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Comparison of the efficacy of two preoxygenation techniques using oxygen reserve index

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Abstract

Background. Preoxygenation is very important to protect the patient from hypoxia before intubation. However, pulse oximetry has some limitations in detecting hypoxia.

Objectives. We aimed to compare the effectiveness of 2 preoxygenation techniques based on oxygen reserve index (ORI) levels.

Materials and methods. Twenty healthy male volunteers were included in the study. They inhaled 100% FiO_2 oxygen administered at 5 L/min as the 1st technique (M1) with a ventilation mask as much as their tidal volumes for 3 min. The 2nd technique (M2) applied 100% FiO_2 oxygen at 10 L/min flow using the same mask and 8 deep inspiratory volumes, which was aimed to be completed within 1 min. Maximum ORI levels, duration to reach that level, and time needed to reach the target ORI level (0.35) and return back to the "0" were measured.

Results. In the M1 group, ORI levels were significantly higher during and after 60 s, according to post hoc tests. In the M2 groups, ORI levels were significantly higher during and after the 4th inspiration, according to post hoc tests. Oxygen reserve index values at the 60th 2nd (M1) and 8th inspiration (M2) were compared as the 8th inspiration corresponded to the 60th second. The maximum ORI values were significantly lower in the M1 group compared to the M2 group ($p < 0.001$ and $p = 0.006$, respectively). Seven volunteers (36.8%) in the M1 group and 2 volunteers (10.5%) in the M2 group could not reach the target ORI (McNemar's test, test statistic 3.2, degrees of freedom (df) = 1, $p = 0.063$). The time to reach the target ORI value and to reach maximum ORI values was significantly longer in the M1 group than in the M2 group ($p = 0.008$ and $p < 0.001$, respectively).

Conclusions. We observed that the 8-deep breath technique is more effective in preoxygenation compared to the 3-min tidal volume technique.

Key words: preoxygenation, oxygen reserve index (ORI), hypoxia prevention, 8-deep breath technique, 3-min tidal volume technique

Background

Administration of 100% oxygen before a "rapid-sequence" induction of anesthesia is recommended to prevent hypoxia during induction.[1]

Historically, many preoxygenation techniques have been described.[2,3] Currently, there are 4 methods of preoxygenation used in routine anesthetic practice: (1) the deep breathing technique; (2) the rapid breathing using a fraction of inspired oxygen (FiO_2) of 1 (100%) for 2 to 5 min; (3) the 4 or 8-vital capacity methods; and (4) the Transnasal Humidified Rapid Insufflation Ventilator Exchange (THRIVE) technique.[4]

The use of intraoperative pulse oximetry (SpO_2) enhances the prevention of hypoxic events and is mandatory in anesthesia and critical care practices.[5,6]

However, because the relationship between the arterial partial pressure of oxygen (PaO_2) and arterial oxygen saturation (SaO_2) is not linear but rather sigmoid, SpO_2 may not provide an additional warning below the levels of 98% until PaO_2 decreases below 70 mm Hg.[7–9]

On the other hand, increasing the PaO_2 above 90–100 mm Hg or more will no longer affect the SpO_2. As a consequence, when SpO_2 is ≥97%, the PaO_2 levels could be anywhere between 90 and 600 mm Hg.[10–12]

These major limitations in clinical practice have forced researchers to develop new methods to measure tissue oxygenation levels. The oxygen reserve index (ORI™; Masimo Corp., Irvine, USA) is a new variable that represents oxygenation status, with a scale between 0.00 and 1.00, and enables noninvasive and continuous measurement of PaO_2 ranging from 100 to 200 mm Hg. Oxygen reserve index has significant potential for predicting both hypoxemia and hyperoxia.[13,14]

Objectives

Considering that SpO_2 monitoring is not sufficient to show hypoxic or hyperoxic events, we aimed to compare the effectiveness of 2 preoxygenation techniques using ORI measurements.

Materials and methods

Following the approval of the Institutional Ethics Committee of the University of Health Sciences Istanbul SUAM (dated 12/22/23, No. 398, and UMIN: 000051009/08/05/23) and the provision of informed consent by each participant, 20 healthy male volunteers with an American Society of Anesthesiology (ASA) of 1 status, ranging in age from 18 to 32 years, were recruited to the study. The study size was assessed using biostatistical methods based on relevant previous studies. All study participants were nonsmokers with no evidence of cardiovascular, respiratory or other systemic diseases. Additional exclusion criteria included hemodynamic disturbances in the operating room and pre-procedural anxiety. Patients with nonivasive blood pressure (NIBP) over 140/90 mm Hg and a preprocedural State Trait Anxiety Inventory (STAI) test level over 41 were also excluded. Each study participant was monitored continuously using electrocardiography (ECG), NIBP sensors and the Masimo Root Radical-7 (Masimo Corp., Irvine, USA) incorporating both ORI-PVI and SpO_2 sensors, which were the disposable adhesive type and were placed on the 4th finger of the contralateral side of the NIBP monitoring and protected under a light-shielding cover. The ORI was based on Masimo Rainbow SET (Masimo Inc, Irvine, USA) technology, in which the pulsatile signals were extracted from 8 wavelengths ranging between 500 and 1,400 nm, enabling the detection of changes in PaO_2 after SaO_2 was maximally saturated according to changes in the peripheral venous oxygen saturation. Oxygen reserve index is a novel, multiwavelength pulse oximeter-based, nondimensional index that ranges from 0 to 1 as PaO_2 increases from about 80 to 200 mm Hg.

As a result of the reliable measurement of peripheral perfusion, the participants' skin temperature was monitored using a thermocouple and maintained at 36.5°C throughout the experiment. During the experiment, oxygen gas flow was tightly controlled using a semi-open anesthesiology circuit and a proper face mask. The SpO_2 and ORI values were displayed and stored using Root with a Radical-7 device (Masimo Corp., Irvine, USA). A universal serial bus (USB) data output port on the Root monitor was connected to a computer (Ideapad 5 14ITL05; Lenovo, Beijing, China) running proprietary Pulse Oximetry Automatic Data Collection software (Masimo Instrument Configuration Tool (MICT) v. V1.2.4.5; Masimo Corp.) to create and store data files that were subsequently analyzed offline.

Each study participant underwent 2 different techniques of preoxygenation. Oxygen was administered by the following 2 methods using the following preoxygenation techniques in each study participant. The 1st method (M1) oxygenated volunteers with 100% FiO_2 at a 5 L/min flow for 3 min while they were breathing normally, which means the inspired volume was as much as their usual tidal volumes (without any leakage, which was ensured by proper mask usage). In the meantime, we recorded SpO_2, ORI, total hemoglobin (SpHb), and Pleth variability index (PVI) values every 30 s and noted their maximum quantities. At the end of the 3 min, we took the masks off the volunteers and waited for ORI values to reach "0" again and noted its duration. Approximately 1 h after the administration of M1, the 2nd method (M2) was employed to oxygenate the volunteers. This involved the administration of 100% FiO_2 and a 10 L/min flow, with the volunteers instructed to take 8 breaths in 1 min, with maximal effort, to reach their maximum forced inspired volumes. In the meantime, we recorded SpO_2, ORI, SpHb, and PVI values after each deep inspiration, and we also noted their maximum quantities, just like in the M1 group.

An ORI of 0.35 was used as the target to be reached, and the duration to achieve this level was recorded in each technique. In addition, after the oxygenation period, maximum ORI levels, time to reach maximum ORI levels, and time for the return of the ORI to its baseline value in room air after cessation of oxygen supplementation (3 min for the M1 technique; 1 min for the M2 technique) were recorded and compared. There was no potential source of bias.

Statistical analyses

Statistical evaluations were performed using the PICOS program on the E-PICOS website, and post hoc analyses using a Friedman's test were performed with the R software (R Foundation for Statistical Computing, Vienna, Austria). Categorical values were given as percentages. Numerical values were given as median and min/max levels because of the small volunteer size of the group (n < 25). Categorical values, such as the ability to reach target ORI levels, were compared between the 2 methods using the McNemar's test. A Wilcoxon signed-rank test was employed to assess the statistical significance of numerical variables between the 2 methods, given the limited number of study participants. Oxygen reserve index changes over time in the M1 and M2 groups were separately evaluated using the Friedman's test, and post hoc analyses were made using the Nemenyi test. P-values <0.05 were accepted as statistically significant.

Results

Twenty volunteers aged 18–32 years with an ASA 1 status were recruited for the study. One volunteer was excluded because of high blood pressure levels altering high STAI 1 test results. Demographic data of the volunteers are provided in Table 1.

Oxygen reserve index changes over time in the M1 group and during inspirations 1–8 in the M2 group are shown in Table 2 and as boxplot graphics in Fig. 1,2. The values of 6 measurements in the M1 group were compared using Friedman's test (n = 19, degrees of freedom (df) = 5, test statistic = 42.322, p < 0.01). Oxygen reserve index levels were significantly higher during and after 60 s, according to post hoc tests (Table 3). In addition, values of 8 measurements in the M2 group were also compared with the Friedman's test (n = 19, df = 7, test statistic = 104.759, p < 0.01). Oxygen reserve index levels were significantly higher during and after the 4th inspiration, according to post hoc tests (Table 4).

Oxygen reserve index values in the 60th second (values of M1ORI60 for the M1 and M2ORI 8th for the M2 groups were compared because the 8th inspiration corresponded to the 60th second in M1 technique and maximum ORI values were significantly lower in the M1 than in the M2

Table 1. Descriptive data of the study group (n = 19)

Patient data	Q1	Median	Q3
Age	23	27	29
BMI	22.53	24.91	26.57
Temperature	36.4	36.5	36.5
STAI	23	31	34
SBP	122	126	131
DBP	72	75	79
ISPO2	98	98	99
IHB	13.1	13.9	14.5

BMI – body mass index; STAI – State Trait Anxiety Inventory; SBP – systolic blood pressure; DBP – diastolic blood pressure; ISPO2 – saturation of oxygen; IHB – blood hemoglobin; Q1 – 1st quartile; Q3 – 3rd quartile.

Table 2. The changes of ORI during time in method 1 and during inspirations in method 2 (n = 19)

Parameters	Min	Max	25th percentile	50th percentile	75th percentile
M1ORI 30	0.00	0.31	0.0000	0.0000	0.0400
M1 ORI 60	0.00	1.00	0.1500	0.3200	0.3700
M1 ORI 90	0.03	1.00	0.2000	0.3700	0.4500
M1 ORI 120	0.15	0.91	0.3000	0.3600	0.5100
M1 ORI 150	0.15	0.96	0.3000	0.3400	0.4900
M1 ORI 180	0.14	0.85	0.2800	0.3400	0.4900
M2 ORI 1st	0.00	0.07	0.0000	0.0000	0.0000
M2 ORI 2nd	0.00	0.41	0.0000	0.0000	0.0000
M2 ORI 3rd	0.00	0.45	0.0000	0.0000	0.0000
M2 ORI 4th	0.00	0.63	0.0000	0.0100	0.0700
M2 ORI 5th	0.00	0.95	0.0100	0.1700	0.4100
M2 ORI 6th	0.00	1.00	0.1600	0.3600	0.4900
M2 ORI 7th	0.00	1.00	0.2600	0.4300	0.5600
M2 ORI 8th	0.00	1.00	0.3300	0.4400	0.5600

M1 – method 1; M2 – method 2.

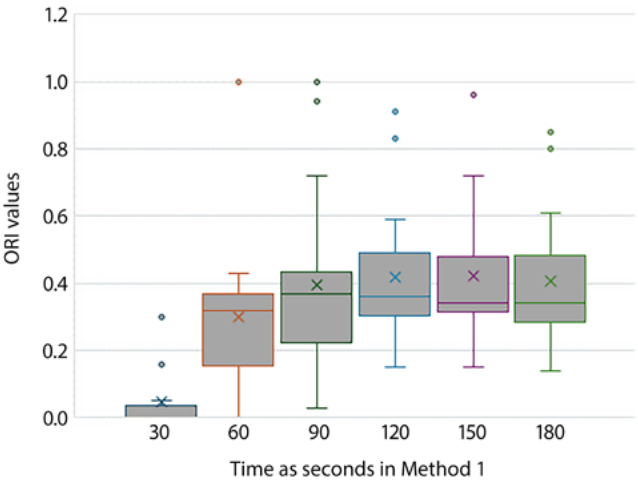

Fig. 1. Boxplot representing changes of oxygen reserve index (ORI) in time in method 1. M1ORI30, 60, 90… etc. showed ORI values measured at 30th, 60th, 90th… etc. seconds

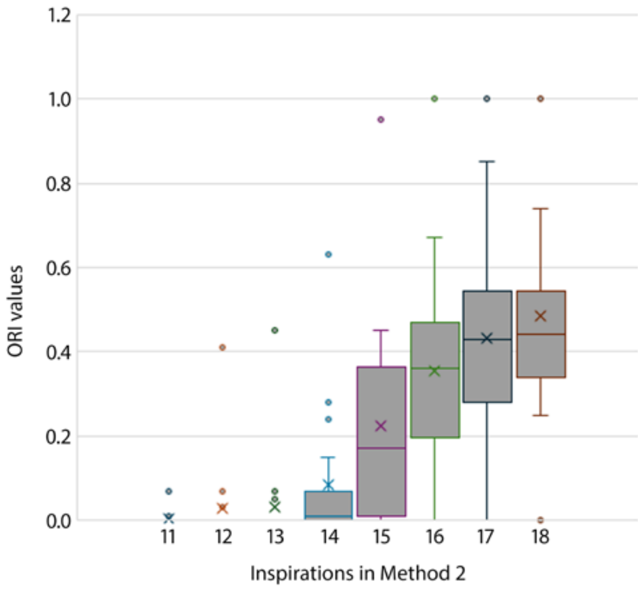

Fig. 2. Boxplot representing changes of oxygen reserve index (ORI) during inspirations from the 1st to the 8th in method 2. M2I1, 2, 3, …, etc. showed ORI values measured during the 1st, 2nd, 3rd, …, etc. inspirations

group ($p < 0.001$ and $p = 0.006$, respectively, Table 5). Seven volunteers (36.8%) in the M1 group and 2 volunteers (10.5%) in the M2 group could not reach the target ORI (McNemar's, test statistic 3.2, df = 1, $p = 0.063$). Times to reach the target values of ORI and to reach maximum ORI values were significantly longer in the M1 than in the M2 group ($p = 0.008$ and $p < 0.001$, respectively). Time to return to baseline ORI values were not significantly different between the 2 groups ($p = 0.071$, Table 5).

Discussion

Preoxygenation is a mandatory technique that extends the safe apnea time for endotracheal intubation, particularly in a "cannot intubate/cannot oxygenate" (CICO) scenario.[15] The procedure is carried out by supplying 100%

Table 3. Comparisons of oxygen reserve index (ORI) values according to time using Friedman test and post hoc Nemenyi test in method 1

Time [s]	Test statistics/p-values&				
	60	90	120	150	180
30	**34.5/<0.001**	**61/<0.001**	**57.5/<0.001**	**59.5/<0.001**	**45.5/<0.001**
60	–	**26.5/0.008**	25/0.033	**23/<0.022**	11/0.56
90	–	–	3.5/0.844	1.5/0.778	15.5/0.776
120	–	–	–	2/0.812	12/0.394
150	–	–	–	–	14/0.144
p-value*	**42.322/<0.001**				

*Friedman test; & – post hoc Nemenyi test; significant p-values are in bold.

Table 4. Comparisons of oxygen reserve index (ORI) values during inspirations using Friedman test and post hoc Nemenyi test in method 2

Ins.	Test statistics/p-values&						
	2	3	4	5	6	7	8
1	2/0.180	1.5/0.285	22/0.006	47/0.001	**66/<0.001**	**81/<0.001**	**92.5/<0.001**
2	–	1.6/0.276	20.5/0.006	45/0.001	**64/<0.001**	**79/<0.001**	**90.5/<0.001**
3	–	–	20/0.005	45.5/0.001	**84.5/<0.001**	**79.5/<0.001**	**91/<0.001**
4	–	–	–	25/0.002	44/0.001	**59/<0.001**	**70.5/<0.001**
5	–	–	–	–	19/0.003	34/0.001	**45.5/<0.001**
6	–	–	–	–	–	15/0.005	26.5/0.002
7	–	–	–	–	–	–	11.5/0.024
p-value*	**104.759/<0.001**						

Ins. – inspirations; * – Friedman test; & – post hoc Nemenyi test; significant p-values are in bold.

Table 5. Comparisons of various oxygen reserve index (ORI) parameters between methods 1 and 2

Parameters	M1 (median)	M2 (median)	Test statistic	p-value*
ORI in the 60th s&	0.32	0.44	3.517	**<0.001**
Maximum ORI	0.46	0.51	2.769	**0.006**
ORI target time	57.5	48	−2.672	**0.008**
ORI max time	110	59	−3.542	**<0.001**
ORI zeroing time	78	114	1.808	0.071

M1– method 1; M2 – method 2; *Wilcoxon paired signed rank test; significant p-values are in bold. & – comparison was made between M1ORI 60 for method 1 and M2 ORI 8th for method 2.

oxygen (FiO_2 of 1.0) before the induction of general anesthesia, and several methods of preoxygenation have been described in the literature. Two of the commonly known standardized approaches are 8 deep breaths in 1 min and tidal volume breathing for 3–5 min, both using 100% inspired oxygen, but there are studies questioning whether the techniques are effective or not.[16–20]

Today, we know a lot about the oxygen cascade. The definition of hypoxia is typically based on SpO_2 measurements. However, it is recognized that SpO_2 does not provide sufficient information about hypoxia at the tissue and cellular levels. However, while we try to protect the patient from hypoxia, we have concerns about the hyperoxia and its side effects at the same time.[21–28] Because some studies have shown that SpO_2 and the partial oxygen pressure changes in arterial blood gas analysis do not match exactly, a new and more sensitive pulse oximeter-based indexing system (ORI) obtained with pulsatile multiple wavelength analysis was defined. Researchers have discussed that ORI may be more sensitive in the measurement of hypoxia, hyperoxia or both. For this purpose, we tried to evaluate 2 major preoxygenation techniques and their benefits on the ORI.

This study is distinct from previous investigations that have established safe apnea times and preoxygenation techniques based on SpO_2 levels. In our study, we observed the effects of different preoxygenation techniques on tissue oxygenation reserve according to the ORI. Furthermore, the M2 group exhibited a more pronounced increase in ORI values and a longer duration of elevated values than the M1 group, which can be a time-saving method in emergency intubations, rapid sequential induction, and in the case of a cesarean section, morbid obesity, etc.[29–32]

We found that the maximum ORI levels varied between volunteers, which shows that oxygen reserve capacity may be different individually, but whatever this level is, it can be reached more quickly with the M2 technique.

According to the literature, Applegate et al. found that an ORI > 0.24 can be considered a $PaO_2 \geq 100$ mm Hg when SpO_2 levels are over 98%.[33] In a study by Szmuk et al.[14] conducted with Masimo, an ORI value of 0.3 provided 85% sensitivity and 80% specificity for a $PaO_2 < 150$ mm Hg.[14] However, an ORI > 0.55 appears to correlate with a $PaO_2 \geq 150$ mm Hg level in light of this data. Our target ORI value was 0.35 because our aim was to put into practice the results of this study in difficult intubation situations.

The time to reach the target ORI was also shorter in the M2 group. Moreover, while 7 study participants in the M1 group could not reach their personal maximum ORI levels, there were only 2 cases that failed in the M2 group. We observed that the study participants adapted better to the M2 technique.

Although the presence of a safe apnea time has been shown to be important in procedures such as bronchoscopy, which is reported in case reports, especially in which apneic oxygenation is used, there are not enough data from clinical studies.[34,35] Instead of safe apnea time, we used reset duration of ORI. We saw that the ORI reset time was longer in the M2 technique.

In addition, while doing this study as we saw in Fig. 2, the 3–4 deep breath technique which was defined in previous years failed, because the ORI values start to increase from the 4th breath. Therefore, study participants need more time to raise their oxygen reserves to the target and max levels.

During preoxygenation, the saturation levels of the study participants were 100%; therefore, we reached the end of that monitoring parameter, indicating it was not a clinically effective tool in comparing the 2 preoxygenation techniques. This finding was similar to the results obtained by Koishi et al., which reported that SpO_2 began to decrease 72 s (mean) after ORI reached 0.00 and the SpO_2 was 99 (98–99%).[36]

Limitations

The study group consisted of healthy volunteers. Therefore, it was not possible to examine the results of patients with different comorbidities. It would have been possible to perform simultaneous matching of the ORI measurements with PaO_2 levels in arterial blood gas analysis. Consequently, it would have been possible to directly measure the oxygen status of the study participants.

Conclusions

We compared 2 preoxygenation techniques using ORI in healthy volunteers. We observed that the M2 technique is more effective in preoxygenation compared to the 3-min tidal volume technique. The M2 technique is preferable, particularly in emergency or difficult intubation situations.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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