Scientific Research Publishing

Open Journal of Anesthesiology, 2023, 13, 1-14
https://www.scirp.org/journal/ojanes
ISSN Online: 2164-5558
ISSN Print: 2164-5531

A Comparison of Arterial Oxygenation between 60% O_2 CPAP and 100% O_2 CPAP during One-Lung Ventilation: A Prospective Randomized Controlled Study

Yuko Yamada[1], Kumiko Tanabe[1], Kiyoshi Nagase[1], Hiroki Iida[1,2*]

[1]Department of Anesthesiology and Pain Medicine, Gifu University Graduate School of Medicine, Gifu, Japan
[2]Anesthesiology and Pain Relief Center, Central Japan International Medical Center, Minokamo, Gifu, Japan
Email: *h-iidamd@xqd.biglobe.ne.jp

How to cite this paper: Yamada, Y., Tanabe, K., Nagase, K. and Iida, H. (2023) A Comparison of Arterial Oxygenation between 60% O_2 CPAP and 100% O_2 CPAP during One-Lung Ventilation: A Prospective Randomized Controlled Study. *Open Journal of Anesthesiology*, **13**, 1-14.
https://doi.org/10.4236/ojanes.2023.131001

Received: December 19, 2022
Accepted: January 28, 2023
Published: January 31, 2023

Abstract

Background: One-lung ventilation (OLV) is generally adopted for thoracic surgery. The systemic application of a high fraction of inspiratory oxygen (F_IO_2) and continuous positive airway pressure (CPAP) to the non-ventilated lung is useful for preventing arterial oxygen desaturation. The adverse effects of elevated F_IO_2 include oxidative lung injury, resorption atelectasis and coronary and peripheral vasoconstriction. It is preferable to avoid hyperoxemia in patients with complications such as chronic obstructive pulmonary disease, idiopathic pneumonia, and bleomycin-treated lungs. We aimed to determine whether the application of 60% O_2 CPAP to the non-ventilated lung is sufficient to provide adequate oxygenation with 60% O_2 to the ventilated lung. **Methods:** A total of 70 patients scheduled to receive elective thoracic surgery requiring OLV were recruited. Left double-lumen tubes were applicable in all surgeries. Patients were randomly allocated to one of two groups, to receive either 60% O_2 CPAP (60% CPAP group, n = 35), or 100% O_2 CPAP (100% CPAP group, n = 35) at a setting of 2 - 3 cmH_2O, applied to the non-ventilated lung. Arterial blood gas analyses were obtained at the following stages: RA, spontaneous breathing under room air (RA); TLV, during total lung ventilation (TLV) prior to the initiation of OLV; T5, 5 min after the initiation of OLV; T15, 15 min after the initiation of OLV; T30, 30 min after the initiation of OLV. **Results:** The PaO_2 value in 60% CPAP group vs. 100% CPAP group at each measurement were as follows: RA (mean [standard deviation: SD], 89.7 [8.2] mmHg vs. 85.8 [11.9] mmHg); TLV (277.9 [52.9] mmHg vs. 269.2 [44.0] mmHg); T5 (191.4 [67.9] mmHg vs. 192.3 [66.0] mmHg); T15 (143.2 [67.3] mmHg vs. 154.7 [60.8] mmHg) and T30 (95.6

[32.0] mmHg vs. 112.5 [36.5] mmHg), respectively. Among the five measurement points, T30 was the only time point at which the 100% CPAP group showed a significantly greater PaO_2 value than the 60% CPAP group ($p = 0.0495$). The SaO_2 at T30 in the 100% CPAP group (97.4 [2.0]%) was also significantly greater than that in the 60% CPAP group (96.3 [2.2]%, $p = 0.039$). No differences were found between the groups regarding changes to the overall PaO_2 values ($p = 0.44$) and SaO_2 values ($p = 0.23$) during the study period. **Conclusions:** Oxygenation could be safely maintained in relatively healthy patients with 60% O_2 OLV and 60% O_2 CPAP. The application of 60% O_2 CPAP during OLV for patients who are not suited to exposure to high F_IO_2 may be an alternative form of respiratory management.

Keywords

CPAP, Double-Lumen Tube, Hyperoxemia, Hypoxemia, One-Lung Ventilation

1. Introduction

One-lung ventilation (OLV) is performed to separate the non-ventilated lung from the ventilated lung in thoracic surgery. Collapse of the surgical lung improves access to the surgical field [1]. Intrapulmonary shunt may decrease oxygenation during OLV due to the collapse of the non-ventilated lung. The application of a high fraction of inspiratory oxygen (F_IO_2) in order to avoid hypoxemia increases atelectatic areas in the ventilated lung [2]. The incidence of hypoxemia during OLV was slightly enhanced (3% - 10%) [3] [4] [5]. Managements for preventing arterial oxygen desaturation during OLV include using high F_IO_2, continuous positive airway pressure (CPAP) to the non-ventilated lung, positive end-expiratory pressure (PEEP) to the ventilated lung, and repeated inflation of the non-ventilated lung [1] [6]. CPAP may potentially reduce mechanical stress by keeping the alveoli open, allowing gas exchange and diverting blood away from the collapsed lung [2]. However, high-pressure CPAP has hemodynamic implications for the non-ventilated lung, causing overexpansion of the non-ventilated lung, which limits surgical access [3]. Thus, to avoid hypoxemia, 100% O_2 is routinely used in the application of CPAP to the non-ventilated lung instead of high-pressure CPAP.

Higher level F_IO_2 is routinely used during OLV to minimize the risk of developing hypoxemia [4] [6] [7]. The effects of progressive hypoxemia, particularly in individuals with coexisting cardiovascular, cerebrovascular, or pulmonary disease, undoubtedly pose a greater risk of compromised circulation [8]. On the other hand, the adverse effects of hyperoxemia and the application of high F_IO_2 include resorption atelectasis, coronary and peripheral vasoconstriction, cardiac output decrease, and direct harm to lung through oxidative stress [9] [10] [11] [12]. Hyperoxemia directly damages the lung in patients with chronic obstruc-

tive pulmonary disease (COPD), idiopathic pneumonia and bleomycin-treated lungs through oxidative stress [13] [14] [15]. Cancer patients have a higher oxidative burden and may have less antioxidant capacity [16]. Lower level F_IO_2 at 0.6 can maintain oxygenation during OLV, and it is less than an inflammatory response, lung edema, thickening of the alveolar wall, or acute injury will occur, in comparison to higher level F_IO_2 at 1.0% [7]. Therefore, the respiratory management that minimizes F_IO_2 levels during OLV is deemed desirable. However, it is currently unclear whether a lower F_IO_2 CPAP can be safely applied to the non-ventilated lung with a lower F_IO_2 to the ventilated lung in the clinical setting.

We aimed to determine whether the application of lower F_IO_2 CPAP to the non-ventilated lung is sufficient to provide adequate oxygenation.

2. Methods

2.1. Study Population

This prospective randomized, controlled study was approved by the university's institutional review board (IRB: 29-29) and written informed consent was obtained from all subjects who participated in the trial. The trial was registered prior to patient enrollment at the University Hospital Medical Information Network in Japan (UMIN 000028137, Principal investigator: Yuko Yamada, Date of registration: July 7, 2017). The study population included patients scheduled to undergo elective video-assisted thoracotomy requiring OLV from July 2017 to August 2019. The inclusion criteria were age >20 years, American Society of Anesthesiologists physical status of 1 - 3 and OLV lasting >45 min. The exclusion criteria were body mass index ≥30 kg/m^2, severe respiratory dysfunction and interstitial lung disease. A decline in pulse oximetric saturation (SpO_2) to <90% measured by pulse oximetry was the indication for interruption of the study; cases in which this occurred were excluded. This article adheres to the applicable Consolidated Standards of Reporting Trials (CONSORT) guidelines.

2.2. Group Allocation

Patients were randomly assigned to one of two groups, receiving either 60% O_2 CPAP (60% CPAP group, n = 35), or 100% O_2 CPAP (100% CPAP group, n = 35). The allocation ratio was 1:1, and a random allocation sequence was performed using sealed opaque envelopes for the purpose of allocation concealment.

2.3. Anesthesia and Double-Lumen Tube Intubation

After the arrival of patients in the operating room, standard monitoring was used. An intraarterial canula was inserted under local anesthesia. A thoracic epidural catheter was placed at the T7 level and a test dose was administered. No further epidural medications were administered until the end of the study period. Anesthesia was induced with propofol, remifentanil, and rocuronium, and maintained with propofol, remifentanil and rocuronium. All patients were intu-

bated with left-sided double-lumen tubes (DLTs) (Broncho-Cath™, Mallinckrodt Medical Ltd., Athlone, Ireland) for both right- and left-sided surgery. An appropriate DLT size was determined based on the diameter of the left mainstem bronchus, measured on preoperative chest computed tomography [17]. The proper position of the DLT was confirmed by fiberoptic bronchoscopy in both the supine and lateral positions. The bronchial cuff of the DLT was positioned, allowing the cephalad surface to be visible just below the carina. The lungs of all patients were ventilated with 60% oxygen. A tidal volume of 6 - 8 mL/kg (predicted body weight) was applied with PEEP of 4 cm H_2O. The respiratory rate was 10 - 15 breaths/min. Systolic blood pressure was maintained within 20% of the preoperative value by the intravenous administration of inotropic agents (ephedrine or phenylephrine). Cardiac output (CO) was monitored continuously using a FloTrac/Vigileo™ (Edwards Lifesciences) system.

2.4. Lung Separation and CPAP Application

Ventilatory variables were kept constant during the study, both during total lung ventilation (TLV) and OLV. The bronchial cuff was connected to a cuff inflator via a three-way stopcock, and then was inflated to a pressure of 20 cm H_2O. OLV was initiated just after the pleura was opened. The non-ventilated lung was exposed to the atmosphere, thus allowing deflation to reach atmospheric pressure. The ventilated lung was ventilated with 60% oxygen during OLV. Patients were randomly allocated to one of two groups, which received either 60% O_2 CPAP (60% CPAP group, n = 35), or 100% O_2 CPAP (100% CPAP group, n = 35) at a setting of 2 - 3 cm H_2O, which was applied to the non-ventilated lung via a CPAP adaptor with a fresh gas flow of 5 l/min using a Broncho-Cath™ CPAP system (Mallinckrodt Medical Ltd., Athlone, Ireland). CPAP was applied for a period of 3 min after the initiation of OLV. During OLV, the cuff pressure monitor was attached using a tube to the gas-sampling site of the patient end of the CPAP system to verify the CPAP level.

2.5. Measurements

Blood gas was measured using a commercially available blood gas analyzer (ABL 700 analyzer; Radiometer, Copenhagen, Denmark). Hemodynamic variables, peak inspiratory pressure (PIP), SpO_2 and arterial blood gas analyses were performed at the following stages: 1) RA, spontaneous breathing under room air (RA); 2) TLV, during TLV prior to the initiation of OLV in the lateral position; 3) T5, 5 min after the initiation of OLV; 4) T15, 15 min after the initiation of OLV; and 5) T30, 30 min after the initiation of OLV (**Figure 1**). All measurements, with the exception of RA, were taken in a lateral position. Hypoxemia was defined as arterial partial pressure of oxygen (PaO_2) <60 mmHg, or SpO_2 was maintained at <90%. Concurrently, thoracic surgeons were asked to comment on the quality of lung collapse after the opening of the chest. The condition of lung collapse was assessed as follows: 0 = impossible surgical access; 1 = poor

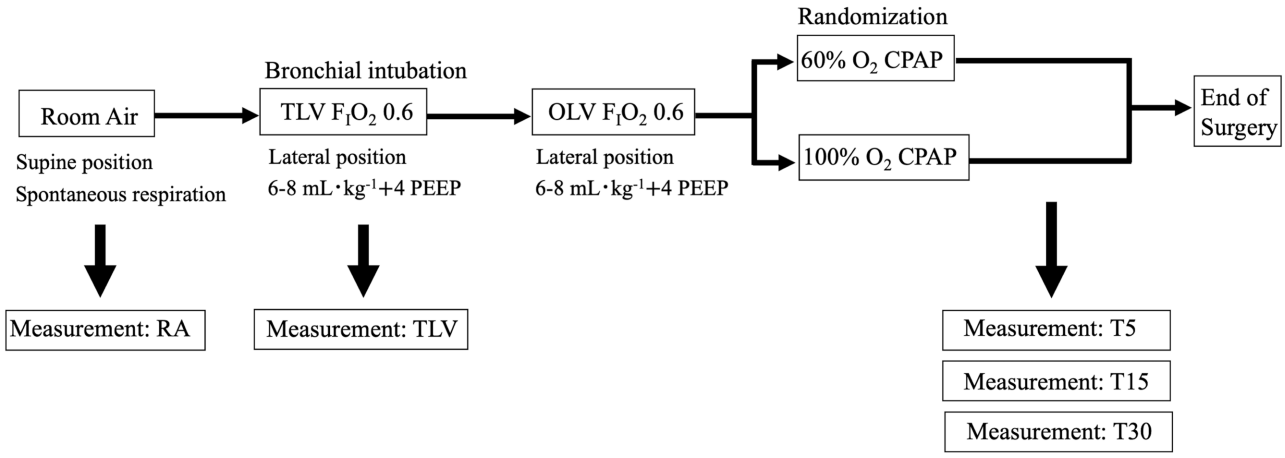

Figure 1. Study protocol. Hemodynamic variables, peak inspiratory pressure, SpO_2 and arterial blood gas analyses were obtained at the following time points: 1) RA, spontaneous breathing under room air (RA); 2) TLV, during TLV prior to the initiation of OLV in the lateral position; 3) T5, 5 min after the initiation of OLV; 4) T15, 15 min after the initiation of OLV; and 5) T30, 30 min after the initiation of OLV.

surgical access; 2 = fair operative field; and 3 = good operative field. Thoracic surgeons were blinded to the group assignments.

2.6. Outcome Variables

The primary outcome of this study was the PaO_2 values of the two groups at 30 min after the initiation of OLV (T30). The secondary outcomes were the differences between the groups in the changes in PaO_2 and arterial oxygen saturation (SaO_2).

2.7. Sample Size Estimation

A type I error estimate of 5% (alpha = 0.05) and a power (1-beta) of 90% were set. The sample size calculation was based on the assumption that the difference in the PaO_2 value of the 2 groups was 25 mmHg, and that the standard deviation (SD) of the groups was 30, according to a previous report [18]. It was estimated that a minimum of 63 patients would be required. To compensate for possible dropouts, the enrollment of 70 patients (*i.e.*, 35 patients per group) was planned.

2.8. Statistical Analysis

All data were analyzed using the SPSS® software program, version 23 (SPSS Inc., Chicago, IL, USA). The characteristics of patients are summarized as the mean [SD] for continuous variables. Frequencies and percentages are shown for categorical variables. For the analysis of the primary outcome variables, the mean PaO_2 of the two groups were compared using Student's *t*-test with a two-sided significance level of 0.05. The primary result was considered statistically significant when the P value was < 0.05. The analyses of arterial blood gas (pH, $PaCO_2$, SaO_2), SpO_2, PIP and hemodynamic variables were the same as in the primary analysis.

For the analysis of the secondary outcome variables, a two-way repeated measures analysis of variance was used to assess the difference between the groups. The secondary results were considered statistically significant when the P value was < 0.05.

3. Results

3.1. Participants

Seventy patients were enrolled in this study from July 2017 to Aug 2019 (Figure 2). The perioperative demographic patient profiles and operative details are summarized in Table 1 and Table 2. Of these 70 patients, 2 patients were excluded from the analysis. Almost all patients (except for 1 lung carcinoid) underwent lung cancer surgery. In these two cases, there was extensive pleural adhesion of the non-ventilated lung and the lung collapse was interrupted. The remaining 68 patients (n = 34 in each group) completed the study (Figure 2).

3.2. Primary Outcome

The PaO_2 value measured at T30 in the 100% CPAP group (mean [SD], 112.5 [36.5] mmHg) was significantly higher than that in the 60% CPAP group (95.6 [32.0] mmHg, p = 0.0495) (Figure 3(a)).

3.3. Secondary Outcome

No difference was found between the groups regarding changes to the overall PaO_2 values during study period (p = 0.44). SaO_2 measured at T30 in the 100%

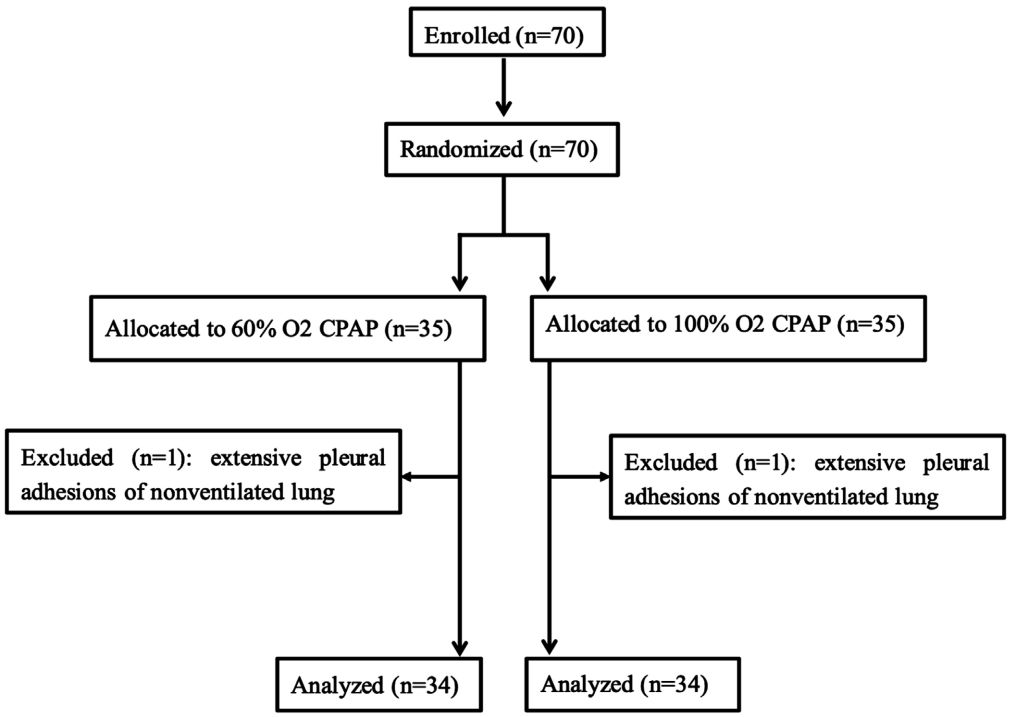

Figure 2. Study flow chart.

Table 1. Patients' characteristics

	60% CPAP-group	100% CPAP-group
Number of patients	34	34
Age (years), mean (SD)	63.0 (10.5)	66.7 (10.4)
Male, n (%)	15 (44.1)	16 (47.1)
Height (cm), mean (SD)	159.4 (8.7)	160.2 (9.4)
Weight (kg), mean (SD)	57.0 (12.7)	59.0 (10.2)
ASA class, I/II/III, n	9/25/0	11/23/0
Never smoker, n (%)	16 (47.1)	16 (47.1)
FEV1/FVC (%), mean (SD)	75.2 (5.3)	74.4 (6.9)
FVC, % of the predicted, mean (SD)	108.1 (13.0)	112.5 (13.0)
Side of surgery, left/right, n (%)	15 (44.1)/19 (55.9)	22 (64.7)/12 (35.3)

Values presented as the mean (standard deviation) or number (proportion). Abbreviations: ASA, American Society of Anesthesiologists; CPAP, continuous positive airway pressure; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; SD, standard deviation.

Table 2. Operative details.

	60% CPAP-group	100% CPAP-group
Number of patients	34	34
Duration of OLV (min), mean (SD)	162.8 (47.8)	166.6 (63.3)
Duration of surgery (min), mean (SD)	190.7 (47.6)	193.4 (65.1)
Conditions for surgery, 0/1/2/3, n (%)	0 (0)/6 (17.6)/ 23 (67.6)/5 (14.7)	0 (0)/9 (26.5)/ 19 (55.9)/6 (17.6)
Type of surgery, n (%)		
Partial resection	2 (5.9)	3 (8.8)
Segmentectomy or wedge resection	13 (38.2)	7 (20.6)
Lobectomy	19 (55.9)	24 (70.6)

Values presented as the mean (standard deviation) or number (%). Abbreviations: CPAP, continuous positive airway pressure; OLV, one lung ventilation; SD, standard deviation.

CPAP group (97.4 [2.0] %) was higher than that in the 60% CPAP group (96.3 [2.2] %, p = 0.039); however, there was no difference between the two groups regarding changes to the overall SaO_2 values during study period (p = 0.23) (**Figure 3(b)**).

3.4. Comparison of Physiologic Variables

The hemodynamic variables, and the results of PIP, SpO_2 and arterial blood gas

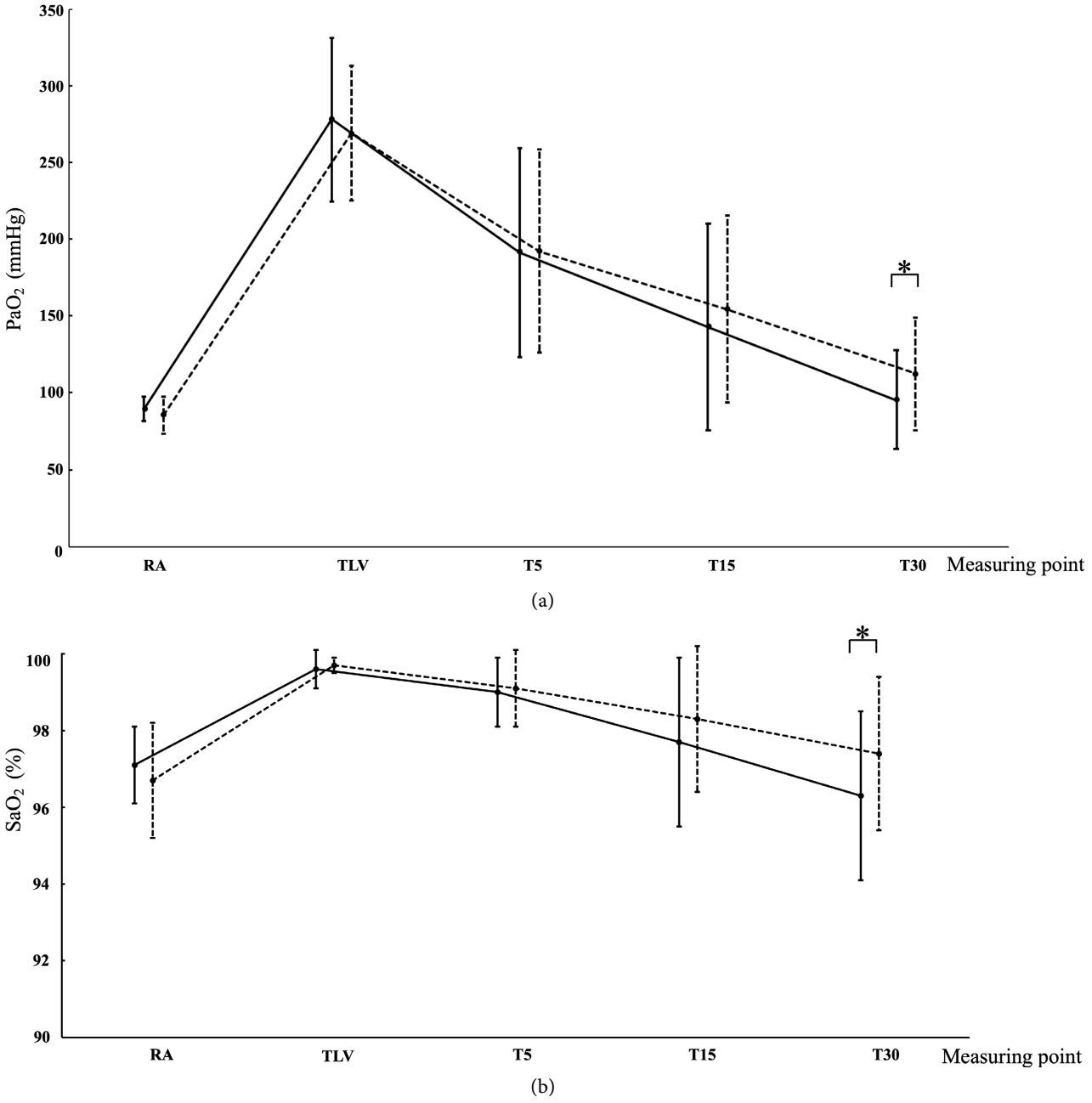

Figure 3. (a). A comparison of PaO_2 between the 60% CPAP and 100% CPAP groups. PaO_2 values were measured at the following time points: 1) RA, spontaneous breathing under room air (RA); 2) TLV, during TLV prior to the initiation of OLV in the lateral position; 3) T5, 5 min after the initiation of OLV; 4)T15, 15 min after the initiation of OLV; and 5) T30, 30 min after the initiation of OLV. In the 100% CPAP group, the PaO_2 value at T30 was significantly higher than that in the 60% CPAP group. No difference was found between the groups regarding changes to the overall PaO_2 values during the study period ($p = 0.44$). The straight line indicates the 60% CPAP group and the dotted line indicates the 100% CPAP group. Values are presented as the mean (standard deviation). *$P < 0.05$. (b) A comparison of SaO_2 between the 60% CPAP and 100% CPAP groups. SaO_2 values were obtained at the following time points: 1) RA, spontaneous breathing under room air (RA); 2) TLV, during TLV prior to the initiation of OLV in the lateral position; 3) T5, 5 min after the initiation of OLV; 4) T15, 15 min after the initiation of OLV; and 5) T30, 30 min after the initiation of OLV. In the 100% CPAP group, the SaO_2 value obtained at T30 was significantly higher than that in the 60% CPAP group. No difference was found between the groups regarding changes to the overall SaO_2 values during the study period ($p = 0.23$). The straight line indicates the 60% CPAP group and the dotted line indicates the 100% CPAP group. Values are presented as the mean (standard deviation). *$P < 0.05$.

analyses (pH, PaO_2, $PaCO_2$, SaO_2) are presented in Table 3. There were no patients with hypoxemia during the study period. $PaCO_2$ values in both groups were maintained at approximately 40 mmHg.

3.5. The Condition of Surgical Field

The surgeons assessed the condition of the surgical field as poor surgical access in 6 patients from the 60% CPAP group and 9 patients from the 100% CPAP group. In these patients, the surgical fields did not interfere to the extent that visibility was disturbed due to the application of CPAP. All surgeries were completed

Table 3. Blood gas analysis and hemodynamic data.

	RA	TLV	T5	T15	T30
pH					
60% CPAP-group	7.44 (0.03)	7.37 (0.03)	7.38 (0.04)	7.39 (0.04)	7.4 (0.04)
100% CPAP-group	7.43 (0.02)	7.36 (0.03)	7.38 (0.03)	7.39 (0.03)	7.4 (0.04)
PaO_2 (mm Hg)					*
60% CPAP-group	89.7 (8.2)	277.9 (52.9)	191.4 (67.9)	143.2 (67.3)	95.6 (32.0)
100% CPAP-group	85.8 (11.9)	269.2 (44.0)	192.3 (66.0)	154.7 (60.8)	112.5 (36.5)
SaO_2 (%)					*
60% CPAP-group	97.1 (1.0)	99.6 (0.5)	99.0 (0.9)	97.7 (2.2)	96.3 (2.2)
100% CPAP-group	96.7 (1.5)	99.7 (0.2)	99.1 (1.0)	98.3 (1.9)	97.4 (2.0)
S_pO_2 (%)					
60% CPAP-group	98.8 (1.3)	100 (0)	99.8 (0.6)	98.9 (1.9)	97.7 (2.2)
100% CPAP-group	98.4 (1.5)	99.9 (0.2)	99.8 (0.6)	99.1 (1.5)	98.4 (1.9)
$PaCO_2$ (mm Hg)					
60% CPAP-group	38.1 (3.2)	45.2 (3.7)	43.6 (3.9)	42.7 (3.9)	41.9 (3.9)
100% CPAP-group	38.7 (2.9)	46.3 (3.7)	44.5 (4.2)	42.9 (4.2)	41.8 (4.2)
PIP (cm H_2O)					
60% CPAP-group		16.8 (1.9)	22.7 (3.9)	22.8 (4.1)	23.2 (3.9)
100% CPAP-group		16.4 (1.6)	23.1 (2.9)	23.0 (3.1)	23.6 (3.3)
Cardiac index (L/min/m^2)					
60% CPAP-group		2.6 (0.5)	2.8 (0.6)	2.8 (0.6)	3.0 (0.6)
100% CPAP-group		2.5 (0.6)	2.6 (0.5)	2.7 (0.7)	2.8 (0.6)
Heart rate (beats/min)					
60% CPAP-group	74.8 (11.4)	65.0 (9.9)	65.9 (9.4)	70.4 (11.1)	74.7 (10.6)
100% CPAP-group	72.7 (12.1)	66.1 (11.0)	65.7 (9.7)	68.2 (9.7)	71.3 (12.3)
Mean arterial pressure (mmHg)					
60% CPAP-group	104.4 (12.9)	73.1 (8.8)	81.1 (9.6)	77.0 (10.1)	73.4 (7.3)
100% CPAP-group	102.2 (13.1)	75.7 (10.3)	80.5 (9.5)	77.4 (10.0)	72.9 (10.3)

Values presented as the mean (standard deviation). *P < 0.05. Abbreviations: CPAP, continuous positive airway pressure; OLV, one lung ventilation; RA, room air; TLV, total lung ventilation; PIP, peak inspiratory pressure.

without interruption. In both groups, CPAP was applied safely. The quality of lung collapse was similar between the groups. None of the patients was graded as 0, where interference is maximal (Table 2).

4. Discussion

In the present study, we compared arterial oxygenation with the application of 60% O_2 CPAP or 100% O_2 CPAP to the non-ventilated lung during 60% O_2 OLV. In our previous study, the lowest PaO_2 value was obtained at 30 min after the initiation of OLV [19]. Therefore, in the present study, we investigated PaO_2 values up to 30 min after the initiation of 60% O_2 OLV. The minimum time required to complete pulmonary artery ligation was 30 min after the initiation of OLV. Among the five PaO_2 values, 30 min after the initiation of OLV was only one time point at which 100% O_2 CPAP was associated with a significantly greater value than 60% O_2 CPAP. However, no difference was found between groups regarding changes to the overall PaO_2 values throughout the study period. Our results suggested that 100% O_2 CPAP would be more applicable for maintaining oxygenation than 60% O_2 CPAP.

SaO_2 obtained from 30 min after the initiation of OLV also showed significantly greater readings for 100% O_2 CPAP than 60% O_2 CPAP. There was no difference between the groups regarding changes to the overall SaO_2 values during the study period. The relationship between PaO_2 and SaO_2 is represented by the oxygen–hemoglobin dissociation curve. PaO_2 is the amount of oxygen dissolved in the blood. SaO_2 is the percentage of hemoglobin bound to oxygen. Our study showed statistically significant differences between the groups in both PaO_2 and SaO_2, however these small differences would reflect no advantage within the clinical situation. In this present study, no patients were presented with hypoxia. The present results indicated that 60% O_2 OLV with 60% O_2 CPAP was at least able to maintain oxygenation without exposure to high F_IO_2, and as such may be applied safely in clinical use.

SpO_2 is a parameter that can be non-invasively measured in routine practice and is substituted for SaO_2 in the clinical setting. In this present study, there was no significant difference in the SpO_2 values of the groups, despite the significant differences in PaO_2 and SaO_2 at the 30 min measurement point. The margin of error of SpO_2 is considered to be within 2% to 3% of the SaO_2 [20] [21] [22]. The small difference in SaO_2 values (1.1%) may have had no effect on the difference in SpO_2 values.

High systemic O_2 delivery is associated with an increased risk of serious adverse effects, including reabsorption atelectasis, decreased capillary perfusion, and cellular oxygen consumption, as well as decreased cardiac output and decreased coronary and cerebral blood flow [23] [24]. Hyperoxia-induced damage due to the production of free radicals is more prominent in the lung, as the lung tissue is continuously exposed to oxygen. There is some evidence suggesting that patients who undergo thoracic surgery may be more susceptible to lung injury from hyperoxia than conventionally thought [25]. Rabbits receiving F_IO_2 0.6

during OLV showed a lower inflammatory response in the lung and less lung injury in comparison to rabbits receiving F_IO_2 1.0 [26]. It is reasonable to attempt to reduce inspired oxygen concentrations in order to protect vulnerable organs in high-risk patients such as those with COPD, idiopathic pneumonia, or bleomycin-treated lungs [7]. No patients in either of our groups developed hyperoxia-induced respiratory or cardiovascular complications. In the absence of clinical complications, our present study could not determine whether high F_IO_2 is truly harmful to the lung function. At least, minimizing F_IO_2 would be a method for avoiding hyperoxia-induced damage in the compromised lung. The lower threshold for SpO_2 is still unknown; however, there is international consensus regarding the achievement of a minimal SpO_2 value of ≥90% with moderate F_IO_2 levels of 0.4 - 0.6 in OLV [27]. Our study showed that the application of 60% O_2 CPAP can assist in minimizing F_IO_2 levels to avoid hypoxemia in patients with a normal lung function. Further studies are required to analyze patients with significantly decreased lung function.

Several management protocols for preventing arterial oxygen desaturation during OLV have been put forward. Repeated inflation of the non-ventilated lung (lung recruitment) is one management for preventing hypoxemia. However, lung recruitment following complete collapse of the lung results in ischemia-reperfusion injury, inducing inflammatory cytokine production in the collapsed lung [2]. Meanwhile, CPAP maintains the patency of non-ventilated alveoli, minimizing the shunt fraction and attenuating the inflammatory cytokine release [2] [28]. A potential limitation of CPAP includes the overexpansion of the non-ventilated lung, which subsequently interferes with surgical access [29] [30]. In the previous study, 6.7% - 30% of patients showed disturbed visibility with CPAP at 5 cm H_2O [28] [30]. In this study, the application of low-level CPAP (2 - 3 cm H_2O) to the non-ventilated lung was shown to be feasible for preventing desaturation during OLV without unnecessary lung distention. The method was simple and applicable in all patients. Thus, low-level CPAP is a preferable respiratory management for avoiding hypoxemia and should be attempted first.

Interaction of the shunt fraction, cardiac output, oxygen expenditure, venous saturation, and hemoglobin levels may affect oxygenation [31]. The shunt fraction during OLV is estimated to be in the order of 20% - 30% of the cardiac output [1] [32]. The cardiac output must be maintained for adequate oxygenation, due to the negative effect of low mixed venous oxygen tensions on oxygen delivery in the setting of a high shunt fractions [32]. Age, pH, carbon dioxide, temperature, CO are the principal non-pharmalogical variables that influence hypoxic pulmonary vasoconstriction [32]. In the present study, there were no significant differences in the above-mentioned factors that affect hypoxic pulmonary vasoconstriction.

5. Limitations

The side of the surgery is an important factor in predicting hypoxemia during

OLV [33]. Patients undergoing left thoracotomy show better PaO_2 values during OLV than those undergoing right thoracotomy, since the left lung normally receives 10% less CO than the right lung [34]. In our study, there were no significant differences related to side of the surgery between the groups. Thus, differences based on the side of surgery likely only had a slight effect on our results.

6. Conclusion

In relatively healthy patients, oxygenation could be safely maintained with 60% O_2 OLV and 60% O_2 CPAP. The application of 60% O_2 CPAP during OLV for patients who are not suited to exposure to high F_IO_2 may be an alternative form of respiratory management.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Karzai, W. and Schwarzkopf, K. (2009) Hypoxemia during One-Lung Ventilation: Prediction, Prevention, and Treatment. *Anesthesiology*, **110**, 1402-1411. https://doi.org/10.1097/ALN.0b013e31819fb15d

[2] Lohser, J. and Slinger, P. (2015) Lung Injury after One-Lung Ventilation: A Review of the Pathophysiologic Mechanisms Affecting the Ventilated and the Collapsed Lung. *Anesthesia & Analgesia*, **121**, 302-318. https://doi.org/10.1213/ANE.0000000000000808

[3] Slinger, P.D., Kruger, M., McRae, K. and Winton, T. (2001) Relation of the Static Compliance Curve and Positive End-Expiratory Pressure to Oxygenation during One-Lung Ventilation. *Anesthesiology*, **95**, 1096-1102. https://doi.org/10.1097/00000542-200111000-00012

[4] Brodsky, J.B. and Lemmens, H.J.M. (2003) Left Double-Lumen Tubes: Clinical Experience with 1,170 Patients. *Journal of Cardiothoracic and Vascular Anesthesia*, **17**, 289-298. https://doi.org/10.1016/S1053-0770(03)00046-6

[5] Hurford, W.E. and Alfille, P.H. (1993) A Quality Improvement Study of the Placement and Complications of Double-Lumen Endobronchial Tubes. *Journal of Cardiothoracic and Vascular Anesthesia*, **7**, 517-520. https://doi.org/10.1016/1053-0770(93)90305-5

[6] Fujiwara, M., Abe, K. and Mashimo, T. (2001) The Effect of Positive End-Expiratory Pressure and Continuous Positive Airway Pressure on the Oxygenation and Shunt Fraction during One-Lung Ventilation with Propofol Anesthesia. *Journal of Clinical Anesthesia*, **13**, 473-477. https://doi.org/10.1016/S0952-8180(01)00310-5

[7] Campos, J.H. and Feider, A. (2018) Hypoxia during One-Lung Ventilation—A Review and Update. *Journal of Cardiothoracic and Vascular Anesthesia*, **32**, 2330-2338. https://doi.org/10.1053/j.jvca.2017.12.026

[8] Bickler, P.E., Feiner, J.R., Lipnick, M.S., Batchelder, P., MacLeod, D.B. and Severinghaus, J.W. (2017) Effects of Acute, Profound Hypoxia on Healthy Humans: Implications for Safety of Tests Evaluating Pulse Oximetry or Tissue Oximetry Performance. *Anesthesia & Analgesia*, **124**, 146-153. https://doi.org/10.1213/ANE.0000000000001421

[9] Asfar, P., Singer, M. and Radermacher, P. (2015) Understanding the Benefits and Harms of Oxygen Therapy. *Intensive Care Medicine*, **41**, 1118-1121. https://doi.org/10.1007/s00134-015-3670-z

[10] Sjoberg, F. and Singer, M. (2013) The Medical Use of Oxygen: A Time for Critical Reappraisal. *Journal of Internal Medicine*, **274**, 505-528. https://doi.org/10.1111/joim.12139

[11] Spoelstra-de Man, A.M., Smit, B., Oudemans-Van Straaten, H.M. and Smulders, Y.M. (2015) Cardiovascular Effects of Hyperoxia during and after Cardiac Surgery. *Anaesthesia*, **70**, 1307-1319. https://doi.org/10.1111/anae.13218

[12] Meyhoff, C.S., Staehr, A.K. and Rasmussen, L.S. (2012) Rational Use of Oxygen in Medical Disease and Anesthesia. *Current Opinion in Anesthesiology*, **25**, 363-370. https://doi.org/10.1097/ACO.0b013e328352b402

[13] Repine, J.E., Bast, A. and Lankhorst, I. (1997) Oxidative Stress in Chronic Obstructive. Pulmonary Disease. Oxidative Stress Study Group. *American Journal of Respiratory and Critical Care Medicine*, **156**, 341-357. https://doi.org/10.1164/ajrccm.156.2.9611013

[14] Kinnula, V.L., Fattman, C.L., Tan, R.J. and Oury, T.D. (2005) Oxidative Stress in Pulmonary Fibrosis: A Possible Role for Redox Modulatory Therapy. *American Journal of Respiratory and Critical Care Medicine*, **172**, 417-422. https://doi.org/10.1164/rccm.200501-017PP

[15] Hughes, S.A. and Benumof, J.L. (1990) Operative Lung Continuous Positive Airway. Pressure to Minimize FIO_2 during One-Lung Ventilation. *Anesthesia & Analgesia*, **71**, 92-95. https://doi.org/10.1213/00000539-199007000-00017

[16] Misthos, P., Katsaragakis, S., Milingos, N., Kakaris, S., Sepsas, E., Athanassiadi, K., Theodorou, D. and Skottis, I. (2005) Postresectional Pulmonary Oxidative Stress in Lung Cancer Patients. The Role of One-Lung Ventilation. *European Journal of Cardio-Thoracic Surgery*, **27**, 379-382. https://doi.org/10.1016/j.ejcts.2004.12.023

[17] Hannallah, M., Benumof, J.L., Silverman, P.M., Kelly, L.C. and Lea, D. (1997) Evaluation of an Approach to Choosing a Left Double-Lumen Tube Size Based on Chest Computed Tomographic Scan Measurement of Left Mainstem Bronchial Diameter. *Journal of Cardiothoracic and Vascular Anesthesia*, **11**, 168-171. https://doi.org/10.1016/S1053-0770(97)90208-1

[18] Cohen, E. and Eisenkraft, J.B. (1996) Positive End-Expiratory Pressure during one-lung Ventilation Improves Oxygenation in Patients with Low Arterial Oxygen Tensions. *Journal of Cardiothoracic and Vascular Anesthesia*, **10**, 578-582. https://doi.org/10.1016/S1053-0770(96)80131-5

[19] Fukuoka, N., Iida, H., Akamatsu, S., Nagase, K., Iwata, H. and Dohi, S. (2009) The Association between the Initial End-Tidal Carbon Dioxide Difference and the Lowest Arterial Oxygen Tension Value Obtained during One-Lung Anesthesia with Propofol or Sevoflurane. *Journal of Cardiothoracic and Vascular Anesthesia*, **23**, 775-779. https://doi.org/10.1053/j.jvca.2009.03.023

[20] Louw, A., Cracco, C., Cerf, C., Harf, A., Duvaldestin, P., Lemaire, F. and Brochard, L. (2001) Accuracy of Pulse Oximetry in the Intensive Care Unit. *Intensive Care Medicine*, **27**, 1606-1613. https://doi.org/10.1007/s001340101064

[21] Wouters, P.F., Gehring, H., Meyfroidt, G., Ponz, L., Gil-Rodriguez, J., Hornberger, C., Bonk, R., Frankenberger, H., Benekos, K., Valais, J., Avgerinos, J. and Konecny, E. (2002) Accuracy of Pulse Oximeters: The European Multi-Center Trial. *Anesthesia & Analgesia*, **94**, S13-S16.

[22] Webb, R.K., Ralston, A.C. and Runciman, W.B. (1991) Potential Errors in Pulse Oxi-

metry II. Effects of Changes in Saturation and Signal Quality. *Anaesthesia*, **46**, 207-212. https://doi.org/10.1111/j.1365-2044.1991.tb09411.x

[23] Damiani, E., Donati, A. and Girardis, M. (2018) Oxygen in the Critically Ill: Friend or Foe? *Current Opinion in Anesthesiology*, **31**, 129-135. https://doi.org/10.1097/ACO.0000000000000559

[24] Farquhar, H., Weatherall, M., Wijesinghe, M., Perrin, K., Ranchord, A., Simmonds, M. and Beasley, R. (2009) Systematic Review of Studies of the Effect of Hyperoxia on Coronary Blood Flow. *American Heart Journal*, **158**, 371-377. https://doi.org/10.1016/j.ahj.2009.05.037

[25] Grichnik, K.P. and D'Amico, T.A. (2004) Acute Lung Injury and Acute Respiratory Distress. Syndrome after Pulmonary Resection. *Seminars in Cardiothoracic and Vascular Anesthesia*, **8**, 317-334. https://doi.org/10.1177/108925320400800405

[26] Xu, Z., Gu, L., Bian, Q., Li, P., Wang, L., Zhang, J. and Qian, Y. (2016) Oxygenation, Inflammatory Response and Lung Injury during One Lung Ventilation in Rabbits Using Inspired Oxygen Fraction of 0.6 vs. 1.0. *Journal of Biomedical Research*, **31**, 56-64.

[27] Pannu, S.R. (2016) Too Much Oxygen: Hyperoxia and Oxygen Management in. Mechanically Ventilated Patients. *Seminars in Respiratory and Critical Care Medicine*, **37**, 16-22. https://doi.org/10.1055/s-0035-1570359

[28] Verhage, R.J.J., Boone, J., Rijkers, G.T., Cromheecke, G.J., Kroese, A.C., Weijs, T.J., Borel Rinkes, I.H.M. and van Hillegersberg, R. (2014) Reduced Local Immune Response with Continuous Positive Airway Pressure during One-Lung Ventilation for Oesophagectomy. *British Journal of Anaesthesia*, **112**, 920-928. https://doi.org/10.1093/bja/aet476

[29] Houge Jr., C.W. (1994) Effectiveness of Low Levels of Nonventilated Lung Continuous. Positive Airway Pressure in Improving Arterial Oxygenation during One-Lung Ventilation. *Anesthesia & Analgesia*, **79**, 364-367. https://doi.org/10.1213/00000539-199408000-00029

[30] Badner, N.H., Goure, C., Bennett, K.E. and Nicolaou, G. (2011) Role of Continuous Positive. Airway Pressure to the Non-Ventilated Lung during One-Lung Ventilation with Low Tidal Volumes. *HSR Proceedings in Intensive Care & Cardiovascular Anesthesia*, **3**, 189-194.

[31] Levin, A.I., Coetzee, J.F. and Coetzee, A. (2008) Arterial Oxygenation and One-Lung. Anesthesia. *Current Opinion in Anesthesiology*, **21**, 28-36. https://doi.org/10.1097/ACO.0b013e3282f2bb79

[32] Lumb, A.B. and Slinger, P. (2015) Hypoxic Pulmonary Vasoconstriction: Physiology and Anesthetic Implications. *Anesthesiology*, **122**, 932-946. https://doi.org/10.1097/ALN.0000000000000569

[33] Slinger, P., Suissa, S. and Triolet, W. (1992) Predicting Arterial Oxygenation during One-Lung Anaesthesia. *Canadian Journal of Anesthesia*, **39**, 1030-1035. https://doi.org/10.1007/BF03008370

[34] Slinger, P., Suissa, S., Adam, J. and Triolet, W. (1990) Predicting Arterial Oxygenation during One-Lung Ventilation with Continuous Positive Airway Pressure to the Nonventilated Lung. *Journal of Cardiothoracic and Vascular Anesthesia*, **4**, 436-440. https://doi.org/10.1016/0888-6296(90)90288-Q