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To Evaluate the Relationship between Oxygen Reserve Index (ORi™) with Arterial Partial Pressure of Oxygen (PaO_2) and Arterial Oxygen Saturation (SaO_2)

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Abstract

Background: Oxygen Reserve Index (ORi™) (Masimo Corp., Irvine, CA, USA) is a novel non-invasive monitoring tool that provides supplementary information on oxygenation, especially within the moderate hyperoxia range. Conventional methods such as arterial blood gas (ABG) analysis, while accurate, are invasive, intermittent, and associated with certain risks. This study investigates the relationship between ORI, arterial partial pressure of oxygen (PaO_2), and arterial oxygen saturation (SaO_2) to evaluate its clinical utility in perioperative oxygen management.

Aims and Objectives: The primary aim was to evaluate the relationship between ORI and PaO_2 in patients undergoing elective neurosurgical procedures under general anesthesia. Secondary objectives included examining the correlation of ORI with SaO_2 and exploring its potential in guiding oxygen therapy titration.

Materials and Methods: This prospective observational study was conducted over one year, enrolling 50 adult patients undergoing elective neurosurgery. Baseline parameters, including heart rate, respiratory rate, SpO_2, and end-tidal CO_2, were recorded preoperatively. ORI values were measured using a multiwavelength pulse co-oximeter (Radical-7, Masimo). Arterial blood gas samples were obtained intraoperatively at 45-minute intervals and during recovery. Statistical analysis was performed using descriptive statistics, Pearson's correlation, and regression analysis, with significance set at $p < 0.05$.

Results: A significant positive correlation ($R^2 = 0.473$, $p < 0.0001$) was observed between ORI and PaO2 for values up to 150 mmHg. Beyond this range, the correlation weakened, suggesting ORI's effectiveness is confined to the moderate hyperoxic range. A stepwise regression model combining PaO2, SaO2, SpO2, and $etCO_2$ showed a strong combined correlation with ORI ($R^2 = 0.512$, $p < 0.0001$). ORI trends were found to reliably reflect changes in PaO_2, particularly within the targeted hyperoxic range.

Conclusion: The study demonstrates that ORI provides valuable non-invasive insights into oxygenation trends, particularly in moderate hyperoxia, and holds potential for guiding oxygen therapy. However, its accuracy in extreme hyperoxic or hypoxic states and its application in diverse clinical scenarios require further validation through larger, multicentric studies.

Keywords: Oxygen Reserve Index (ORi™) (Masimo Corp., Irvine, CA, USA); Arterial Partial Pressure of Oxygen (PaO2); Arterial Oxygen Saturation (SaO2); Perioperative Oxygenation; Moderate Hyperoxia; Oxygen Therapy Titration; Non-Invasive Monitoring; Neurosurgery; Pulse Co-Oximetry; Perioperative Care

Abbreviations

ORI: Oxygen Reserve Index; PaO2: Arterial Partial Pressure of Oxygen; SaO_2: Arterial Oxygen Saturation; ABG: Arterial Blood Gas; PACU: Post-Anesthesia Care Unit; COPD: Chronic Obstructive Pulmonary Disease; ECG: Electrocardiogram; MAC: Minimum Alveolar Concentration; PEEP: Positive End-Expiratory Pressure; SD: Standard Deviation; FiO_2: Fraction of Inspired Oxygen; SpO_2: Standard Practice in Assessing Oxygen Saturation; $ETCO_2$: End-Tidal CO_2;

Introduction

Oxygen supplementation in the perioperative setting plays a crucial role in preventing hypoxia and its associated risks, particularly in patients undergoing major surgery or those in critical care [1]. Hypoxemia in the perioperative period is a significant concern, often exacerbated by factors such as obesity, difficult airway management, rapid sequence induction, and one-lung ventilation. These risk factors contribute to oxygen desaturation, which can lead to a range of adverse outcomes, especially in the early postoperative phase in the post-anesthesia care unit (PACU). During this period, effective oxygenation is critical to prevent complications like tissue hypoxia, organ dysfunction, and delayed recovery [2,3].

While supplemental oxygen is routinely administered to manage oxygenation, excessive oxygen levels can also result in harmful effects, particularly in patients with underlying pulmonary conditions like chronic obstructive pulmonary disease (COPD). Hyperoxia, resulting from high-flow oxygen therapy, has been associated with increased infarct size and higher mortality in conditions such as myocardial infarction. This highlights the importance of carefully titrating oxygen therapy to maintain optimal oxygen levels while avoiding both hypoxia and hyperoxia [4-7].

Materials and Methods

This prospective observational study was approved by the institutional ethics committee, with written informed consent obtained from all participants. The study aimed to evaluate the relationship between the Oxygen Reserve Index (ORI), arterial partial pressure of oxygen (PaO_2), and arterial oxygen saturation (SaO_2) in patients undergoing elective neurosurgical procedures under general anesthesia. A total of 50 adult patients scheduled for elective neurosurgery with orotracheal intubation were enrolled. Inclusion criteria required that arterial catheterization and intraoperative blood gas analysis be part of the patient management protocol [8,9].

Baseline vital signs, including heart rate, respiratory rate, temperature, SpO_2, electrocardiogram (ECG), and end-tidal CO_2 ($etCO_2$), were recorded preoperatively. ORI values were simultaneously measured using a multiwavelength pulse co-oximeter (Radical-7, Masimo). Intravenous access was established in all patients prior to anesthesia induction. Routine preoxygenation was performed, and a baseline arterial blood gas (ABG) sample was collected. Anesthesia was induced with fentanyl (2µg/kg), midazolam (0.02 mg/kg), and propofol (2mg/kg), followed by muscle relaxation with atracurium (0.5mg/kg). Maintenance of anesthesia was achieved with a combination of oxygen, nitrous oxide, and sevoflurane, targeting a minimum alveolar concentration (MAC) of 0.8–1.2 under low-flow conditions [10-13].

Arterial blood gas sampling was conducted intraoperatively at 45-minute intervals. Further ABG samples were obtained immediately after extubation, and during the recovery phase, two additional samples were collected every 15 minutes while the patient was receiving 2L of oxygen via nasal cannula. ORI measurements were recorded alongside each ABG sample. Therapeutic interventions, such as adjustments to PaO_2 when levels fell below 100 mmHg, as well as the use of positive end-expiratory pressure (PEEP) and recruitment maneuvers in cases of hypoxemia, were noted. Instances of hyperoxia (PaO_2 >200 mmHg) and corresponding interventions were also documented.

Statistical analysis was performed using descriptive statistics, with data expressed as mean ± standard deviation (SD), frequencies, and percentages, as appropriate. Pearson's correlation coefficient was used to assess the relationship between PaO_2, SaO_2, and ORI [14]. Regression analysis was conducted to examine the correlation between PaO_2, SaO_2, and pooled ORI values derived from ABG samples. A p-value of less than 0.05 was considered statistically significant. All statistical analyses were performed using Microsoft Excel 2013 and SPSS version 21.

Results

In this study, 50 participants were successfully enrolled, with a mean age of 44.74 ± 15.25 years. The cohort predominantly comprised 68% males and 32% females. Throughout the perioperative period, key parameters were closely monitored, including oxygen saturation (SaO_2), partial pressure of oxygen (PaO2), oxygen reserve index (ORI), and fraction of inspired oxygen (FiO_2). Preoperative SaO_2 was 99.16 ± 0.68%, which increased slightly post-intubation and remained high through extubation. PaO_2 was initially 95.23 ± 3.79 mmHg and demonstrated a substantial increase following preoxygenation, peaking at 221.58 mmHg at extubation [15,16].

The ORI, a novel measure of oxygen reserve, demonstrated a significant increase from 0.38 ± 0.13 preoperatively to

0.85 ± 0.09 during intubation and maintained stability through extubation before returning to baseline values. These findings suggest that ORI is sensitive to changes in oxygenation during critical periods, such as intubation and extubation [17].

Further analysis revealed a strong, statistically significant positive correlation between changes in PaO_2 and ORI ($R^2 = 0.473$, $P < 0.0001$), particularly for PaO_2 values up to 150 mmHg [18]. Notably, no significant correlation was observed for PaO_2 levels exceeding 150 mmHg, indicating that ORI may be most effective in reflecting oxygenation changes within this range. In contrast, FiO_2 showed a non-linear relationship with ORI ($R^2 = 0.455$, $P < 0.0001$), which warrants further exploration [19].

A stepwise linear regression model combining PaO_2, SpO_2, $etCO_2$, and SaO_2 demonstrated a strong combined correlation with ORI ($R^2 = 0.512$, $P < 0.0001$), supporting the potential clinical utility of ORI in guiding oxygen therapy. The study's findings suggest that ORI may be an effective tool for oxygen titration, particularly for maintaining PaO_2 within optimal ranges. Further investigation into its role in clinical practice is recommended [20,21].

The introduction of the Oxygen Reserve Index (ORI) provides a novel, non-invasive means to monitor oxygenation status. ORI is a continuous measurement that reflects oxygenation within the moderate hyperoxia range (PaO2 100-200 mmHg). It offers several advantages over traditional pulse oximetry by detecting early signs of oxygenation deterioration before changes in SpO_2 occur. This allows clinicians to adjust oxygen delivery more accurately, preventing both hypoxemia and unintentional hyperoxia. The aim of this study is to assess the relationship between ORI, arterial partial pressure of oxygen (PaO_2), and arterial oxygen saturation (SaO_2) in perioperative patients, exploring its potential to enhance perioperative oxygen management and improve patient outcomes [22-25].

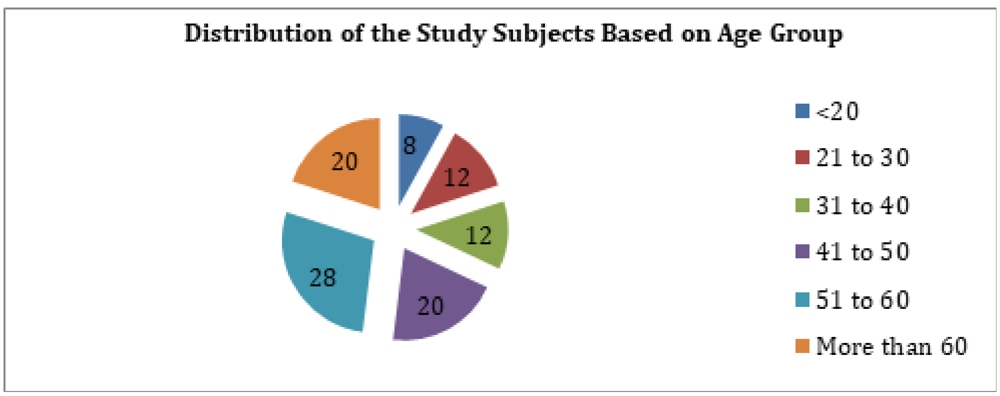


Figure 1: Distribution of the Study Subjects Based on Age Group.

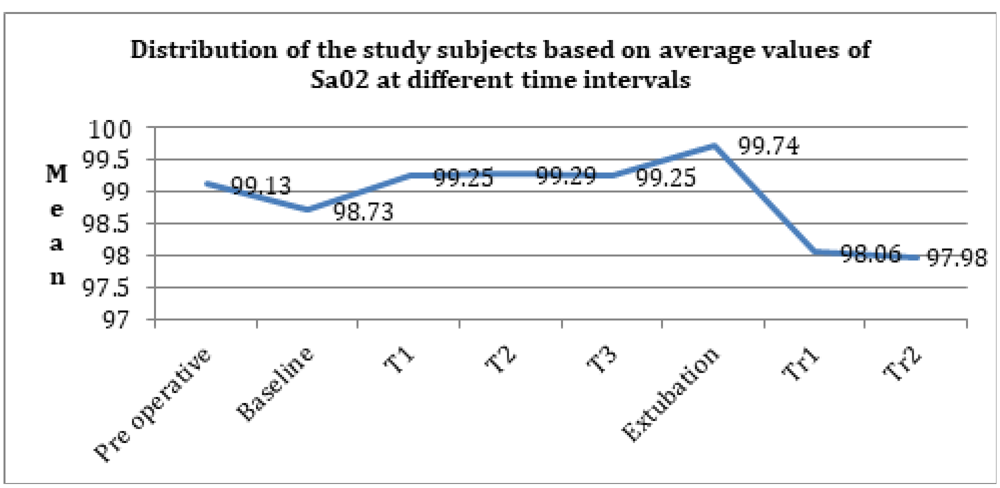


Figure 2: Distribution of the study subjects based on average values of Sa02 at different time intervals.

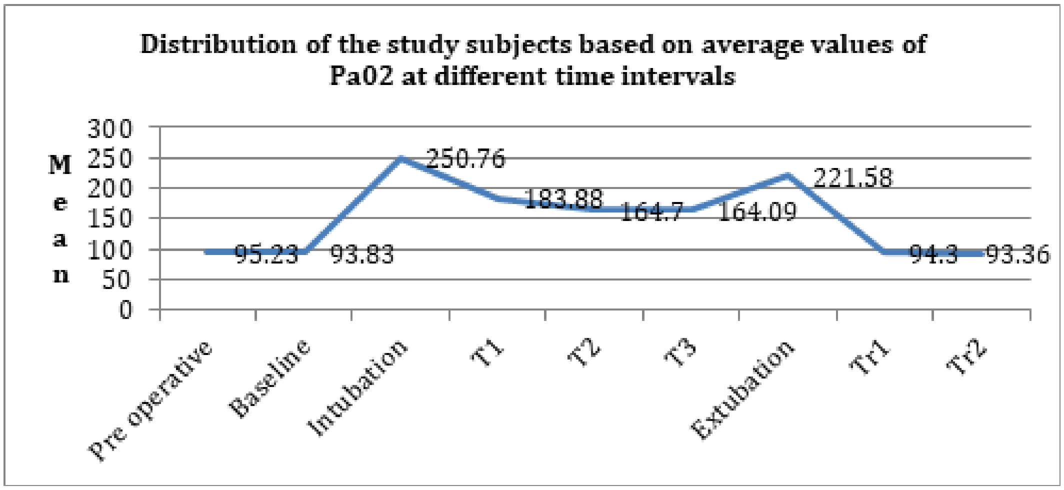
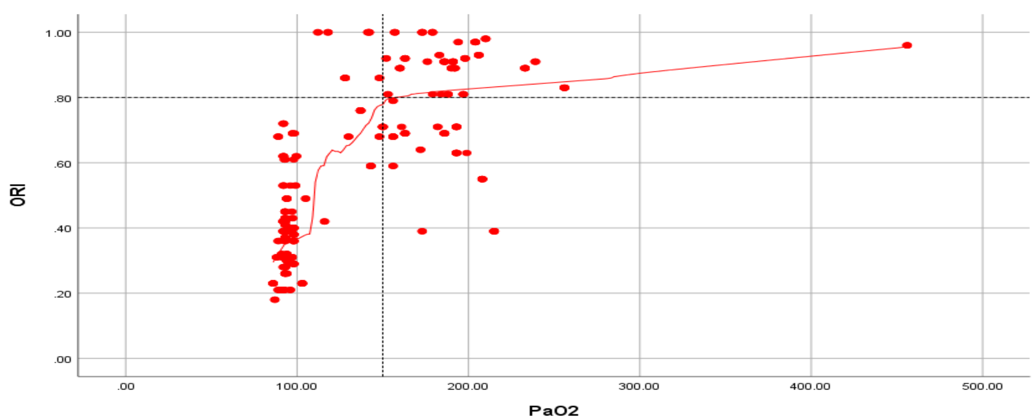


Figure 3: Distribution of the study subjects based on average values of PaO_2 at different time intervals.



r=0.652; P value <0.001; r2=0.425.The ORI was moderately positive correlated with PaO_2.
Prediction equation of ORI after simple linear regression. ORI at Tn =0.198+ (PaO_2 at Tn)*0.004.
Figure 4: Scatter diagram showing correlation of ORI with PaO_2.

Discussion

Monitoring oxygen levels during anesthesia is crucial for patient safety, and pulse oximetry has become a standard practice in assessing oxygen saturation (SpO_2) [1,26,27]. While pulse oximetry is effective for detecting hypoxemia and monitoring oxygen therapy, its ability to provide information on the partial pressure of oxygen (PaO_2) is limited, especially in patients receiving supplemental oxygen.

In such cases, SpO_2 may remain elevated (above 97%) even with significant changes in PaO_2, which can range from normal to hyperoxic levels. Arterial blood gas (ABG) analysis is a more accurate method for assessing PaO_2, but it is invasive, time-consuming, and associated with risks such as blood loss and puncture complications [28].

This study aimed to evaluate the relationship between the oxygen reserve index (ORI) and both PaO_2 and SpO_2 in the perioperative period. We observed a strong positive correlation between ORI and PaO_2 up to 150mmHg [29-34]. Beyond this threshold, however, the correlation between ORI and PaO_2 diminished, indicating that ORI may be most effective in the moderate hyperoxic range. Our findings are consistent with those of Applegate RL, et al. [2], who suggested that ORI values above 0.24 correspond to PaO_2 ≥100 mmHg, and ORI values above 0.55 consistently indicate PaO_2 ≥150mmHg.

In contrast, the relationship between ORI and PaO_2 for levels exceeding 150 mmHg was weak, suggesting that ORI may not be as useful in extreme hyperoxia [35,36]. Additionally, since no hypoxic events (PaO_2 <80 mmHg or SpO_2 <94%) were observed in our study, we could not assess the relationship between ORI and hypoxia. This aligns with findings from Vos, et al., who demonstrated a high concordance rate between ORI and PaO_2 within the moderate hyperoxic range, supporting the potential of ORI in detecting hypoxia in clinical settings [37-41].

ORI demonstrates potential as a non-invasive tool for monitoring oxygenation during anesthesia, particularly in moderate hyperoxia [42-45]. However, its effectiveness in extreme hyperoxic or hypoxic states warrants further investigation. Future prospective studies should focus on refining ORI thresholds for optimizing oxygen titration and explore its broader clinical applications in perioperative care [46].

Szmuk P, et al. [3] evaluated ORI's role in pediatric anesthesia induction, demonstrating that ORI detected oxygen desaturation approximately 31.5 seconds before a drop in SpO_2 was observed. This early warning facilitated timely clinical interventions, reducing the likelihood of severe hypoxemia. The study underscored ORI's significance in pediatric anesthesia, where rapid desaturation is a major concern due to the smaller functional residual capacity in children [47-49].

A study by Applegate RL, et al. [4] explored ORI in pediatric patients with respiratory compromise. Findings suggested that ORI provided earlier detection of declining oxygen reserves, helping clinicians anticipate and mitigate hypoxic episodes. This was particularly beneficial in patients prone to airway obstruction or ventilation difficulties, reinforcing ORI's role in pediatric critical care [50].

Fleming NW, et al. [5] investigated ORI in high-risk surgical patients and found that it provided a median early warning time of 48.4 seconds before SpO_2 dropped. This extended monitoring period allowed anesthesiologists to make timely adjustments in airway management and oxygen supplementation, reducing intraoperative hypoxic complications. The study emphasized the importance of ORI in procedures where prolonged intubation and ventilation were required [51].

A retrospective analysis by Ryu JH et al. [6] examined ORI's role in patients undergoing RARP. The study identified that an ORI value below 0.16 was an independent risk factor for intraoperative hypoxia. Patients with lower ORI values required more frequent oxygen interventions, indicating the parameter's potential in predicting and preventing hypoxic events during robotic surgeries [48,49].

Saracoglu KT et al. [7] compared ORI in morbidly obese patients versus those with normal BMI, demonstrating that ORI predicted hypoxemia earlier than traditional SpO_2 monitoring. Given the increased risk of airway obstruction and ventilation difficulties in obese patients, ORI was recommended as an additional monitoring tool to enhance perioperative safety [51].

Conclusion

This prospective observational study, conducted over the course of one year, aimed to evaluate the relationship between the oxygen reserve index (ORI) and both SaO_2 and PaO_2 during the perioperative period. The study enrolled 50 patients, and the findings revealed a positive linear correlation between ORI and PaO_2, particularly within the moderate hyperoxic range (PaO_2 up to 150mmHg). ORI trends effectively reflected changes in PaO_2, providing reliable information for the titration of oxygen therapy. However, the study highlights that while ORI offers valuable insights into oxygenation trends, absolute ORI values should not be interpreted as direct indicators of PaO_2. This study did not report any adverse events, underscoring the safety of utilizing ORI as a monitoring tool in the perioperative setting.

Monitoring a patient's oxygen status during anaesthesia using pulse oximetry is essential and is considered standard care in the perioperative setting. Nevertheless, monitoring oxygenation using pulse oximetry has its limitations, because during normoxia and hyperoxia, oxygen saturation (SpO_2) is >97% in the typical patient, especially in those patients receiving supplemental oxygen. Meanwhile, actual partial pressure of oxygen dissolved in arterial blood (PaO_2) can vary substantially ranging from normoxia (80–100 mm Hg) to extreme hyperoxia (≈500–600 mm Hg). Hence, SpO_2 monitoring gives little information on PaO_2 under such circumstances, necessitating arterial blood gas analysis (BGA), which is both invasive and gives intermittent information on oxygenation only. In addition, it is associated with additional costs and time delay, blood loss when performed repeatedly, and occurrence of puncture-related complications.

The integration of ORI into routine perioperative monitoring presents a promising advancement in patient safety. By providing early detection of declining oxygen reserves, ORI enables clinicians to intervene before hypoxia becomes critical. Further large-scale studies are recommended to validate ORI's effectiveness across broader patient populations and surgical scenarios.

Limitations

The study has several limitations that warrant consideration. First, it was conducted with a relatively small sample size from a single-center setting, which may limit the generalizability of the findings. Larger, multicentric studies are essential to validate and extrapolate these results. Additionally, the measurement and calculation of ORI are influenced by numerous physiological factors such as pH, temperature, and $PaCO_2$, contributing to notable inter-individual variability.

Another limitation is that ORI readings may be unreliable in conditions where peripheral perfusion is compromised, such as in patients experiencing shock or those receiving high-dose vasopressor therapy. Furthermore, the impact of patient comorbidities, including severe anemia and cardiopulmonary diseases, as well as clinical factors like the type of fluids administered, hemodynamic instability, and the use of vasoactive agents, on ORI accuracy requires more comprehensive investigation.

Future research should address these limitations to provide a clearer understanding of the utility and reliability of ORI across diverse clinical scenarios.

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Data availability:

All data are publicly available or listed in the results of the paper.

Declarations

Ethical approval: Ethical approval from our Hospital institutional Ethics Committee was obtained prior to initiation of the research work. This study was approved by the Ethics Committee decision no: EC/225/2018 Date: 30/01/2019. All procedures followed were in accordance with the ethical standards of the responsible committee.
Informed consent: Informed consent was obtained from all patients included in the study.

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