



# Oxygen Reserve Index and Arterial Partial Pressure of Oxygen: Relationship in Open Heart Surgery

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## Abstract

**Background:** Mild to moderate hyperoxia is potentially beneficial to patients undergoing open heart surgery. Oxygen Reserve Index (ORI) is a novel parameter that correlates to arterial oxygen tension (PaO<sub>2</sub>) in the hyperoxic range. This prospective study aimed to assess whether the relationship between ORI and PaO<sub>2</sub> remains intact in the setting of open-heart surgery. **Methods:** This study included patients undergoing valve, aortic arch and coronary artery bypass grafting (CABG) surgeries, on and off pump, between September 1st 2019 and August 31st 2021. Enrolled patients had arterial blood gas samples collected and analyzed after induction of anesthesia and increases in FiO<sub>2</sub> in steps of 0.08 with ORI being recorded at the time of sample collection for cross reference and analysis. **Results:** ORI values showed a statistically significant correlation with PaO<sub>2</sub> values in the 100–200 mmHg range ( $r=0.8193$ ,  $p<0.001$ ). Additionally, there was a significant correlation between ORI and SpO<sub>2</sub> values in the range of 95% and 100% ( $r=0.529$ ,  $p<0.05$ ). **Conclusions:** The preserved relationship between ORI and PaO<sub>2</sub> in the mild and moderate hyperoxic range can allow more precise titration of oxygen therapy to guide therapy targeting normoxia, mildly and moderately hyperoxia. Additionally, it could have a potential use as an early warning system for impending hypoxia.

**Key words:** Oxygen Reserve Index · Hyperoxia · Cardiac surgery

## 1 Introduction

Conventional pulse oximetry (SpO<sub>2</sub>) provides valuable information about the oxygen saturation in blood which has been proven to have a good correlation with arterial saturation of oxygen (SaO<sub>2</sub>) [1, 2]. However, despite it being a most significant advance in patient monitoring, SpO<sub>2</sub> is unable to

differentiate between states of normoxia and hyperoxia in healthy patients receiving supplemental oxygen [3] where, for example, a reading of more than 97% can be associated with a wide range of PaO<sub>2</sub> (80mmHg~600mmHg). Although pulse oximetry has become accepted universally as part of the standard of care in clinical practice as it can detect states of hypoxemia, it remains limited in not being able to detect hyperoxia, which in extreme situations could cause harm through upregulating oxidative stress pathways or paradoxically impairing oxygen delivery to organs [4, 5]. Conversely, moderate hyperoxia could be desirable in certain situations like pre-oxygenation before induction of anesthesia [6] or during off pump coronary artery bypass grafting (CABG) surgery [7] to counteract the impaired oxygen supply and delivery caused by those situations.

The Oxygen Reserve Index (ORI) is a novel noninvasive and continuous dimensionless parameter intended to provide insight into the oxygenation status of a patient within the moderate hyperoxic range (PaO<sub>2</sub> > 100 and ≤ 200 mm Hg) [8–10]. Previous studies in the pediatric population have shown that ORI detects impending desaturations before noticeable changes in SpO<sub>2</sub> occur [11] and can be

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used as an indicator of moderate hyperoxia intraoperatively [12]. In this study, we investigated if the relationship between ORI and PaO<sub>2</sub> is preserved in the setting of open-heart surgery. An intact relationship would allow for tighter control of oxygen levels to achieve moderate hyperoxia while potentially allowing early detection and preemptive interventions to mitigate imminent hypoxemia.

## 2 Methods

### 2.1 Trial Design

This study was a prospective observational, proof-of-concept, single center study conducted at the Babbain Cardiac Center, Dammam, Saudi Arabia, over a 24-month period between September 1st 2019 and August 31st 2021. The study was approved by the local Institutional Ethics Committee (IRB-2018-17). Written informed consent for enrollment and to use the data was obtained from each patient or from legal surrogate.

### 2.2 Patients

Eligible patients were adults scheduled to undergo non-emergent open heart surgery including valve, aortic root, and CABG surgeries either on or off cardiopulmonary bypass. Exclusion criteria were severe restrictive or obstructive respiratory disease, emergency cardiac surgery, and patients coming on inotropic support, vasodilators or established mechanical ventilation.

### 2.3 Interventions

Enrolled patients were continued on all their preoperative medications, except ACE Inhibitors, until the morning of the surgery. Additionally, all patients received anxiolysis with oral diazepam (5-10mg) the night before the surgery and 1-2mg lorazepam on the morning of surgery. All patients were connected to a 5 lead ECG and noninvasive blood pressure monitors. A pulse co-oximeter sensor (R1 25L Masimo Rainbow Disposable RD Lite; Masimo Inc, Irvine, CA, USA) was placed on the right index finger and connected to the Radical 7 monitor (part of the Massimo Root Platform) for SpO<sub>2</sub> and ORI measurements. An opaque shield to prevent exposure to ambient light was applied over the sensor.

A 20 gauge arterial cannula was inserted under local anesthesia in the one radial artery using an aseptic technique. All paired arterial blood gas (ABG) samples were drawn from the radial artery catheter and were collected into standard 1-ml heparinized syringes. To ensure the accuracy of blood

gas analysis, the samples were deaerated, carefully mixed and analyzed promptly after drawing them. A baseline ABG sample along with ORI and SpO<sub>2</sub> readings were collected and recorded on room air before induction of anesthesia.

Subsequently, general anesthesia was induced in a standardized technique using midazolam, fentanyl, and etomidate with rocuronium used for paralysis. Ventilation was facilitated using a Drager Primus anesthetic machine and maintenance of anesthesia was done using sevoflurane. Invasive and noninvasive hemodynamic monitoring was maintained all throughout the procedure and hemodynamic stability was ensured with maintenance of Mean Arterial Pressure (MAP) of 60 mmHg or more by judicious use of vasopressors.

After induction of general anesthesia and endotracheal intubation, FiO<sub>2</sub> was reduced to 0.22 and the first blood gas sample was drawn along with a recording of the ORI and SpO<sub>2</sub> at that moment. Then, FiO<sub>2</sub> was increased in steps of 0.08 and blood gas samples were drawn after maintenance of each interval step for 5 minutes at least. Sample analysis was paired with recordings of ORI and SpO<sub>2</sub> at each step.

### 2.4 Data Collection and Analysis

Electronic data was retrieved and stored from the standard anesthesia (Drager Primus) and Radical-7 monitors and imported into Microsoft Excel 2010 (Microsoft, Redmond, WA) for analysis. A complete set of data was collected as per protocol. A visual inspection of the data plots was performed to detect any artifact-induced outliers or missing data.

### 2.5 Statistical Analysis

Data was tabulated and analyzed using SPSS program (Statistical Package for Social Sciences) version 26 (IBM Inc, Chicago, IL) in the following domains:

- Descriptive analysis (mean  $\pm$  SD) for numerical data
- Frequency and percentage of non-numerical data
- Pearson correlation coefficient ( $r$ ) was used to correlate two numerical parameters
- Linear regression curves were done for all correlations
- $p$  value was considered significant if it was  $<0.05$  and highly significant if it was  $<0.01$ , this applied to all tests.
- Scatter plot was created to visualize the relationship between ORI and PaO<sub>2</sub> using Microsoft Excel 2016

**Table 1** Patient Characteristics

Patients Enrolled and analyzed	(n = 50)
Age (y) ± SD	57.94 ± 8.07
BMI ± SD	31.73 ± 3.62
Sex (M/F)	30/20
Diabetes Mellitus	38
Hypertension	42
ACE inhibitors	45
Diuretics	26
Beta blockers	45
Duration of surgery (hours)	4.18 ± 0.68
Surgical procedure	
Valve repair/replace alone or combined	14
CABG	32 (total)
OFF PUMP	23
ON PUMP	9
Other cardiac or major vascular surgery	4
ASA classification n (%)	
III	6 (12%)
IV	44 (88%)

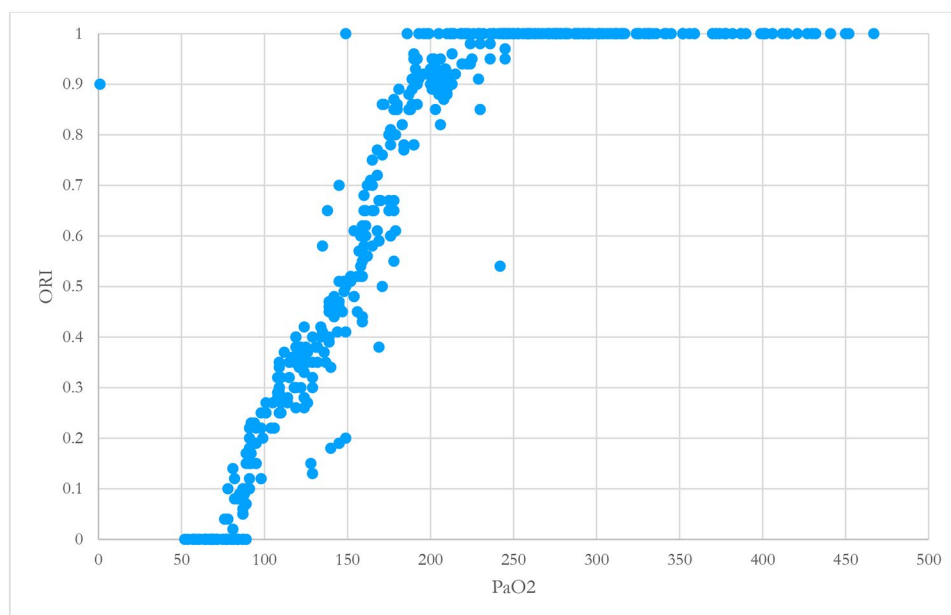
### 3 Results

During the period between September 1st 2019 and August 31st 2021, 50 patients who met the inclusion criteria were recruited after giving consent to be included in the study. A total of 500 paired readings (PaO<sub>2</sub> with corresponding SpO<sub>2</sub> and ORI) were collected. Characteristics of the patients and respective procedures are presented in the Table 1.

#### 3.1 ORI Sensitivity Range

Where PaO<sub>2</sub> was in the range of 100–200 mmHg, there was a highly statistically significant correlation with ORI

**Fig. 1** - Relationship between PaO<sub>2</sub> and ORI



( $r=0.8193$ ,  $p<0.001$ , Fig. 1). Additionally, a significant correlation was observed between ORI and FiO<sub>2</sub> ( $r=0.693$ ,  $p<0.001$ , Fig. 2) as well as ORI and SpO<sub>2</sub> in the range of 95% and 100% ( $r=0.529$ ,  $p<0.05$ , Fig. 3). Additionally, we can observe that where SpO<sub>2</sub>'s sensitivity and specificity tails off drastically once it reaches 100%, ORI continues to be more sensitive and specific at higher PaO<sub>2</sub> values and thresholds (Fig. 4).

#### 3.2 Association of PaO<sub>2</sub> with ORI Outside the Sensitive Range

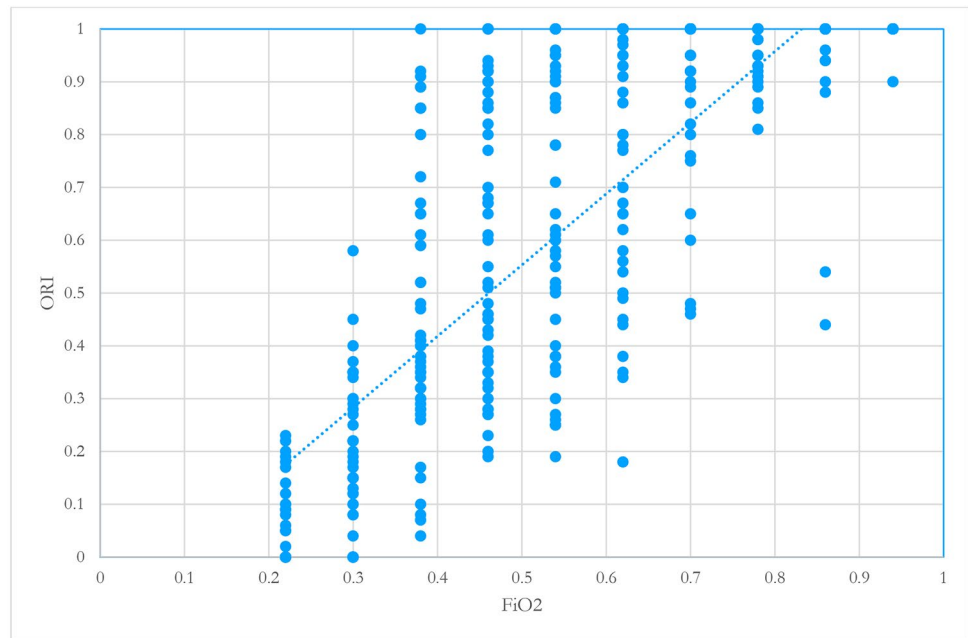
An additional finding of the study was that an ORI of 0 consistently correlated with a PaO<sub>2</sub> of less than 90mmHg and an SpO<sub>2</sub> ranged between 87% and 96% (n = 44 data points)

### 4 Discussion

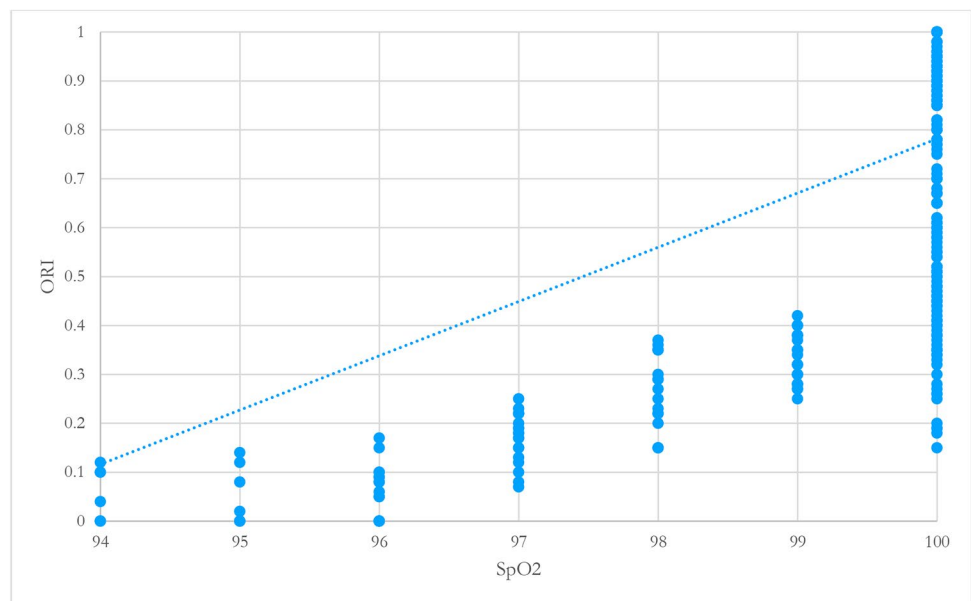
The main finding of this prospective, observational study is a significant relationship between the ORI and SpO<sub>2</sub>, FiO<sub>2</sub> and PaO<sub>2</sub> in high risk, adult cardiac surgical patients. Previous data showed a linear correlation between ORI and PaO<sub>2</sub> values between 62 mmHg and 240 mmHg [10] and 100 mmHg and 200 mmHg [12]. The findings from these studies in addition to ours suggest that ORI reasonably correlates to PaO<sub>2</sub> in the mild and moderate hyperoxic range.

When subjected to extremely elevated oxygen tensions, cardiac surgery patients on CPB exhibit undesirable sequelae including a reduction in lung vital capacity and an elevation in proinflammatory markers leading to oxidative myocardial damage [6] [13]. The use of ORI in this patient

**Fig. 2** Relationship between  $\text{FiO}_2$  and ORI



**Fig. 3** - Relationship between ORI and  $\text{SpO}_2$

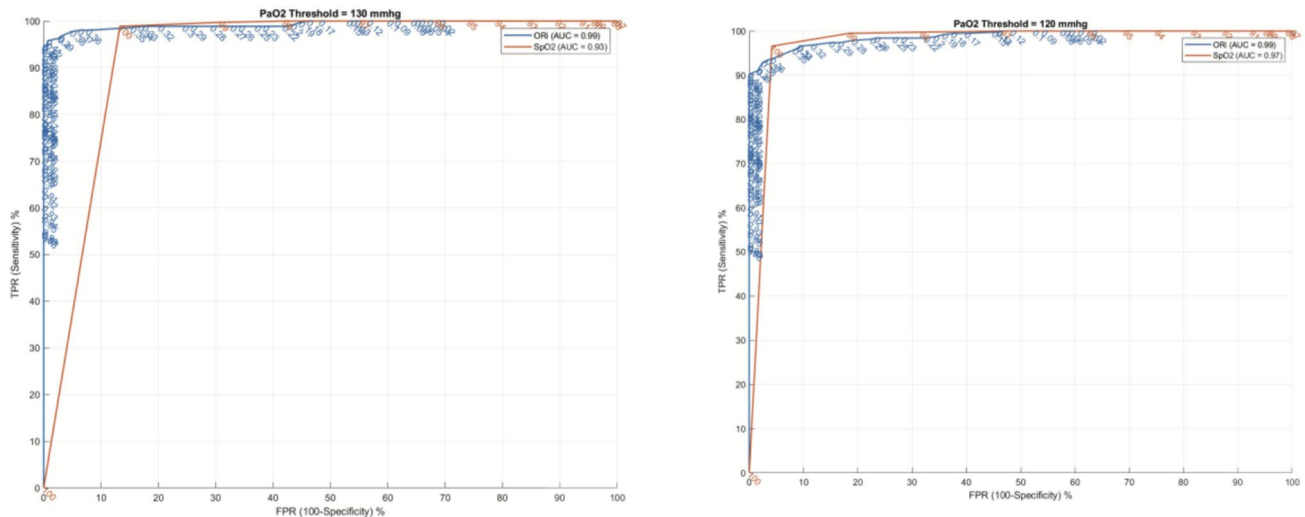


population can allow more careful titration of oxygen levels to avoid potentially dangerous hyperoxic states.

In the wider surgical patient population, hyperoxia may cause vasoconstriction and increase microcirculatory heterogeneity, thereby compromising perfusion and, hence, actual oxygen delivery [5], which in a wide range of conditions, such as ischemic heart disease, stroke and after cardiac arrest, is associated with increased morbidity and mortality [7]. This information also reflects the potential of ORI monitoring in the critical care setting. Physicians can utilize it in patients receiving supplemental oxygen through modalities including invasive and noninvasive ventilation,

preventing undesirable elevated  $\text{PaO}_2$  levels that have been associated with increased mortality [15].

About 4% of surgical patients have been shown to develop postoperative respiratory failure resulting in more than 25 times the in-hospital mortality from respiratory failure seen in other patients (10.3% vs 0.4%) [1]. These patients as well as many other groups of patients at risk of hypoxaemia, could benefit from ORI in addition to pulse oximetry as it can provide an early warning of impending oxygen desaturation, allowing for early intervention and possibly improving outcome [2]. When used as a monitoring tool in the process of induction and intubation, an ORI



**Fig. 4** – AUC comparing SpO2 and ORI specificity and sensitivity at PaO2 thresholds of 120mmHg and 130mmHg

value of 1, can allow the physician to expect PaO<sub>2</sub> levels to be at a level equal to or higher than 200mmHg, this information can be used as an indicator that denitrogenation is complete and the process of intubation can proceed. During this apneic period, ORI will provide an early warning of impending hypoxia ahead of SpO<sub>2</sub> changes, allowing the clinician to make a better-informed decision on whether to persist with the attempt of intubation, or abandoning the procedure in order to oxygenate the patient [16]. This utility of ORI has been demonstrated previously in different patient populations, including pediatric [12] and obese patients [14]. The same data in Fig. 1 alludes to a potential utility of ORI in procedures requiring apneic oxygenation (such as bronchoscopy), or deflation of the lungs (such as sternotomy or Internal Mammary Artery harvesting in cardiac surgery), allowing the physician to act earlier before impending hypoxia occurs.

In conclusion, this study shows that the consistent relationship between ORI and PaO<sub>2</sub> in the normoxic and moderately hyperoxic range can allow more precise titration of oxygen therapy to prevent unintentional hyperoxia, and facilitate oxygen therapy in the mild and moderate hyperoxic range even in patients undergoing major open heart surgery. Additionally, there is a potential for ORI to be used as an early warning system for desaturation, but that would require further studies.

**Author Contribution** Drs. M. F., H. W., and H. A. designed the trial and collected the data, Drs. M. S. and F. L. analyzed and interpreted the data and drafted the manuscript. All authors have read and approved the submitted manuscript.

## Declaration

**Competing interests** The authors declare no competing interests.

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