

The Use of Oxygen Reserve Index in One-Lung Ventilation and Its Impact On Peripheral Oxygen Saturation, Perfusion Index and Pleth Variability Index

Gonul Sagiroglu

Trakya University Faculty of Medicine

Ayse Baysal (✉ draysebay@yahoo.com)

Pendik District Hospital, Istanbul, Turkey

Yekta Altemur Karamustafaoglu

Trakya University Faculty of Medicine

Research Article

Keywords: one lung ventilation, hypoxemia, oxygen reserve index, perfusion index, pleth variability index

Posted Date: November 1st, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-990585/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at BMC Anesthesiology on December 1st, 2021. See the published version at <https://doi.org/10.1186/s12871-021-01539-8>.

Abstract

Background: Our goal is to investigate the use of the Oxygen Reserve Index (ORi) and its relation with peripheral oxygen saturation, perfusion index (PI), and pleth variability index (PVI) during one-lung ventilation (OLV).

Methods: Fifty patients undergoing general anesthesia and OLV for elective thoracic surgeries were enrolled in an observational cohort study in a tertiary care teaching hospital. During general anesthesia induction, propofol, fentanyl, and rocuronium at appropriate doses were administered intravenously. All patients required OLV after a left-sided double-lumen tube insertion during intubation. Hypoxemia during OLV was defined as peripheral oxygen saturation (SpO_2) value of less than 95% when the inspired oxygen fraction (FiO_2) is above 60% on a pulse oximetry device. ORi, pulse oximetry, PI, and PVI were measured continuously. Sensitivity, specificity, positive and negative predictive values, likelihood ratios, and accuracy were calculated for ORi equals zero in different anesthesia time points to predict hypoxemia. At Clinicaltrials.gov registry, the Registration ID is NCT05050552.

Results: The accuracy for predicting hypoxemia during anesthesia induction at ORi value equals zero at five minutes after intubation in the supine position (DS5) showed a sensitivity of 92.3% (95% CI 84.9-99.6), specificity of 81.1% (95% CI 70.2-91.9), and an accuracy of 84.0% (95% CI 73.8-94.2). ORi and SpO_2 correlation was found at DS5 ($p = 0.044$), 5 minutes after lateral position with two-lung ventilation (DL5) ($p = 0.039$), and at 10 minutes after OLV (OLV10) ($p = 0.011$).

Conclusions: ORi equals zero at the time point of five minutes after tracheal intubation in the supine position (DS5) showed high sensitivity and specificity for predicting hypoxemia at a less than 95% value.

1. Introduction

1.1 One-lung ventilation and thoracic surgeries

There is an ongoing investigation to provide advanced monitoring techniques during one-lung ventilation (OLV) and general inhalational anesthesia during thoracic surgeries. For elective lung tumor-related operative procedures, the surgical team performs either a video-assisted thoracoscopy (VATS) or thoracotomy operation. There is usually a request from the surgeon for a collapsed lung where they perform the operative procedure in a surgical field. The lower, dependent lung is ventilated, whereas the upper, non-dependent lung collapses when opening the chest. There is perfusion in this lung, causing a transpulmonary shunt without ventilation. The transpulmonary shunt in the non-dependent lung is the main reason for hypoxemia during OLV.[1, 2] The other causes of hypoxemia can be listed as; the collapse of the non-dependent lung, reduction of the functional residual capacity, effects of inhalational and general anesthesia, lateral decubitus position, development of atelectasis in the ventilated dependent lung. Atelectasis occurs as a result of other factors, and these are; lateral decubitus positioning, increased closure of small airways with old age, mechanical compression-related events in the mediastinum, and

compression by the abdominal contents and reduction of the elastic recoil mechanism. [2, 3] The OLV is performed in a lateral decubitus position after a double-lumen tube (DLT) is inserted in a supine position during tracheal intubation. The pathophysiological changes in cardiac and respiratory functions have been discussed in detail elsewhere.¹ Despite the correct placement of the DLT, hypoxemia occurs in approximately 10–25% of patients. [3, 4]

1.2 Definition of hypoxemia during one-lung ventilation

The definition of hypoxemia during OLV is a decrease in partial arterial oxygen pressure (PaO₂) of less than 60 mmHg when the inspired oxygen fraction (FiO₂) is greater than 50%. [3] This correlates to a peripheral oxygen saturation (SpO₂) value of 90%. [3] However, during OLV, the oxygen delivery to the patient under general anesthesia is the result of various interactions between hemoglobin, oxygen saturation, and cardiac output. [4] There is a classical presentation of the sigmoid shape of the oxy-hemoglobin dissociation curve that provides the understanding of the relationship between the levels of arterial hemoglobin oxygen saturation (SaO₂) and partial pressure of oxygen in the arterial blood (PaO₂). A derivative of arterial oxygen saturation can be measured peripherally using a non-invasive monitoring device, which is called peripheral oxygen saturation (SpO₂) measurement by a pulse oximetry device. Pulse oximetry is a continuous monitoring device to assess oxygenation within three seconds as it averages out the readings. It measures the PaO₂ levels in the range of 0 to 100 mmHg, where a FiO₂ level equals to 21%. However, a pulse oximetry device cannot consistently detect desaturation when FiO₂ is greater than 50%. [2–4] During such FiO₂ levels of greater than 50%, SpO₂ values observed by pulse oximetry remain above 90% until PaO₂ value falls below 60 mmHg. [3, 4] Therefore, there is another approach to keep SpO₂ values above 95% in OLV procedures and to provide a higher FiO₂ to be able to prevent hypoxemic events. [5] In the literature, reports show that atelectasis occurs during general anesthesia induction, which causes ventilation/perfusion mismatch even before switching to OLV. [5–7] Although the causes of OLV-induced hypoxemia are multifactorial, early detection of hypoxemia before the onset of OLV allows the application of different ventilation strategies to improve oxygenation. [3–6]

1.3 Pulse Oximetry versus Oxygen Reserve Index for detection of hyperoxia or hypoxemia

The Oxygen Reserve Index (ORi) is a multiwavelength pulse oximeter, and it provides continuous analyzes of PaO₂ values of moderate hyperoxia at a range of 100-200 mmHg. [2–5, 7–9] This device has the capability to measure several oximeter-related parameters, and these include; ORi, SpO₂, Perfusion Index (PI), and perfusion pleth variability (PVI). The multiwave pulse co-oximetry device can provide a calculated oxygen reserve index (ORi) for pulse oximetry values greater than 98%, such as; in an incidence where a falling PaO₂ value approaches 100 mm Hg and a SpO₂ value is greater than 98% an ORi value decreases and approaches to a value of 0.24. [9] This observation in a previous study provided data that ORi may provide information in both clinical situations where there is an impending hypoxic state or an unintended hyperoxic state. [5–9] ORi parameter provides a value that ranges between “1,” which shows a significant oxygen reserve, to “0,” which shows no oxygen reserve. ORi begins to increase from 0.00 at about a PaO₂ of 100 mmHg, and reaches a plateau of 1.00 at approximately 200 mmHg. A

relation between ORi and cardiac output, oxygen consumption, blood acid-base balance partial pressure of carbon dioxide, temperature, the amount of peripheral venous oxygen saturation, and the presence of various abnormal hemoglobins. [5, 7–10] Perfusion index (PI) is an indicator of the relative strength of the pulsatile signal from pulse oximetry. A higher PI value shows that the pulsatile signal is higher and peripheral circulation at the sensor site has improved accordingly. The perfusion pleth variability (PVI) is relative variability in the pleth waveform and provides a value between 0 and 100 in a noninvasive measurement from pulse oximetry. PVI is an automatic measurement of the dynamic change in PI that occurs during a complete respiratory cycle. [11, 12]

The main objective of this study is to investigate the possible benefits of using the oxygen reserve index (ORi) parameter during one-lung ventilation (OLV) while performing elective thoracic operations under general inhalational anesthesia. For this purpose, ORi values are compared to primary hemodynamical parameters (heart rate and systemic arterial and mean arterial blood pressures) as well as oximeter-related parameters, and these include; peripheral oxygen saturation, PI, and PVI. Our secondary goal is to investigate whether a relationship exists between these hemodynamical and oximeter parameters by using statistical analytic methods.

2. Methods

2.1 Patients and Settings

The investigators performed a prospective observational cohort study in 14 months of a period on patients requiring elective thoracic surgery for open lung resection via a thoracotomy or VATS at the Trakya University School of Medicine Hospital, Edirne, Turkey. The investigators conducted the study between 2020 and 2021. After the Hospital Ethics Committee (TÜTF-BAEK 2020/108) and a collection of written informed consent from all patients, the study was started. Out of a total of 59 patients who were considered for thoracic surgery, 50 patients underwent either VATS or open thoracotomy for a suspicious lung tumor that required either lobectomy, pneumonectomy, lung biopsy, or wedge resection. The Human Research Ethics Committee of Trakya University Medical Faculty, Edirne, Turkey, approved this clinical study protocol and related investigation procedures. All patients gave written informed consent for the clinical study during the preoperative visit. The study is registered in Clinicaltrials.gov registry, and the Registration ID is NCT05050552. The pulmonary function tests, including the percentage of expected, forced expired volume during the first second (FEV1%), the ratio of FEV1/FVC% (percentage of expected forced vital capacity to FEV1) were done in some patients with suspected severe lung disease because of the global pandemic in 2020 and 2021. Patients with FEV1 between 30 and 80% and FEV1/FVC ratio of <70% were defined as a moderate chronic obstructive pulmonary disease level in the literature. These patients were included, whereas severely restricted patients were excluded. [2, 3]

Inclusion criteria included; all patients aged 22 to 80 years old, American Society of Anesthesiologists Physical Status (ASA-PS) risk groups of 1 to 3, undergoing elective thoracic surgery, either open lung resection with thoracotomy or VATS operative procedure, general anesthesia, inhalational anesthesia, DLT

insertion and afterward use of OLV for all patients. Exclusion criteria include; refusal to participate in a study, history of severe asthma, preoperative renal insufficiency (creatinine >114 $\mu\text{mol/L}$); preoperative liver dysfunction (aspartate amino transferase-AST >40 U/L, alanine amino transferase-ALT >40 U/L); previous history of coronary or vascular disease with an ejection fraction less than 40 %, lung function study showing an FEV1 less than 50%, history of severe chronic respiratory disease of the non-operated lung, pregnancy, history of previous pulmonary resection and hemoglobinopathies. [8–10]

2.2 The Anesthetic Management, Definition of Hypoxemia and Collected Data during OLV

Premedication was not included to prevent hypoxemia-related events. After admitting a patient to the operating theatre, anesthesiologists applied pulse oximetry, electrocardiogram, and noninvasive blood and measured routinely. The anesthesiologist monitored parameters include; heart rate (HR), mean arterial pressure (MAP), systolic blood pressure (SBP), and diastolic blood pressure (DBP). The anesthesiologists provided general anesthesia using intravenous doses of propofol (Pofol, Fresenius Pharmaceutical, Turkey), 2 to 3 mg/kg, rocuronium (Esmeron, Organon Pharmaceuticals, USA) at a dose of 0.6 mg/kg, and fentanyl (Janssen fentanyl, Janssen Pharmaceutical, Belgium) at a quantity of 2 to 3 mcg/kg. The anesthesiologist placed a 20 Gauge radial artery catheter on all patients and connected it to a disposable pressure transducer to provide continuous monitoring following the induction of anesthesia. During tracheal intubation, a left Robertshaw DLT is used. The anesthesiologists performed anesthesia maintenance using inhalational anesthetic of sevoflurane (Sevorane, Abbott Pharmaceutical, USA) at an end-tidal concentration of 1 to 2% and intravenous fentanyl boluses at a dose of 0.5 to 1 mcg/kg every hourly to keep mean arterial blood pressure between 60 and 80 mmHg. During surgery, intravenous rocuronium was used at a maintenance dose of 0.05 mg/kg every hour. All patients received lactated Ringer's solution infusion.

In addition to standard follow-up parameters, ORi, PI, PVI were continuously monitored through the Masimo oximeter device. During the study, hemodynamical data, including MAP, SBP, DBP, HR, ORi, PI, PVI, and SpO₂, were collected at thirteen different time points of anesthesia. During the collection of these parameters, Radical-7 Pulse CO-Oximeter is used to measure oximeter parameters of ORi, PI, and PVI (Masimo Inc, Irvine, CA, USA). The investigators measured peripheral oxygen saturation using a Pulse CO-Oximetry probe. For other oximeter-related parameters, the Rainbow R1 25-L probe was used, a product of the same company. [8, 9]

All patients received intravenous metoclopramide 10 mg (Metoclopramide, Yeni Pharmaceutical, Turkey) to prevent postoperative nausea and vomiting. After general anesthesia induction and intubation, the anesthesiologists provided mechanical ventilation, and two lung ventilation in the supine position required the settings of a tidal volume of 8–10 ml/kg, inspiration to expiration ratio of 1:2, and respiratory rate of 10–12/min, without positive end-expiratory pressure (PEEP). During operation, the surgical team provided a lateral decubitus position before incision. OLV was initiated after positioning. The dependent lung was ventilated with a tidal volume of 6–8 ml/kg, I: E ratio of 1:2, respiratory rate of 12–14/min with

an unchanged FiO₂ of 0.5 with an Aestiva 3000 ventilator (Datex-Ohmeda Inc. Madison, U.S.A.). During surgery, the anesthesiologists were responsible for the anesthesia maintenance with inhalational anesthesia of sevoflurane, intravenous rocuronium maintenance dose of 0.05 mg/kg every hourly, and intravenous fentanyl maintenance dose of 1 to 2 mcg/kg. All patients received lactated Ringer's solution infusion. [5, 13]

Hypoxemia during OLV was defined as a SpO₂ value of less than 95% when the FiO₂ value is equal to or greater than 60% on a pulse oximetry device. [5, 10] The anesthesiologist who conducts the anesthesia during surgery was responsible for increasing FiO₂, using bag-mask ventilation of 100% for a while, implementing an alveolar recruitment maneuver, or using continuous positive airway pressure to the collapsed lung during a desaturation of SpO₂ value less than 95%.¹[2, 3, 8–10, 13, 15] After secure oxygen saturation was achieved, a fiberoptic bronchoscopy examination was performed to ensure the proper position of the DLT, which was repositioned when needed. Any of these interventions was recorded in the case report form.

Hemodynamical and oximeter-related data of MAP, SBP, DBP, HR, SpO₂, PaO₂, ORi, PI, and PVI values were recorded at thirteen different time points during anesthesia induction and maintenance of the surgery. Baseline values of ORi provide data before preoxygenation, and afterward, patients were preoxygenated with 100% oxygen. The second set of values is at the end of preoxygenation, which was around one minute after anesthesia preoxygenation. The third set of values was after general anesthesia induction with a 100% mask ventilation before laryngoscopy. [8–10, 15] The other ten different time-points are also determined during anesthesia maintenance throughout the thoracic operation. These include; 5 minutes after tracheal intubation during two-lung ventilation in the supine position and 5 minutes after placing the patient in a lateral position with two-lung ventilation; at 1 minute after OLV placement, at two minutes after OLV placement, and afterward at five minutes 10 minutes, 15 minutes, 30 minutes, 45 minutes, 60 minutes and 90 minutes.

For the collected parameters, which are; MAP, SBP, DBP, HR, SpO₂, PaO₂, ORi, PI, and PVI values, a correlation between these parameters was sought in statistical analysis. The duration of surgery, anesthesia, and estimated duration of OLV were recorded.

2.3 The Management of Hypoxemic Events and Other Unwanted Events During Surgery

The anesthesiologists provided oxygen titration depending on the SpO₂ and PaO₂ values in our study group of patients. The data collectors were usual residents in anesthesiology, and they performed a blood gas analysis at the DL5 time point. After induction, patients were routinely ventilated with 50% FiO₂ (50% oxygen + 50% air mixture, 1 liter/minute fresh gas flow). The value of FiO₂ rises depending on pulse oximeter value between 60% and 100% to keep SpO₂ values greater than 94. The incidence of thromboembolic complications, arrhythmia, pneumonia, the duration of hospital and intensive care unit stay were recorded.[9, 13, 15–18]

Intravenous ephedrine (Ephedrine, Osel Pharmaceutical, Turkey) at a dose of 10 mg bolus injections were considered if SBP was less than 90 mmHg. Hypotension was defined as a decrease in MAP more significant than 20% after anesthesia induction and treated with intermittent bolus doses of 5 mg ephedrine. The definition of hypotension was based on previous studies. [12]

2.4 Summary of Surgical Procedure

Surgical resection was performed through a posterolateral thoracotomy. A suspicious tumor is located, and necessary frozen section samples were obtained for pathological evaluation. At the end of the operation, the suspicious mass was removed from its location. The other surrounding bronchial tissues and structures were inspected by using a fiberoptic bronchoscopic device. The necessary closure related procedure, including necessary suturing, aspiration, and irrigation of fluids and blood, are performed. [13, 15, 18]

2.5 The Ethical Considerations

Trakya University Faculty of Medicine University Ethical Committee agreed and approved the study in February 2020. All patients approved the fully informed written consent to participate in the study. The participants had confidentiality during the study process and were able to withdraw from the research process at any time. The investigators discussed any expected benefits or potential harm for the research in detail.

2.6 Statistical Analysis

The investigators used an SPSS 15.0 (Statistical Package for Sciences, USA) program to analyze the data of our clinical study. Data were presented as mean \pm SD and numbers (percentages), as indicated. Normality was tested with the Kolmogorov-Smirnov test. Some parameters are reported as median (interquartile range [IQR], 25th to 75th percentile). Sensibility, specificity, positive and negative predicted values, likelihood ratios, and their respective confidence intervals were obtained from a two-by-two contingency table for the validity of ORi equals to zero during different moments before and after OLV was achieved to predict the first hypoxemia (SpO₂ value of < 95%) episode after OLV.⁸⁻¹⁰ The proportion of true positives and true negatives in all evaluated cases was considered to be accurate. The level of statistical significance was a p-value of less than 0.05. For calculation of sample size, a hypoxemia rate of 30% after OLV, and a 10% precision at 95% confidence intervals, an alpha error of 0.05, and a power of 80%, the number of patients for the study was calculated as 28 patients. [8, 10, 15]

3. Results

The investigators performed the clinical study on a total of 50 patients in a 14 months period. The median age of the whole group was 53 years (22 - 80). There were 28 males and 22 females. The data presented in Table 1 provides demographic information, co-morbidities, pulmonary function tests of 26 patients with possible moderate to severe lung disorders, as well as surgical approach and type of surgery. Pulmonary function tests were not obtained from all patients due to the COVID-19 pandemic.

Table 1. Demographic Data and Operation Characteristics of Patients undergoing Elective Thoracic Surgery with Open Lung Ventilation.

Age, (year)	55.46 ± 13.85
Height, (cm)	168.5 ± 8.43
Weight, (kg)	77.76 ± 16.1
Body mass index, (kg/m ²)	27.54 ± 6.17
Gender, n (%)	
Female	22 (44)
Male	28 (56)
ASA-PS, n (%)	
I	5 (10)
II	27 (54)
III	18 (36)
FVC, (mL)	2.87 ± 0.68
FEV1	2.3 ± 0.59
Smoking, n (%)	34 (68)
COPD, n (%)	11 (22)
Hypertension, n (%)	17 (34)
Diabetes mellitus, n (%)	8 (16)
Coronary artery disease, n (%)	6 (12)
Right side intervention, n (%)	24 (48)
Surgical approach, n (%)	
Thoracotomy	27 (54)
VATS	23 (46)
Type of surgery, n (%)	
Lung biopsy	12 (24)
Wedge resection	19 (38)
Lobectomy	14 (28)
Pneumonectomy	5 (10)
Duration of operation, (min)	71.3 ± 37.59

Abbreviations: ASA-PS, American Society of Anesthesiologists-physical status; BMI, body mass index; COPD, chronic obstructive pulmonary disease; FVC, forced vital capacity; FEV₁, forced expiratory volume first second; VATS, video assisted; thoracoscopic surgery.

Hemodynamic and oximeter data were continuously monitored. The investigators collected the data during several phases of the anesthesia and surgery. First, during the patient's arrival to the operating room in the supine position breathing room air (basal), and during preoxygenation with 100% oxygen in the supine position (preoxygenation), 5 minutes after tracheal intubation during two-lung ventilation in the supine position (ORiDS5), 5 minutes after placing the patient in a lateral position with two-lung ventilation (ORiDL5), at 1 minute after OLV placement (OROLV1), 2 minutes after OLV placement (OROLV120), 5 minutes (OROLV5), 10 minutes (OROLV10), 15 minutes (OROLV15), 30 minutes (OROLV30), 45 minutes (OROLV45), and 60 minutes (OROLV60) and 90 minutes (OROLV90). At the time point of five minutes after tracheal intubation in the supine position (ORiDS5), ORi = 0 value was observed in 12 of the 19 patients who presented with SpO₂ values of less than 95%, which is defined as hypoxemia. Table 2 shows the diagnostic test for ORi = 0 at different time points during anesthesia induction and maintenance for predicting hypoxemia at a level of SpO₂ less than 95% during OLV. At the time point of ORiDS5, which presents five minutes after tracheal intubation in the supine position, recorded ORi equals zero together with a higher incidence of SpO₂ values of less than 95%. Therefore, the accuracy for predicting hypoxemia during anesthesia induction showed a sensitivity of 92.3% (95% CI 84.9-99.6), specificity of 81.1% (95% CI 70.2-91.9), and an accuracy of 84.0% (95% CI 73.8- 94.2).

Table 2. The Data Analysis of ORi Equals to Zero and Accuracy for Predicting Hypoxemia During OLV at Different Time Points of Surgery.

	Sensitivity	Specificity	PPV	NPV	PLHR	NLHR	Accuracy
Preoxygenation (95% CI)	0.15 (0.1-0.3)	91.9 (84.3-99.5)	40 (26.4-53.6)	75.6 (63.6-87.5)	1.9 (1.9-5.7)	0.9 (0.8-1)	72 (59.6-84.4)
ORIDS5 = 0 (95% CI)	92.3 (84.9-99.6)	81.1 (70.2-91.9)	63.2 (49.8-76.5)	96.8 (91.9-100)	4.9 (1.1-10.9)	0.1 (0.1-0.2)	84 (73.8-94.2)
ORIDL5 = 0 (95% CI)	69.2 (56.4-82)	83.3 (73-93.7)	81.8 (71.1-92.5)	71.4 (58.9-84)	4.2 (1.4-9.7)	0.4 (0.2-0.5)	76 (64.2-87.8)
OROLV1 = 0 (95% CI)	63.6 (50.3-77)	75 (63-87)	66.7 (53.6-79.7)	72.4 (60-84.8)	2.6 (1.8-6.9)	0.5 (0.3-0.6)	70 (57.3-82.7)
OROLV2 = 0 (95% CI)	65.2 (52-78.4)	70.4 (57.7-83)	68.2 (55.3-81.1)	70.4 (57.7-83)	2.2 (1.9-6.2)	0.5 (0.4-0.6)	69.4 (56.6-82.2)
OROLV5 = 0 (95% CI)	56.5 (42.8-70.3)	66.7 (53.6-79.7)	59.1 (45.5-72.7)	64.3 (51-77.6)	1.7 (0.7-2.7)	0.7 (0.5-0.8)	62 (48.5-75.5)
OROLV10 = 0 (95% CI)	56 (42.2-70)	64 (50.7-77.3)	60.9 (47.3-74.4)	59.3 (50-72.9)	1.6 (0.6-2.6)	0.7 (0.6-0.8)	60 (46.4-73.6)
OROLV15 = 0 (95% CI)	52.2 (38-66.3)	68 (54.8-81.2)	60 (46.1-73.9)	60.7 (46.9-74.5)	1.6 (0.6-2.7)	0.7 (0.6-0.8)	60.4 (46.6-74.3)
OROLV30 = 0 (95% CI)	43.8 (29.7-57.8)	64 (50.4-77.6)	43.8 (29.7-57.8)	64 (50.4-77.6)	1.2 (0.2-2.2)	0.9 (0.8-1)	56.1 (42.1-70.1)
OROLV45 = 0 (95% CI)	40 (23.3-56.7)	72.2 (57-87.5)	54.5 (37.6-71.5)	59.1 (42.3-75.9)	1.4 (0.3-2.7)	0.8 (0.7-1)	57.6 (40.7-74.4)
OROLV60 = 0 (95% CI)	53.3 (35.8-70.9)	68.8 (52.4-85.1)	61.5 (44.4-78.7)	61.1 (43.9-78.3)	1.7 (0.4-3)	0.7 (0.5-0.8)	61.3 (44.1-78.4)
OROLV90 = 0 (95% CI)	50	66.7	71.4	44.4	1.5	0.8	56.3

(25.5-75)	(43.6-90)	(49.3-93.6)	(20.1-68.8)	(0.2-4.3)	(0.5-0.9)	(31.9-80.6)
-----------	-----------	-------------	-------------	-----------	-----------	-------------

Abbreviations: ORi, oxygen reserve index; OR, oxygen reserve; OLV, one-lung ventilation; PPV, positive predictive value; NPV, negative predictive value; PLHR, positive likelihood ratio; NLHR, negative likelihood ratio; CI, confidential interval; ORiDS5, ORi under mechanical ventilation 5 minutes after intubation in supine position; ORiDL5, ORi under mechanical ventilation 5 minutes after positioning in the lateral decubitus position; OROLV1, ORi after 1 minutes of OLV; OROLV2, ORi after 2 minutes of OLV; OROLV5, ORi after 5 minutes of OLV; OROLV10, ORi after 10 minutes of OLV; OROLV15, ORi after 15 minutes of OLV; OROLV30, ORi after 30 minutes of OLV; OROLV45, ORi after 45 minutes of OLV; OROLV60, ORi after 60 minutes of OLV; OROLV90, ORi after 90 minutes of OLV.

In Figure 1, data analysis provides thirteen different time points during the anesthesia induction and maintenance of the surgery. In this analysis, a correlation of ORi and SpO2 values at different time points during the anesthesia induction and maintenance periods are shown in a continuous graph. This correlation shows that a strong correlation between ORi and SpO2 was found at the at time points of DS5; ($r = 0.286$, $p = 0.044$), DL5 ($r = 0.293$, $p = 0.039$), at OLV10; there is a significant correlation with SpO2 ($r = 0.360$, $p = 0.011$) (Figure 1).

Later, we statistically evaluated the representative trends of the oxygen reserve index (ORi) and perfusion index (PI) values and the oxygen reserve index (ORi) and pleth variability index (PVI) values at different time points during anesthesia induction and maintainance of thoracic surgery. These are represented in Figure 2 and 3.

Table 3 shows the median values and interquartile range of PI and PVI values at different measurement points during the study. The analysis of correlations between these PI and PVI values showed a correlation between PI and PVI values at the time point of ORiDL5 ($r = -0.284$, $p = 0.046$). In other time points, a correlation was not observed. Table 4 provides time-dependent correlations between ORi with SpO2, PI, and PVI. These correlation analysis provide data that ORi has significant correlations with SpO2, PI and PVI at some specific time points and these include; 1- at time point of DS5; ($r = 0.286$, $p = 0.044$), DL5 ($r = 0.293$, $p = 0.039$), and OLV10; there is a significant correlation with SpO2 ($r = 0.360$, $p = 0.011$), 2- at time point of DLS5; there is a significant negative correlation with PI ($r = -0.332$, $p = 0.019$), whereas; 3- no correlations with PVI was noted.

Table 3. The Median Values and Interquartile Range of Perfusion Index (PI) and Pleth Variability Index (PVI) Values at Different Measurement Points of Surgery.

Time (min)	Perfusion Index (PI)		Pleth Variability Index (PVI)	
	Median	Interquartile range (IQR)	Median	Interquartile range (IQR)
Baseline	1.55	0.86-2.3	20.5	14-30.25
Preoxygenation	1.8	1.3-2.6	18.5	13-30.25
DS5	1.6	1-2.5	16	11-21
DL5	1.7	1.28-2.3	17	12-26
OLV1	1.3	0.61-1.3	16.5	11.75-23
OLV2	1.1	0.63-1.93	13.5	10-21.25
OLV5	1.3	0.64-1.93	14	10-20.25
OLV10	1.3	0.71-1.7	17	10.5-22.5
OLV15	1.25	0.76-2.1	15	10.25-21
OLV30	1.1	0.66-2	17	10-22
OLV45	1.3	0.82-2.1	14	8.5-20.5
OLV60	1.2	0.63-2.2	14	10-22
OLV90	1.1	0.73-2	13	8.5-18.75

Abbreviations: PI, perfusion index; PVI, pleth variability index; IQR, interquartile range; DLV, double-lung ventilation; OLV, one-lung ventilation; DS5, under mechanical ventilation 5 minutes after intubation in supine position; DL5, under mechanical ventilation 5 minutes after positioning in the lateral decubitus position; OLV1, after 1 minutes of OLV; OLV2, after 2 minutes of OLV; OLV5, after 5 minutes of OLV; OLV10, after 10 minutes of OLV; OLV15, after 15 minutes of OLV; OLV30, after 30 minutes of OLV; OLV45, after 45 minutes of OLV; OLV60, after 60 minutes of OLV; OLV90, after 90 minutes of OLV.

Table 4. Time-Dependent Correlations between Oxygen Reserve Index (OR_i) with Peripheral Oxygen Saturation (SpO₂), Perfusion Index (PI) and Pleth Variability Index (PVI) during Surgery.

Time (min)	Peripheral Oxygen Saturation (SpO ₂)		Perfusion Index (PI)			Pleth Variability Index (PVI)	
	r	p	r	p	r	p	
Preoxygenation	0.121	0.404	0.042	0.774	0.017	0.908	
DS5	0.286	0.044*	-0.332	0.019*	0.073	0.617	
DL5	0.293	0.039*	-0.010	0.947	0.089	0.540	
OLV1	-0.030	0.834	0.020	0.888	-0.013	0.984	
OLV2	-0.087	0.548	0.158	0.272	-0.147	0.307	
OLV5	-0.249	0.081	0.133	0.358	-0.001	0.997	
OLV10	0.360	0.011*	-0.240	0.097	-0.058	0.692	
OLV15	0.241	0.099	-0.247	0.091	-0.175	0.234	
OLV30	-0.162	0.313	0.305	0.053	-0.189	0.237	
OLV45	0.270	0.129	-0.115	0.529	0.038	0.837	
OLV60	0.092	0.630	-0.179	0.344	-0.036	0.850	
OLV90	-0.412	0.113	0.433	0.094	-0.167	0.535	

Abbreviations: ORi, Oxygen Reserve Index; SpO₂, peripheral oxygen saturation; PI, perfusion index; PVI, pleth variability index; DLV, double-lung ventilation; OLV, one-lung ventilation; DS5, under mechanical ventilation 5 minutes after intubation in supine position; DL5, under mechanical ventilation 5 minutes after positioning in the lateral decubitus position; OLV1, after 1 minutes of OLV; OLV2, after 2 minutes of OLV; OLV5, after 5 minutes of OLV; OLV10, after 10 minutes of OLV; OLV15, after 15 minutes of OLV; OLV30, after 30 minutes of OLV; OLV45, after 45 minutes of OLV; OLV60, after 60 minutes of OLV; OLV90, after 90 minutes of OLV.

For hemodynamical parameters, as collected as; MAP, SBP, DBP, HR oximeter related SpO₂ values, a correlation between these parameters were not found in statistical analysis (p>0.05). In our study, we demonstrated a time-dependent correlation between PVI and MAP at the time point of OLV90, indicating that PVI showed a relation to MAP at a late stage of the thoracic surgical procedure.

4. Discussion

The main findings of this study shows that; at the time point of five minutes after tracheal intubation in the supine position recorded ORi equals zero and we demonstrated that at this time point a high sensitivity and specificity for predicting hypoxemia of less than 95% is present. This finding has been

supported by several recent studies [8-10,15,18-20] In summary, the results show that for PaO₂ values less than 240 mmHg, there is a strong positive correlation with ORi values. [18-20]

In our study, ORi and peripheral oxygen saturation recorded as SpO₂ values correlate at the time point of ten minutes after OLV whereas, previous studies demonstrated a continuous correlation between ORi and PaO₂ values. [8-10,13-15,18-21] Time-dependent correlations between ORi with SpO₂, revealed that; at time points of DS5, DL5, and OLV10; there is a significant correlation with SpO₂. When this oximeter-related parameter is used along with the pulse oximeter monitoring, ORi values may present and record early signs of the downward trend of PaO₂ in comparison to a pulse oximetry value. Our findings are consistent with previous studies on the use of ORi parameter values and arterial or peripheral oxygen desaturation associated collected values during OLV for elective thoracic surgeries. [8,9,13,15,18] Our findings show similarity with a recent study by Alday and his colleagues[8] however, they also suggested that these values may be used to prevent unnecessary hyperoxemia. In our study, it is clear that as the FiO₂ values are greater than 50% in our patients, the use of ORi provides valuable data as it correlated with SpO₂ values at different time points after anesthesia induction. In another study, Applegate and his colleagues compared the ORi and PaO₂ values, and a positive correlation was observed for PaO₂ values of 240 mmHg or lower ($r = 0.536$, $p < 0.01$) in comparison to PaO₂ values of higher than 240 mmHg ($r = 0.0016$, $p > 0.05$). [9] In addition, fifteen patients undergoing elective thoracic surgery using OLV were evaluated for PaO₂ and ORi parameters throughout the surgical procedure. This study shows that ORi has a significant correlation with PaO₂ ($r = 0.671$, $p < 0.01$). [18] In other studies, a continuous correlation between ORi and PaO₂ values was demonstrated. [13-16,18-21]

During pulse oximetry monitoring, there is a sigmoidal relationship between arterial oxygenation in blood gas value and peripheral oxygenation, which is preset as SpO₂ on the pulse oximetry device. This relationship causes no change in pulse oximeter values until PaO₂ falls below 80 mmHg. Afterward, there is a sudden drop in pulse oximetry value; however, the PaO₂ is unacceptable for more than three to five minutes. Therefore, there is a need to investigate a larger scale of several wavelengths to detect quantitative measurement of methemoglobin, carboxyhemoglobin, and total hemoglobin, and a newly presented device achieved this. Masimo Rainbow Signal Extraction Technology introduced the device. [13-16]

ORi is a parameter-driven from this device that is between 0 and 1 values, and it is sensitive to the changes in arterial oxygenation in the blood, with the range of 100 to 200 mmHg. [2,8-10,13,18-21] When oxygenation is in the moderate hyperoxic content showing an arterial blood oxygenation value of 100-240 mmHg in arterial blood gas analysis, the pulse oximeter SpO₂ value remains 100%, whereas there is a decrease in the value of ORi. [2,18-21] In our study, Figure 1 and Table 4 provides data on time-dependent correlations between ORi with SpO₂.

Increased intrathoracic pressure with respiration will lead to more immediate reductions in peripheral perfusion in patients with a fluid deficit. In this case, a decrease in the PI value of the patient will be observed. As a result of these changes with respiration, the highest and lowest PI ratio corresponds to the

PVI. High PVI values are observed in patients with a high fluid deficit or those who do not respond to fluid application changes with changes in the PI.[11,12,23,24] We evaluated the representative trends of the oxygen reserve index (ORi) and perfusion index (PI) values and the oxygen reserve index (ORi) and pleth variability index (PVI) values at different time points during anesthesia induction and maintenance of thoracic surgery and our findings are in correspondence with the previous findings that fluid deficit or fluid overload causes changes in PI and PVI values. This can be observed in our representative trend graphs in Figure 2 and 3.

Our study provides valuable data for the investigation of correlations between ORi and PI, and PVI. One lung ventilation with DLT has significant cardiopulmonary physiological changes, as has been discussed elsewhere.[14-17] Our study provides data that at a time point of DLS5, there is a significant negative correlation with PI ($r = -0.332$, $p = 0.019$), whereas; no correlations with PVI were noted. This finding is thought to result from anesthesia induction-related medications and especially the use of opioid medications.[3-6,12]

The use of FiO₂ values above 40% during anesthesia is related to hyperoxemia, and this high oxygenation decreases cardiac output by reducing heart rate and causing systemic vasoconstriction. Furthermore, hyperoxemia is a potent vasoconstrictor stimulus to the coronary circulation, functioning at the level of the microvascular resistance vessels.[20,21] Tsuchiya et al. demonstrated that the PVI could be used to evaluate anesthesia-induced hypotension in patients undergoing general anesthesia without age group classification. [23] This technique has been used in patients undergoing mechanical ventilation in the intensive care unit to detect fluid responsiveness through respiratory patterns and peripheral perfusion changes.[11] There are insufficient data to distinguish the cause of hypotension due to peripheral vasodilatation and fluid redistribution or cardiac output decrease after general anesthesia. [23,24] High PVI values are observed in patients with a high fluid deficit or those who do not respond to fluid application changes with changes in the PI.[24]

In our study, we demonstrated a time-dependent correlation between PVI and MAP at the time point of OLV90, indicating that PVI showed a relation to MAP at a late stage of the surgical procedure. Recently, it is pointed out in a meta-analysis that PVI is a reliable marker in evaluating a response to fluid management.[16]

5. Limitations

Malpositioning of DLT may cause hypoxemia, and we have included these patients in our study; therefore, our study is limited. [25] Previously, the arterial blood gas oxygenation results show that PaO₂ values were higher during right-sided OLV than left-sided OLV. Although it could be predicted that ORi would decrease before the decrease in SpO₂ during left-sided OLV, the actual extent should be evaluated. [16,18-21] When oxygenation is in the moderate hyperoxic range of PaO₂ values between 100 and 240 mmHg, ORi decreases, but SpO₂ does not.[20]

6. Conclusions

This study indicates that ORi and peripheral oxygen saturation values correlate at the time point of ten minutes after OLV whereas, previous studies demonstrated a continuous correlation between ORi and PaO₂ values. ORi equals zero at a time point of five minutes after tracheal intubation in the supine position showed high sensitivity and specificity for predicting hypoxemia of less than 95%. Time-dependent correlations between ORi with SpO₂, PI, and PVI revealed that; at time points of DS5, DL5, and OLV10; there is a significant correlation with SpO₂, at a time point of DS5; there is a significant negative correlation with PI, whereas; no correlations with PVI was noted.

Abbreviations

ASA-PS = American Society of Anesthesiologists Physical Status

CI = Confidential interval

DBP = Diastolic blood pressure

DLT = Double lumen tube

FiO₂ = Fraction of inspired oxygen

HR = Heart rate

IQR = Interquartile range

ORi = Oxygen reserve index

OLV = One-lung ventilation

PaCO₂ = Arterial partial pressure of carbon dioxide

PaO₂ = Arterial partial pressure of oxygen

PI = Perfusion index

PVI = Pleth variability index

SpO₂ = Peripheral oxygen saturation

VATS = Video-assisted thoracoscopy

MAP = Mean arterial pressure

SBP = Systolic blood pressure

SD = Standard deviation

Declarations

Acknowledgment: Authors would like to thank all the patients for their willingness to participate in the study and their patience.

Availability of Data and materials: The data is available by permission from Dr. Gonul Sagiroglu, Trakya University, School of Medicine, Department of Anesthesiology, Edirne, Istanbul, email address: gonul.sagiroglu45@gmail.com. Please contact this address for permission. Administrative permissions are not required to access the raw data. The authors have agreed to give permission to the data and materials during registration at clinicaltrials.gov.

Conflict of Interests: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

Consent for Publication: Not Applicable

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institution and/or national research committee. Informed consent was obtained from all individual participants included in the study.

Funding: The authors received no financial support for the research and/or authorship of this article. This study was done solely by the funding of in Anesthesiology and Reanimation Department of Trakya University Trakya School of Medicine Hospital, Edirne, Turkey.

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

Author Contributions: Concept – G.S., Y.A.K.; Design – G.S., Y.A.K.; Supervision – G.S.,

Y.A.K.; Data Collection and/or Processing – G.S., Y.A.K.; Analysis and/or

Interpretation – G.S.;A.B.; Literature Review – G.S., Y.A.K., A.B.; Writer – G.S., Y.A.K; A.B.; Critical Review – G.S., A.B.

References

1. Lohser J, Slinger P. Lung injury after one-lung ventilation: a review of the pathophysiologic mechanisms affecting the ventilated and the collapsed lung. *Anesth Analg* 2015;121:302–18.

<https://doi.org/10.1213/ANE.0000000000000808>

2. Campos JH and Sharma A. Predictors of hypoxemia during one-lung ventilation in thoracic surgery: is oxygen reserve index (ORi) the answer? *J Cardiothorac Vasc Anesth* 2020;4:423–425. <https://doi.org/10.1053/j.jvca.2019.08.017>.
3. Karzai W, Schwarzkopf K. Hypoxemia during one-lung ventilation: prediction, prevention, and treatment. *Anesthesiology* 2009;110:1402–1411. <https://doi.org/10.1097/ALN.0b013e31819fb15d>
4. Hahm TS, Jeong H, Ahn HJ. Systemic Oxygen Delivery during One-Lung Ventilation: Comparison between Propofol and Sevoflurane Anaesthesia in a Randomised Controlled Trial. *J Clin Med*. 2019;8:1438. <https://doi.org/10.3390/jcm8091438>
5. Liu TJ, Shih MS, Lee WL, et al. Hypoxemia during one-lung ventilation for robot-assisted coronary artery bypass graft surgery. *Ann Thorac Surg*. 2013;96:127–132. <https://doi.org/10.1016/j.athoracsur.2013.04.017>
6. Marongiu I, Spinelli E, Mauri T. Cardio-respiratory physiology during one-lung ventilation: complex interactions in need of advanced monitoring. *Ann Transl Med* 2020;8:524 <https://doi.org/10.21037/atm.2020.03.179>.
7. Chen ST, Min S. Oxygen reserve index, a new method of monitoring oxygenation status: what do we need to know? *Chin Med J (Engl)* 2020;133:229–234. doi: 10.1097/CM9.0000000000000625.
8. Alday E, Nieves JM, Planas A. Oxygen reserve index predicts hypoxemia during one lung ventilation. An observational diagnostic study. *J Cardiothorac Vasc Anesth* 2020;34:417–4. <https://doi.org/10.1053/j.jvca.2019.06.035>
9. Applegate RL 2nd, Dorotta IL, Wells B, Juma D, Applegate PM. The relationship between oxygen reserve index and arterial partial pressure of oxygen during surgery. *Anesth Analg* 2016;123:626–633 <https://doi.org/10.1213/ANE.0000000000001262>.
10. Durkin C, Romano K, Egan S, Lohser J. Hypoxemia During One-Lung Ventilation: Does It Really Matter? [published online ahead of print, 2021 Jul 7]. *Curr Anesthesiol Rep*. 2021;1–7. <https://doi.org/10.1007/s40140-021-00470-5>
11. Scheeren TWL, Belda FJ, Perel A. The oxygen reserve index (ORi): a new tool to monitor oxygen therapy. *J Clin Monit Comput* 2018;32:379–389. <https://doi.org/10.1007/s10877-017-0049-4>.
12. Loupec T, Nanadoumgar H, Frasca D, L et al. Pleth variability index predicts fluid responsiveness in critically ill patients. *Crit Care Med* 2011;39:294–299. <https://doi.org/10.1097/CCM.0b013e3181ffde1c>.
13. Yuksek A. Utility of the pleth variability index in predicting anesthesia-induced hypotension in geriatric patients. *Turk J Med Sci* 2021;51:134–139. <https://doi.org/10.3906/sag-1912-132>.
14. Ishida Y, Okada T, Kobayashi T, Uchino H. ORi™: a new indicator of oxygenation. *J Anesth*. 2021;35(5):734–740. doi:10.1007/s00540-021-02938-4
15. Yoon S, Kim BR, Min SH, et al. Repeated intermittent hypoxic stimuli to operative lung reduce hypoxemia during subsequent one-lung ventilation for thoracoscopic surgery: A randomized controlled trial. *PLoS One* 2021;16:e0249880. <https://doi.org/10.1371/journal.pone.0249880>

16. Jia FJ, Yan QY, Sun Q, Tuxun T, Liu H, Shao L. Liberal versus restrictive fluid management in abdominal surgery: a meta-analysis. *Surg Today*. 2017;47:344–56. <https://doi.org/10.1007/s00595-016-1393-6>
17. Tusman G, Bohm SH, Suarez-Sipmann F. Alveolar recruitment maneuvers for one-lung ventilation during thoracic anesthesia. *Curr Anesthesiol Rep* 2014;4:160–169.
18. Koishi W, Kumagai M, Ogawa S, Hongo S, Suzuki K. Monitoring the oxygen reserve index can contribute to the early detection of deterioration in blood oxygenation during one-lung ventilation. *Minerva Anesthesiol* 2018;84:1063–1069. <https://doi.org/10.23736/S0375-9393.18.12622-8>.
19. Yoshida K, Isosu T, Noji Y, et al. Usefulness of oxygen reserve index (ORi™), a new parameter of oxygenation reserve potential, for rapid sequence induction of general anesthesia. *J Clin Monit Comput* 2018;32:687–691. <https://doi.org/10.1007/s10877-017-0068-1>.
20. Yoshida K, Isosu T, Noji Y, et al. Adjustment of oxygen reserve index (ORi™) to avoid excessive hyperoxia during general anesthesia. *J Clin Monit Comput* 2020;34(3):509–514.
21. Chen ST, Min S. Oxygen reserve index, a new method of monitoring oxygenation status: what do we need to know? *Chin Med J* 2020;133:229–234. <https://doi.org/10.1097/CM9.0000000000000625>.
22. Habre W, Peták F. Perioperative use of oxygen: variabilities across age. *Br J Anaesth* 2014;113 Suppl 2:ii26-ii36. <https://doi.org/10.1093/bja/aeu380>.
23. Tsuchiya M, Yamada T, Asada A. Pleth variability index predicts hypotension during anesthesia induction. *Acta Anaesthesiol Scand* 2010;54:596–602. <https://doi.org/10.1111/j.1399-6576.2010.02225.x>.
24. Cannesson M, Desebbe O, Rosamel P, et al. Pleth variability index to monitor the respiratory variations in the pulse oximeter plethysmographic waveform amplitude and predict fluid responsiveness in the operating theatre. *Br J Anaesth* 2008;101.2:200–206. <https://doi.org/10.1093/bja/aen133>.
25. Inoue S, Nishimine N, Kitaguchi K, Furuya H, Taniguchi S. Double lumen tube location predicts tube malposition and hypoxaemia during one lung ventilation. *Br J Anaesth* 2004;92:195–201. <https://doi.org/10.1093/bja/ae055>.

Figures

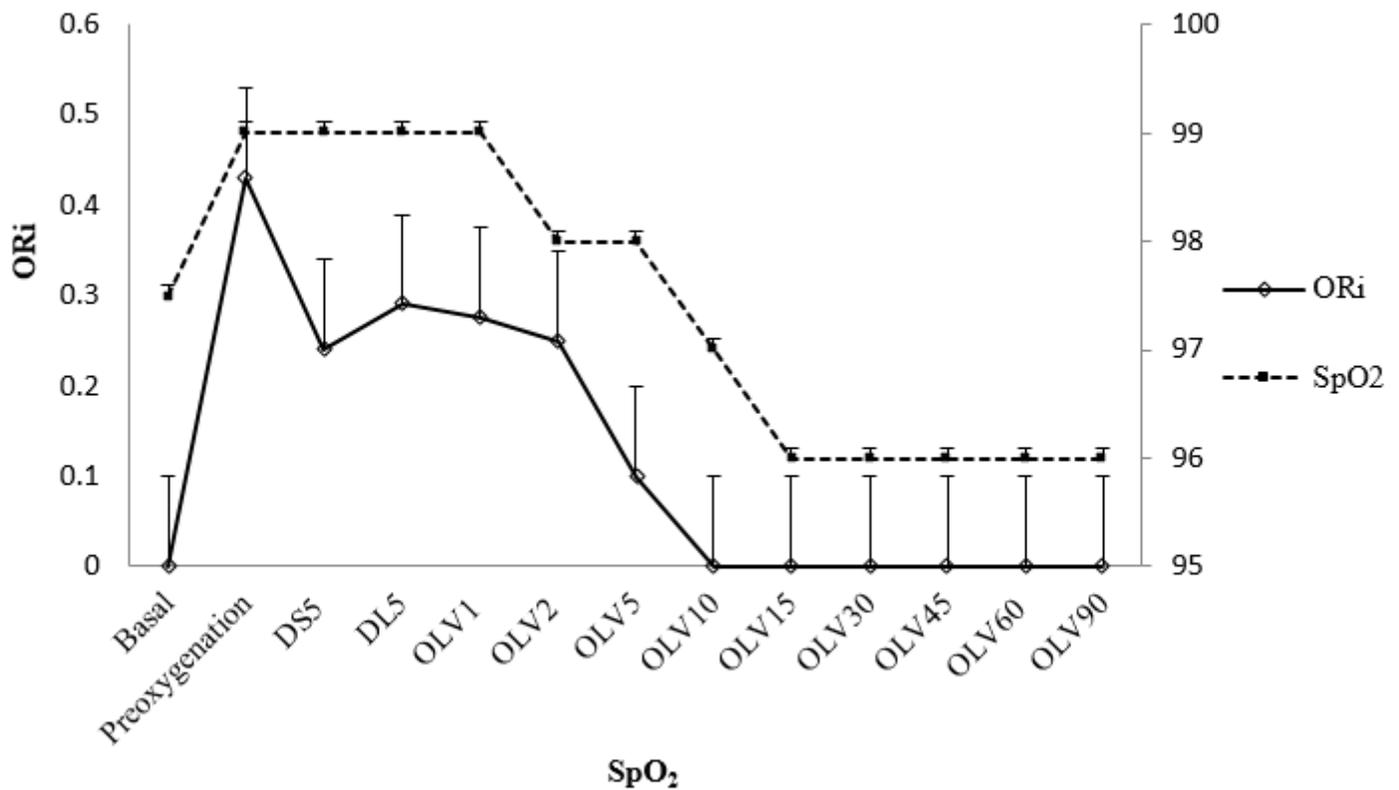


Figure 1

The Representative Trends of Oxygen Reserve Index (ORi) and Peripheral Oxygen Saturation (SpO₂) Values at Different Time Points during Surgery. Abbreviations: ORi, oxygen reserve index; SpO₂, peripheral oxygen saturation; DLV, double-lung ventilation; OLV, one-lung ventilation; DS5, under mechanical ventilation 5 minutes after intubation in supine position; DL5, under mechanical ventilation 5 minutes after positioning in the lateral decubitus position; OLV1, after 1 minutes of OLV; OLV2, after 2 minutes of OLV; OLV5, after 5 minutes of OLV; OLV10, after 10 minutes of OLV; OLV15, after 15 minutes of OLV; OLV30, after 30 minutes of OLV; OLV45, after 45 minutes of OLV; OLV60, after 60 minutes of OLV; OLV90, after 90 minutes of OLV.

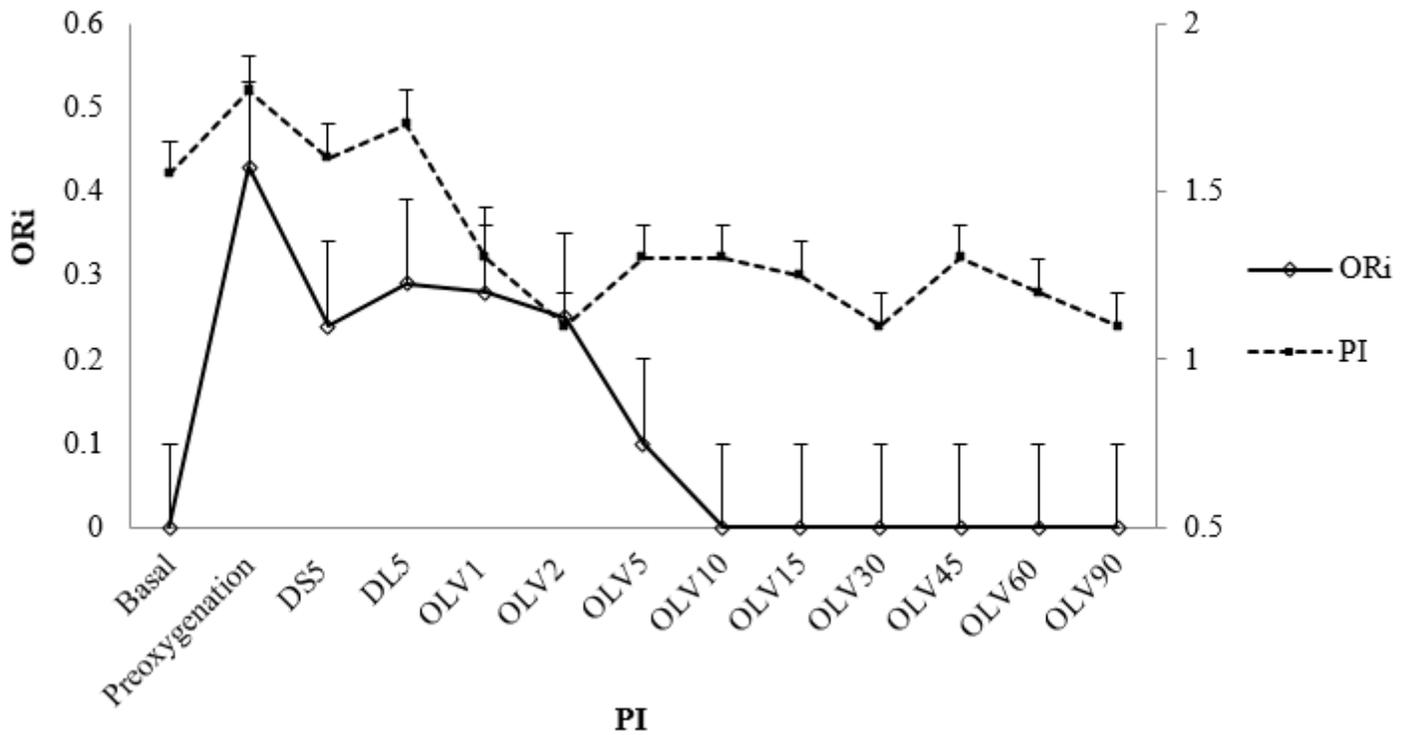


Figure 2

The Oxygen Reserve Index (ORi) and Perfusion Index (PI) Values at Different Time Points of Surgery. Abbreviations: ORi, oxygen reserve index; PI, perfusion index; DLV, double-lung ventilation; OLV, one-lung ventilation; DS5, under mechanical ventilation 5 minutes after intubation in supine position; DL5, under mechanical ventilation 5 minutes after positioning in the lateral decubitus position; OLV1, after 1 minutes of OLV; OLV2, after 2 minutes of OLV; OLV5, after 5 minutes of OLV; OLV10, after 10 minutes of OLV; OLV15, after 15 minutes of OLV; OLV30, after 30 minutes of OLV; OLV45, after 45 minutes of OLV; OLV60, after 60 minutes of OLV; OLV90, after 90 minutes of OLV.

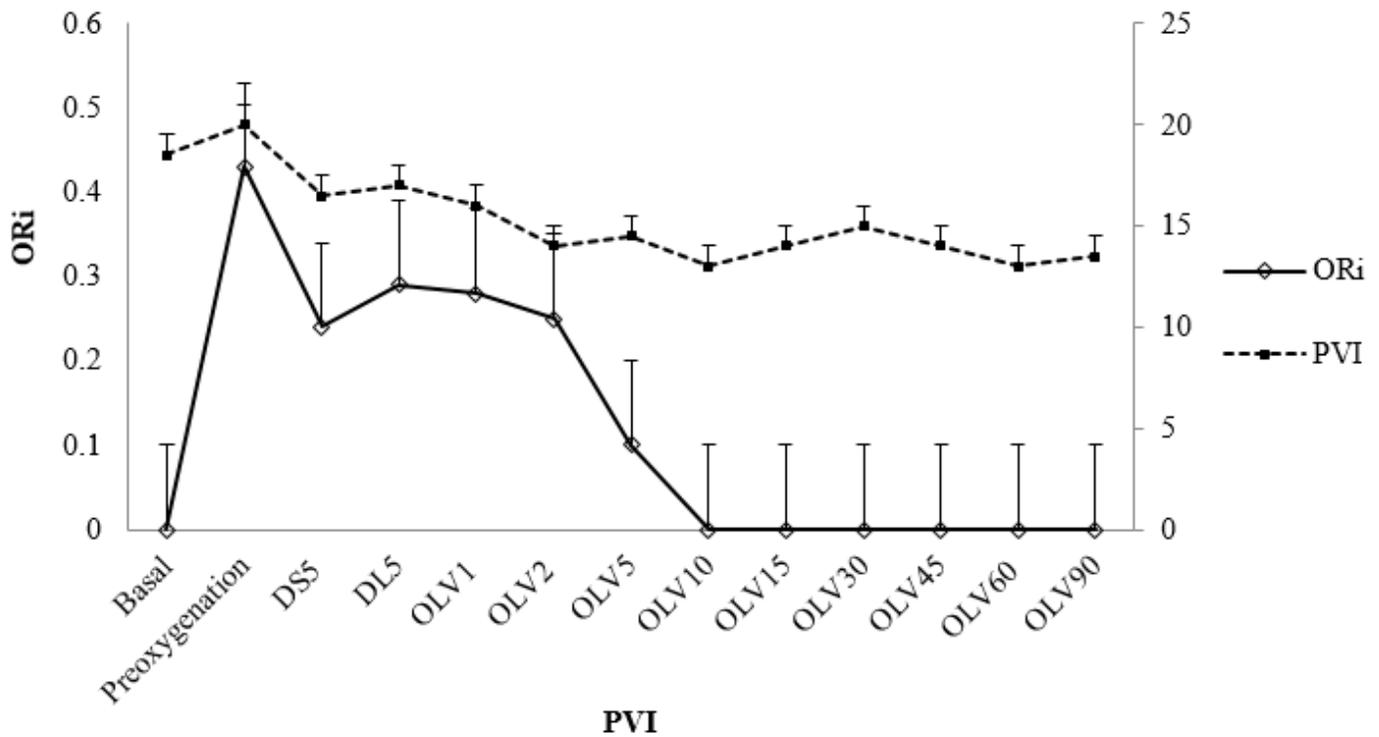


Figure 3

The Oxygen Reserve Index (ORi) and Pleth Variability Index (PVI) Values at Different Time Points of Surgery. Abbreviations: ORi, oxygen reserve index; PVI, pleth variability index; DLV, double-lung ventilation; OLV, one-lung ventilation; DS5, under mechanical ventilation 5 minutes after intubation in supine position; DL5, under mechanical ventilation 5 minutes after positioning in the lateral decubitus position; OLV1, after 1 minutes of OLV; OLV2, after 2 minutes of OLV; OLV5, after 5 minutes of OLV; OLV10, after 10 minutes of OLV; OLV15, after 15 minutes of OLV; OLV30, after 30 minutes of OLV; OLV45, after 45 minutes of OLV; OLV60, after 60 minutes of OLV; OLV90, after 90 minutes of OLV.