accumulate, their impact on oxygenation becomes more pronounced, potentially explaining the differences observed later in the procedure. We believe this could be one of the reasons for the observed differences and underscores the importance of timing and frequency in FiO2 titration during intraoperative oxygen management.

Considering the increasing number of surgeries and intensive care patients worldwide, complications caused by hyperoxemia affect quality of life, increase morbidity and mortality, contribute to environmental harm due to unnecessary oxygen use, and result in workforce loss and substantial economic losses. ORi provides clinicians with a crucial tool to detect and prevent hyperoxemia noninvasively. The advantage of using ORi with SpO2 in preventing both hypoxemia and hyperoxemia is evident.

Limitations

First, one of the limitations of this study is the hourly recording of parameters during surgery, which may not fully capture significant fluctuations in oxygen utilization and delivery that can occur during major abdominal procedures. While automated continuous electronic recording could provide more robust and detailed data, this approach was not feasible within the scope of our study. Future research should consider incorporating continuous monitoring techniques to gain a more comprehensive understanding of intraoperative oxygen dynamics. Second, the study was conducted in a single center, which may limit the generalizability of the findings to other hospitals or geographical regions. Multicenter studies are recommended to validate the results across different populations and healthcare settings. Third, the specific focus on patients undergoing major abdominal surgery may limit the applicability of the findings to other surgical procedures or patient groups. Further studies are needed to assess whether the observed effects are consistent across different types of surgeries and patient demographics.

Additionally, while our study demonstrates a significant reduction in hyperoxia in the ORi group, it is important to acknowledge the limitations of our dataset, particularly the limited number of data points in surgeries lasting less than 3 h. The effectiveness of ORi-guided FiO2 titration in preventing hyperoxia is promising; however, the observed differences may be influenced by the small sample size and the number of data points collected. These factors necessitate a cautious interpretation of our findings. Future studies with more frequent data collection and larger sample sizes are essential to confirm the robustness of these results and to provide a more detailed understanding of intraoperative oxygen dynamics.

Conclusion

The combined use of SpO_2 and ORi may provide optimum oxygenation by successfully guiding FiO_2 titration. Therefore, we believe that the routine use of ORi monitoring among standard monitoring methods in operating rooms will provide significant benefits by completing SpO_2, both because it can be used noninvasively and because of its beneficial role in the detection of hyperoxia.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13741-024-00456-x.

Supplementary Material 1: Supplementary Figure 1. Relationship between ORi and PaO2 across all time periods for both groups.

Supplementary Material 2: Supplemental Table 1. Regression model obtained to predict the PaO_2 variable with ORi in each time period.

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Authors' contributions
Conception: Pelin Uzun Sarıtaş, Aykut Sarıtaş, Merve Çetin Poyraz, Gaye Aydın. Study design: Pelin Uzun Sarıtaş, Aykut Sarıtaş, Gaye Aydın. Data acquisition: Pelin Uzun Sarıtaş, Merve Çetin Poyraz, Gaye Aydın. Data analysis: Pelin Uzun Sarıtaş, Aykut Sarıtaş, Gaye Aydın. Data interpretation: Pelin Uzun Sarıtaş, Aykut Sarıtaş, Merve Çetin Poyraz, Gaye Aydın. Drafting of the manuscript: Pelin Uzun Sarıtaş, Aykut Sarıtaş, Merve Çetin Poyraz, Gaye Aydın. Revision of the manuscript: Pelin Uzun Sarıtaş, Aykut Sarıtaş. Approval of the final manuscript version: Pelin Uzun Sarıtaş, Aykut Sarıtaş, Merve Çetin Poyraz, Gaye Aydın. All authors have read and agreed to the version of the manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board and Ethics Committee of the Health Sciences University İzmir Tepecik Training and Research Hospital (approval number 01 12/08/2020). Written informed consent was obtained from each patient's next of kin. The clinical trials (ClinicaTrials.gov) registration number is NCT05770583. Patients who met the inclusion criteria were given the option to participate after receiving comprehensive information about the study's purpose, associated risks, and benefits. The information sheet explicitly stated that declining participation would not impact the quality of care or their relationship with healthcare professionals, and confidentiality would be maintained. Written consent was obtained from each participant.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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