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Original Article ANESTHESIOLOGY & REANIMATION

Oxygen titration with Oxygen Reserve Index in minimally invasive repair of pectus excavatum, a randomized controlled trial

Agshin Mirzayev,[1] Gul Cakmak,[1] Ruslan Abdullayev,[1] Tunc Lacin,[2] Zuhal Aykac,[1] Ayten Saracoglu[1]

[1]Department of Anesthesiology and Intensive Care, Marmara University Faculty of Medicine, Istanbul, Turkiye

[2]Department of Thoracic Surgery, Marmara University Faculty of Medicine, Istanbul, Turkiye

ABSTRACT

OBJECTIVE: Perioperative hypoxemia is common during minimally invasive repair of pectus excavatum (MIRPE). Oxygen Reserve Index (ORI™) is a noninvasive method that shows blood oxygenation status. In addition, this method provides information about hypoxemia earlier than pulse oximetry. The primary aim of this study was to examine the value of ORI monitoring as an early predictor of hypoxemia during surgery. The secondary aim was to evaluate the value of ORI monitoring as a guide for oxygen titration to prevent hyperoxemia.

METHODS: This randomized controlled study enrolled 128 pediatric patients aged 8-18 years scheduled for elective MIRPE surgery. Patients were followed up with continuous peripheral oxygen saturation (SpO_2) measurement in the control group (Group C) and continuous ORI monitoring in the study group (Group O). After pneumothorax, a decrease of 1% in basal SpO_2 and 0.05 from basal ORI was considered clinically significant. Patient demographics, pre-induction, pre-first and second pneumothorax, and postoperative ORI, mean arterial pressure, temperature, perfusion index, end-tidal carbon dioxide values, length of hospital stay, anesthesia, and surgery durations were recorded.

RESULTS: Desaturation time was 59.46±15.57 seconds in Group O based on ORI, and 177.64±20.94 seconds in Group C according to SpO_2, and the difference was significant ($p<0.001$). Use of $FiO_2>0.6$ was lower in Group O, compared with Group C ($p<0.05$). Length of hospital stay was lower in Group O ($p=0.002$).

CONCLUSION: ORI may detect hypoxemia earlier than SpO_2 monitoring during MIRPE surgery. ORI monitorization decreases exposure time to high oxygen concentrations and may increase patient safety during MIRPE surgery in pediatric patients.

Keywords: Anesthesia; funnel chest; hyperoxia; hypoxia; pediatric.

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Pectus excavatum is the most common congenital thoracic wall deformity in children [1]. The incidence varies between 0.1 and 0.8 per one hundred individuals. Restrictive changes are observed in respiratory function tests of the patients [2]. A mild to moderate decrease may be detected in the forced expiratory volume in the first second and the forced vital capacity [3]. The most effective method of treatment is surgery [4]. Minimally invasive repair of pectus excavatum (MIRPE), also known as the Nuss procedure, is a technique that is commonly used for pectus excavatum surgery. The most significant problem that may be encountered during the surgical

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Correspondence: Ruslan ABDULLAYEV, MD. Marmara Universitesi Tip Fakultesi, Anesteziyoloji ve Yogun Bakim Klinigi, Istanbul, Turkiye.
Tel: +90 216 625 45 45 e-mail: ruslan_jnr@hotmail.com

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procedure, in which iatrogenic pneumothorax is created is the development of desaturation in this patient group whose lung capacity is already limited, and the risk of deepening of hypoxemia sometimes in cases where a second pneumothorax is required [5]. However, although this condition does not occur in every patient, the patient's oxygenation status is unknown since the values obtained by peripheral oxygen saturation measurement may have delayed representation of the patient's clinical condition. Therefore, clinicians try to prevent desaturation by increasing the FiO_2 inhaled by the patient before iatrogenic pneumothorax to prevent hypoxemia. However, this may be an unnecessary measure and can result in hyperoxemia. Monitoring the patient's oxygenation status is particularly important in this context. Furthermore, pulse oximetry may detect hypoxia and normoxia, but not hyperoxia.

Oxygen Reserve Index (ORI™) (Masimo Corp., Irvine, CA, USA), operated with multi-wave co-oximeter principle, is a non-invasive method indicating the oxygenation status of the blood [6]. The ORI may ensure continuous monitoring of pulmonary gas exchanges. The key advantages of the technique include continuous measuring and non-invasive design. ORI presents values between 0 and 1 without any unit and may warn the clinicians about the patients' oxygen status changes through optionally adjustable alarms. It additionally provides information about hypoxemia earlier than a pulse oximeter when the PaO_2 is below 100 mm Hg [7]. Moreover, it may guide the clinician by providing information about hyperoxia when SpO_2 is above 98% [8]. The primary aim of this study was to determine the duration of high or low oxygen concentration during MIRPE procedure. The secondary aim was to assess the length of hospital stay after MIRPE procedure in ORI and control groups. We hypothesized that ORI would detect hypoxemia earlier than SpO_2, and ORI monitoring would help shorten the duration of hyperoxemia.

MATERIALS AND METHODS

The Marmara University Faculty of Medicine Clinical Research Ethics Committee granted approval for this study (date: 02.02.2018, number: 09.2018.138) and parental consent was obtained for this randomized controlled study. A total of 128 patients aged 8–18 years undergoing elective MIRPE surgery between 01.03.2018 and 01.03.2019 were recruited. The patients were randomized into two groups by the sealed envelope method.

Highlight key points

- Oxygen Reserve Index (ORI™) detects perioperative hypoxemia earlier than standard peripheral oxygen saturation monitoring.
- Use of Oxygen Reserve Index monitorization shortens perioperative exposure time to hyperoxemia.
- Perioperative Oxygen Reserve Index monitorization can decrease hospital length of stay of the patients.

In the control group (Group C), patients were followed up with continuous SpO_2 measurement as standard. In the study group (Group O), continuous ORI monitoring, perfusion index (PI), and SpO_2 measurements were applied. Parents who refused to participate or were unable to fully understand the research protocol; patients who did not receive consent from their first-degree relatives or legal guardians; those who developed intraoperative complications; those who were reoperated, those with American Society of Anesthesiologists (ASA) III-V physical status, and those with known serious respiratory and/or cardiac comorbidities were excluded from the study. The trial was registered at the Australian New Zealand Clinical Trials Registry (https://www.anzctr.org.au: ACTRN12619001581156). The study was conducted in accordance with the Declaration of Helsinki.

After the patients were admitted to the operating room, they were placed in a supine head-up position of 30 degrees on the operating table and electrocardiography, SpO_2, PI, noninvasive blood pressure and temperature monitoring were performed routinely. In addition to standard monitoring, basal ORI values were recorded in Group O with the Masimo Rainbow R1 25-L probe (Rainbow® sensor, R2-25, Revision L, Masimo Corp., Irvine, CA, USA). The ORI probe was attached to the 4th finger of the left hand in all the patients for standardization purposes. ORI values were monitored with Root® with Radical-7® (Masimo Corp., Irvine, CA, USA) device.

General anesthesia induction was done by propofol 2–3 mg/kg, remifentanil 0.5–1 μg/kg and rocuronium bromide 0.6 mg/kg, and maintenance of anesthesia was provided by desflurane 6% in oxygen-air mixture and remifentanil infusion at a rate of 0.1–0.25 μg/kg/min. The patients' demographic and anthropometric variables; comorbidities; operation and anesthesia durations; the amount of intravenous fluid administered intraoperatively, and use of vasopressors; pre-induction, pre-first and second pneumothorax, and postoperative ORI val-

ues, mean arterial pressure (MAP), temperature, PI, end-tidal carbon dioxide levels were recorded. Additionally, postoperative complications and lengths of hospital stays were noted. In case of hypotension, ephedrine 5 mg intravenous (IV) bolus was used as a vasopressor in repeated doses. Hypotension was defined as a MAP value <60 mmHg or a decrease in MAP >20% compared with the baseline preoperative measurement [9].

During minimally invasive repair of pectus excavatum, in order to correct the deformity of the chest wall, a nickel-chrome mixture steel bar is placed under the skin and muscles of the patient by the guidance of a thoracoscopy [10]. A manufactured titanium bar is placed in patients with allergies. The protruding chest front wall is pressed back to the chest front wall for the normal position to fix the bar. First and second pneumothoraces were formed in patients. A tunnel introducer was first entered into the right chest cavity. Then this introducer was removed from the left chest cavity so that an area for the bar could be created. These processes are called first and second pneumothorax.

Patients received ondansetron 4 mg IV (3 mg for patients <40 kg) for postoperative nausea-vomiting prophylaxis. Paracetamol 1 g IV (15 mg/kg for <40 kg patients), morphine 0.1 mg/kg IV, and bilateral serratus anterior block were performed for postoperative analgesia. For the serratus anterior area block, 20 mL (15 mL for <40 kg patients) of a local anesthetic mixture of lidocaine 0.5% and bupivacaine 0.25% was applied to each side. In addition, an IV morphine patient-controlled analgesia device was also provided to the patients. For the patient-controlled analgesia protocol, the demand dose was 1 mL (0.5 mL for <40 kg patients) of morphine 1 mg/mL solution without basal infusion, and the lockout time was set to 10 minutes. At the end of the operation, remifentanil infusion was terminated, inhalation anesthetic was turned off, neostigmine 30 μg/kg IV combination with atropine 15 μg/kg IV or sugammadex 2 mg/kg IV was administered to reverse neuromuscular blockade, and patients with full muscle strength were extubated. Chest radiographs of all the patients were examined on the first postoperative day.

Volume-controlled ventilation mode with a tidal volume: 6–8 mL/kg, maximum peak airway pressure (P_{max}): 30 cm H_2O, FiO_2: 0.4, positive end-expiratory pressure: 5 cm H_2O and respiratory rate: 12–14/min was set. The time elapsed until the first pneumothorax was recorded. After induction, FiO_2 was adjusted to 0.4 and titrated between 0.6–1.0 with the onset of pneumothorax according to the decrease in ORI in Group O and SpO_2 in Group C. A decrease of 0.05 from the highest ORI value was accepted as the beginning of the ORI decrease as a reference from the study of Koishi et al. [11]. A 1% decrease from the SpO_2 value was accepted as the beginning of the SpO_2 decrease, and application times of $FiO_2 \leq 0.6$ were recorded. For oxygen titration, the lower limit of SpO_2 in Group C was accepted as 96% based on the study of Röttgering et al. [12]. The lower limit of ORI in Group O was accepted as 0.24 based on the study of Applegate et al. [13]. FiO_2 was titrated in order with SpO_2 monitoring in Group C and according to ORI monitoring in Group O. FiO_2 application times of 0.4, 0.6, 0.8 and 1.0 were recorded. FiO_2 was also titrated by increasing or decreasing by 20% , and the duration of FiO_2 values ≤ 0.6 and $FiO_2 > 0.6$ was recorded until the end of the operation. FiO_2 was not reduced below 0.4.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 21.0 (Statistical Package for the Social Sciences, Armonk, NY, USA). The distribution of variables was analyzed using the Kolmogorov–Smirnov test. Comparisons between the groups for categorical variables were performed using Pearson's Chi-square test and Fisher's Exact Test. The conformity of continuous numerical variables to normal distribution was checked with the Shapiro-Wilk test. Independent samples t-test (student t-test) was used to compare numerical variables with normal distribution, and Mann Whitney U test for those that did not fit the normal distribution. Repeated measurements were analyzed with the Wilcoxon test. Spearman's correlation analysis was used to examine the correlation between the variables. A value of $p<0.05$ was considered statistically significant. It was calculated that 60 cases should be included in each group, provided that the margin of error is 5%, the power of the study is 90%, and the standard effect size is 0.60 to detect a 20% decrease in the FiO_2 value administered to the patients intraoperatively. Considering the possible losses, we included 128 patients in the study.

RESULTS

One hundred and twenty-eight patients were enrolled in the study; however, data of 61 patients in Group O and 64 patients in Group C were analyzed. Three patients in

Table 1. Demographics, and perioperative variables of the patients

Variables	Group O (n=61)		Group C (n=64)		p
	Mean±SD	Median	Mean±SD	Median	
Age (years)	16.66±1.75	17	16.44±2.29	17	0.942
Height (cm)	172.06±12.46	175	168.5±11.97	171	0.032
Body weight (kg)	57.92±8.77	58	56.80±12.69	58.5	0.705
BMI (kg/m^2)	19.61±3.03	19.02	19.82±3.23	19.6	0.445
Hbpreop (g/dL)	14.52±1.74	14.6	14.51±1.50	15	1.000
Hospital stay (days)	4.0±0.86	4	4.66±1.42	4	**0.002***
Duration of anesthesia (min)	74.21±14.44	72	76.78±11.87	80	0.102
Duration of surgery (min)	58.85±12.60	60	61.25±11.09	60	0.123
Intraoperative fluid use (mL)	756.56±179.46	800	759.38±172.26	775	0.062

Mann Whitney U test was used in the analyses. *: P<0.05; BMI: Body mass index; Hbpreop: Preoperative hemoglobin value; Group O: Study group; Group C: Control group; SD: Standard deviation.

Table 2. Distribution of vital signs, ORI, and PI values before anesthesia induction

Variables before anesthesia induction	Group O (n=61)		Group C (n=64)		p
	Mean±SD	Median	Mean±SD	Median	
MAP (mm Hg)	87.15±8.68	86.5	87.03±8.81	87	0.941^t
Heart rate (beats/min)	88.95±13.42	88	87.48±10.44	87	0.495^t
SpO_2 (%)	98.57±0.56	99	98.47±0.62	98.5	0.350
$EtCO_2$ (mm Hg)	0±0	0	0±0	0	1.000
Body temperature (°C)	36.54±0.20	36.6	36.59±0.12	36.6	0.270
ORI	0.001±0.02	0	–	–	
PI	4.24±1.50	4.4	4.22±1.29	4.26	0.916

t: Independent samples t test (student t test) was used. Mann Whitney U test was used in other analyses. MAP: Mean arterial pressure; SpO_2: Peripheral oxygen saturation; $EtCO_2$: End-tidal carbon dioxide; ORI: Oxygen Reserve Index; PI: Perfusion Index; Group O: Study group; Group C: Control group; SD: Standard deviation.

Group O were excluded due to intraoperative lung and diaphragm injuries. Ninety-six (76.8%) patients were male; the mean age of the patients was 16.3±1.85 years. The physical status of 97.6% of the patients was ASA I, and the remaining were ASA II. There was no significant difference between the two groups regarding demographic data, Table 1. Hospitalization duration was significantly lower in Group O than in Group C (p=0.002). Vital signs, ORI, and PI values of the patients before induction are presented in Table 2. The groups had no significant difference regarding MAP, heart rate, SpO_2, $EtCO_2$, body temperature, ORI and PI values recorded before induction (p>0.05).

Vital signs, ORI, PI values and other parameters of the patients before the first pneumothorax are given in Table 3. There was no statistically significant difference between the groups for FiO_2>0.6 and ≤0.6 duration, heart rate, SpO_2, $EtCO_2$, amount of bleeding, vasopressor requirement, inhalation agent level, and PI values before the first pneumothorax. MAP and body temperature values before the first pneumothorax were significantly lower in Group O than in Group C (p=0.008, p<0.001, respectively).

Decrease time in SpO_2 was comparable between the groups (175.8±29.2 and 177.6±20.9 seconds for Group O and Group C, respectively; p=0.691). Decrease time

Table 3. Distribution of vital signs, ORI, PI, and other parameters of the patients before first pneumothorax

Variables before first pneumothorax	Group O (n=61)		Group C (n=64)		p
	Mean±SD	Median	Mean±SD	Median	
FiO_2 ≤0.6 duration (min)	19.21±3.82	19	20.16±4.18	20	0.392
FiO_2 >0.6 duration (min)	0±0	0	0±0	0	1.0
MAP (mm Hg)	71.1±11.58	72	76.22±9.60	76	**0.008**[t]*
Heart rate (beats/min)	81.21±14.01	79	80.02±11.32	80.5	0.841
SpO^2 (%)	98.70±0.72	99	98.78±0.42	99	0.983
$EtCO_2$ (mm Hg)	34.92±2.66	35	34.48±1.77	35	0.452
Body temperature (°C)	36.36±0.27	36.4	36.54±0.15	36.6	<**0.001***
Amount of bleeding (mL)	6.39±2.76	5	6.97±2.45	5	0.076
Vasopressor requirement (mg)	1.72±2.40	0	2.11±2.49	0	0.374
Inhalation agent level (%)	5.79±0.76	5.98	6.02±0.42	6	0.126
ORI	0.60±0.26	0.56	–	–	
PI	4.35±1.25	4.3	4.42±1.20	4.38	0.750[t]

t: Independent samples t test (student t test) was used. Mann Whitney U test was used in other analyses. *: P<0.05; FiO_2≤0.6 duration, time spent in fractional inspired oxygen of 0.6 or less; FiO_2>0.6 duration, time spent in fractional inspired oxygen above 0.6; MAP: Mean arterial pressure; SpO_2: Peripheral oxygen saturation; $EtCO_2$: End-tidal carbon dioxide; ORI: Oxygen Reserve Index; PI: Perfusion Index; Group O: Study group; Group C: Control group; SD: Standard deviation.

Table 4. Distribution of vital signs, ORI, PI, and other parameters of the patients before second pneumothorax

Variables before second pneumothorax	Group O (n=61)		Group C (n=64)		p
	Mean±SD	Median	Mean±SD	Median	
FiO_2 ≤0.6 duration (min)	24.10±3.97	24	24.78±4.31	24	0.549
FiO_2 >0.6 duration (min)	1.23±1.47	1	1.66±1.25	1	**0.017***
MAP (mm Hg)	70.33±9.57	71	70.53±6.98	69.5	0.921
Heart rate (beats/min)	81.87±14.51	83	80.06±12.45	82.5	0.456[t]
SpO_2 (%)	98.66±0.81	99	97.91±1.00	98	<**0.001***
$EtCO_2$ (mm Hg)	38.54±2.34	39	38.91±1.52	39	0.227
Body temperature (°C)	36.14±1.293	36.2	36.25±0.13	36.3	**0.009***
Amount of bleeding (mL)	8.93±4.09	10	8.13±2.60	10	0.481
Vasopressor requirement (mg)	1.97±2.93	0	2.19±2.65	0	0.480
Inhalation agent level (%)	5.85±0.39	5.9	5.99±0.44	6	0.074
ORI	0.62±3.57	0.16	–	–	
PI	4.56±1.47	4.6	5.20±1.85	4.9	0.065

t: Independent samples t test (student t test) was used. Mann Whitney U test was used in other analyses. *: P<0.05; FiO_2≤0.6 duration, time spent in fractional inspired oxygen of 0.6 or less; FiO_2>0.6 duration, time spent in fractional inspired oxygen above 0.6; MAP: Mean arterial pressure; SpO_2: Peripheral oxygen saturation; $EtCO_2$: End-tidal carbon dioxide; ORI: Oxygen Reserve Index; PI: Perfusion Index; Group O: Study group; Group C: Control group; SD: Standard deviation.

in ORI was 59.5±15.6 seconds in Group O, which was significantly lower, compared to the SpO_2 decrease time in the same group (p<0.001).

The body temperature was significantly lower and SpO_2 values were significantly higher in Group O than in Group C before the second pneumothorax (p=0.009

Table 5. Distribution of vital signs, ORI, PI, and other parameters after surgery

Variables after surgery	Group O (n=61)		Group C (n=64)		p
	Mean±SD	Median	Mean±SD	Median	
FiO_2 ≤0.6 duration (min)	71.31±14.40	72	65.11±11.72	66	**0.009**[t*]
FiO_2 >0.6 duration (min)	2.59±2.00	2	11.48±5.47	10	<**0.001***
MAP (mm Hg)	71.72±9.55	71	75.33±9.73	75	**0.039**[t*]
Heart rate (beats/min)	82.82±12.54	83	82.72±10.59	83	0.961[t]
SpO_2 (%)	98.90±0.30	99	98.84±0.37	99	0.335
$EtCO_2$ (mm Hg)	35.10±2.07	35	34.70±2.46	34.5	0.283
Body temperature (°C)	36.02±0.30	36	36.05±0.23	36.1	0.230
Amount of bleeding (mL)	26.39±15.87	20	28.36±14.39	25	0.229
Vasopressor requirement (mg)	2.54±3.94	0	1.48±2.30	0	0.251
Inhalation agent level (%)	5.86±0.45	5.9	5.96±0.45	5.9	0.225[t]
ORI	0.61±0.29	0.59	–	–	
PI	2.44±0.90	2.4	2.64±0.68	2.52	0.153[t]

t: Independent samples t test (student t test) was used. Mann Whitney U test was used in other analyses. *: P<0.05; FiO_2≤0.6 duration, time spent in fractional inspired oxygen of 0.6 or less; FiO_2>0.6 duration, time spent in fractional inspired oxygen above 0.6; MAP: Mean arterial pressure; SpO_2: Peripheral oxygen saturation; $EtCO_2$: End-tidal carbon dioxide; ORI: Oxygen Reserve Index; PI: Perfusion Index; Group O: Study group; Group C: Control group; SD: Standard deviation.

and p<0.001, respectively), Table 4. FiO_2>0.6 usage duration was also significantly lower in Group O than in Group C before the second pneumothorax (p=0.017).

Measured at the end of the surgery, FiO_2>0.6 duration and MAP values were significantly lower in Group O compared with Group C (p<0.001, p<0.039, respectively), Table 5.

Postoperative FiO_2>0.6 duration was significantly lower in Group O, compared with Group C [2 (0–8) and 10 (4–31) minutes, respectively; p<0.001)].

The distribution of FiO_2>0.6 before the second pneumothorax was significantly lower in Group O compared with Group C (55.7 and 84.4%, respectively; p=0.006), Table 6.

There was a significant and small negative correlation between ORI and body temperature values before the first and second pneumothoraxes (r=-0.298, p=0.001 and r=-0.325, p<0.001 before the first and second pneumothoraxes, respectively).

DISCUSSION

In the present study, the effectiveness of ORI monitoring was investigated to detect early hypoxemia caused by iatrogenic pneumothorax that occurs during MIRPE surgery, and to reveal hyperoxemia that may develop with high inspiratory oxygen fraction inhaled to the patient for the treatment of this condition. It was detected that ORI monitoring is superior to the conventional method of peripheral oxygen saturation measurement as it warns the clinician earlier than the decrease in SpO_2, shortens the exposure time to high FiO_2 levels during pneumothorax, resulting in a lower FiO_2 requirement in the intraoperative period and a shorter hospitalization duration.

Since intraoperative hypoxia and hypoxemia may cause serious complications, the primary goal in hemodynamic management is to keep oxygen delivery at a level sufficient to meet all metabolic needs. Ehrenfeld et al. [14] showed in their study that 6.8% of the patients had a hypoxemic event intraoperatively (defined as SpO_2<90%), and 3.5% developed a severe hypoxemic event lasting longer than 2 minutes (SpO_2<85%). Early detection of upcoming hypoxia may provide additional time for the clinician to implement the treatment required before the onset of SpO_2 decrease. Alday et al. [8] found that ORI values equal to 0 five minutes after intubation could predict the development of hypoxemia during single lung ventilation in cases of thoracic surgery performed with one lung ventilation (OLV). It was revealed that ORI may provide an earlier warning before appearance of any change in SpO_2 when oxygenation was disrupted. Szmuk et al. [15] showed that

Table 6. Distribution of the FiO_2 values above 0.6 before second pneumothorax and ORI values above 0.55 evaluated at various times

Variables	Group O (n=61)		Group C (n=64)		p
	n	%	n	%	
FiO_2 value before the second pneumothorax					
≤0.6	27	44.3	10	15.6	**0.006***
>0.6	34	55.7	54	84.4	
ORI value					
Before the first pneumothorax					
≤0.55	30	49.18	–	–	
>0.55	31	50.82	–	–	
Before the second pneumothorax					
≤0.55	60	98.3	–	–	
>0.55	1	1.7	–	–	
End of the surgery					
≤0.55	32	52.5	–	–	
>0.55	29	47.5	–	–	

FiO_2: Fractional inspired oxygen concentration; ORI: Oxygen Reserve Index; Group O: Study group; Group C: Control group; *: P<0.05.

ORI detects the upcoming desaturation 31.5 seconds before the decrease in SpO_2 occurs during anesthesia induction. Similarly, Koishi et al. [11] demonstrated that ORI value decreased significantly earlier than SpO_2 in patients who underwent pressure-controlled OLV with FiO_2 0.6 (171±102 vs 372±231 sec, respectively, p<0.01). Vos et al. [16] in their study conducted on volunteers, made the subjects breathe O_2 with a tightly fitting mask at FiO_2 ranging from 0.14 to 1.0 gradually increasing, and the ORI value reached zero about 30 seconds before SpO_2 began to decrease. In our study, hypoxia was detected much earlier with ORI monitoring, similar to the studies in the literature. The development of hypoxia was found to be approximately 60 seconds in the ORI group and approximately 177 seconds in the study group.

Avoiding hyperoxia in the follow-up of patients receiving oxygen therapy and maintaining normoxic levels with oxygen titration gained more importance with the demonstration of a meaningful relationship between increased mortality and hyperoxia [17].

In addition to the known cardiovascular system effects, in a study examining the toxic effects of high-fraction O_2 therapy on the lungs, though little, there was evidence that albumin and transferrin were detected in the alveolar lavage fluid within 24 hours, and pulmonary edema and inflammatory cell accumulations occurred at the 48th hour of exposure to hyperoxia [18]. Furthermore, it is known that all these microscopic changes facilitate the formation of atelectasis in patients with high FiO_2 administration, which is an important cause that paves the way for postoperative pulmonary complications [19]. Ihnken et al. [20] compared the lung function tests of two patient groups in whom hyperoxia (PaO_2 400 mmHg) and normoxia (PaO_2 140 mmHg) were maintained during cardiopulmonary bypass. This study found preoperative and postoperative 5th-day vital capacities and FEV1 of the patients lower in the hyperoxic group. Furthermore, in our study control chest X-rays on the second postoperative day revealed that postoperative atelectasis developed in four patients in the control group and one in the study group. This difference might have been insignificant because there were patients whose diagnosis was missed since thoracic computed tomography, the gold standard method for detecting atelectasis, was not used.

The development of atelectasis secondary to hyperoxemia has been demonstrated by many studies. One of these studies found that when a FiO_2 of 1.0 was used, atelectasis occured within 5 min. On the other hand, when 0.4 FiO_2 was used, atelectasis did not occur for at least 40 min. With 100% oxygen, the shunt increased

from 0.3% to 6.5%, with atelectasis formation corresponding to an area of 8.0 cm^2. With 30% oxygen, shunt increased to only 2.1%, with minimal atelectasis (0.2 cm^2) [21]. In a study by Saracoglu et al. [22] where oxygen titration was performed by ORI in lung resection surgeries with OLV, positive correlation was detected between the duration of administration of FiO_2>0.8 and the duration of hospitalization of the patients. Another study conducted by the same group in pediatric patients found a positive correlation between ORI values and length of hospital stay. It was emphasized that this might occur due to atelectasis caused by hyperoxemia [23]. Similarly, the duration of hospital stay was shorter in the patients followed up with ORI in our study (4.0±0.86 and 4.66±1.42, respectively; p=0.002). Better oxygen titration was performed in patients in the ORI group, and higher FiO_2 durations were significantly shorter compared to the control group (2.59±2.00 and 11.49±5.87 min, respectively; p<0.001). This was associated with prevention of atelectasis due to better oxygen titration with ORI monitoring and a shorter exposure time of FiO_2>0.6. Although there is not enough proof to conclude the increase in hospital stays, we believe that hyperoxemia due to high oxygen concentration use may have been a crucial factor in the observed difference in hospitalization durations between the groups in our study. Many other factors influence the length of hospital stay, such as ASA physical status, blood loss, and duration of surgery. However, none differed between the groups studied, further highlighting the importance of hyperoxemia. The lowest allowable oxygen concentration should be preferred during general anesthesia to avoid the formation of atelectasis. Our results highlight the need for individual adjustment of FiO_2 in the intraoperative period and the importance of avoiding unnecessarily high oxygen concentrations.

The highest ORI value, which may be measured in ORI monitoring, was 1. In this study, the ORI value was 1 in 12 patients until the first pneumothorax and in 10 patients at the end of the operation, even in cases where the inspired oxygen concentration was 0.4. This result suggests that patients may be exposed to hyperoxia during standard monitoring, even during the use of FiO_2, which is not remarkably high in the intraoperative period, such as 0.4. Since optimal FiO_2 titration was maintained in the ORI group, no difference was found between ORI values <0.55 before and after the first pneumothorax. Our data demonstrated that by ORI monitoring, FiO_2 increase is prevented prophylactically in patients with an ORI value of 0.55 between the first and second pneumothoraxes through early detection of hypoxemia that may develop due to iatrogenic pneumothorax.

Our study observed an increase in ORI value by decreased body temperature. This was interpreted as the decrease in the body's metabolic activity, and thus the resulting decrease in oxygen consumption, resulting in an increase in ORI values. Furthermore, decreased body temperature may cause widespread vasoconstriction, reduce extremity blood flow, and adversely affect ORI monitoring.

Studies in the literature indicate that extremity blood flow and perfusion index affect the reliability of monitoring techniques based on spectrophotometric principles from the fingers [24]. There was no statistically significant difference in PI values between the two groups in our study. This supports that the perfusion distribution was comparable in both groups, and the measurements were reliable.

Our study has some limitations. Firstly, oxygenation status should be supported by real-time arterial/venous blood values; however, we could not investigate the association between PaO_2 and ORI since PaO_2 monitoring could not be performed in all patients because an invasive method such as intraarterial catheterization is not implemented on routine basis during the surgical procedure. Secondly, SpO_2 values were allowed to decrease to up to 96% in hypoxemia after pneumothorax, and it was not observed how deep oxygenation could be with pneumothorax since oxygen support was increased afterward. Thirdly, in the postoperative follow-up of the patients, the development of atelectasis could have been monitored with lung ultrasonography which is a more practical method than thorax computed tomography imaging which is the gold standard method. Further studies utilizing this method are required.

Conclusion

In this prospective randomized controlled trial, ORI monitoring reduced the need for oxygen administration over 60% concentration by approximately 50% in comparison to the control group during minimally invasive pectus excavatum repair surgery. Moreover, the hospital stay duration decreased by 1 to 2 days. ORI monitoring, a noninvasive method, may be superior to conventional methods in optimizing blood oxygenation and may increase patient safety by reducing postoperative morbidity with easier oxygen titration.

Ethics Committee Approval: The Marmara University Clinical Research Ethics Committee granted approval for this study (date: 02.02.2018, number: 09.2018.138).

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