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Impact of absence of critical respiratory rate change on oxygen desaturation following tracheal extubation after general anaesthesia: a propensity score-matched analysis

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Abstract

Background: It has been suggested that oxygen desaturation may be paradoxically related to the absence of an abnormal respiratory rate (RR) during acoustic respiratory rate (RRa) monitoring in a postoperative setting. We retrospectively compared the incidence of desaruration in patients without an abnormal RR with that in patients with an abnormal RR using propensity scorer matching. We also explored the factors contributing to oxygen desaturation without an RR monitoring alert.

Methods: We used ≤ 8 h postoperative data of the first 935 patients. Outcomes of patients with and without critical RR changes (RR > 30 or < 8 beats per min for > 2 min) (critical RR change vs. noncritical RR change) were first compared according to oxygen desaturation levels (SpO_2 < 90% for > 10 s). Multivariate analysis was used to determine oxygen desaturation-associated explanatory factors.

Results: Propensity score matching yielded 259 patients without critical RR changes and 259 patients with critical RR changes, respectively. Oxygen desaturation rates were higher in patients without critical RR changes [noncritical RR change vs. critical RR change: 39/220 (15.1%) vs. 16/243 (6.2%)]. An odds ratio and 95% CI for the noncritical RR change was 2.56 (1.38–4.55, $P = 0.002$). A critical change in the RRa was not observed in 576 patients; of these, oxygen desaturation was observed in 76 (13.2%) patients. Surgery duration (OR, 1.018 per 10 min increase; 95% CI, 1.002 to 1.035) was independently associated with oxygen desaturation without critical RR change.

Conclusion: Postoperative oxygen desaturation paradoxically occurred more frequently in patients without critical RR changes, whose RR was monitored by the RRa under oxygen therapy. The duration of surgery may explain the possibility of postoperative oxygen desaturation without an RRa device alert.

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Key words: respiratory rate monitoring; acoustic respiratory rate; oxygen desaturation

Pulse oximetry (SpO_2) allows for a continuous, non-invasive monitoring of oxygenation; however, supplemental oxygen may delay the diagnosis of hypoventilation caused by bradypnea or respiratory deterioration [1, 2]. Thus, the Anesthesia Patient Safety Foundation recommends both SpO_2 and respiration rate monitoring, particularly following extubation and narcotic analgesic use for pain management [2, 3]. A non-invasive respiratory monitoring device using adhesive sensors with an integrated acoustic transducer positioned on the patient's throat [Rainbow Acoustic Monitoring™ (RAM), Masimo Corp., Irvine, CA, USA] is a relatively new method of ventilation monitoring. Recently, clinical investigations to confirm an accurate estimation of the respiratory rate (RR) produced by this device have been reported [4–7].

The average postoperative patient receiving supplemental oxygen may rarely develop hypoxia provided that

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normoventilation is maintained [1, 2]. Based on this theory, we have implemented the use of a pulse oximeter with an acoustic RR (RRa) monitoring device (Rad-87™, version 7805, Masimo Corp.) in postoperative settings outside the intensive care unit. However, we have occasionally encountered desaturated patients without an RRa device alert although not with an alert under this monitoring system. It is likely that oxygen desaturation is paradoxically related to the absence of an abnormal RR in our postoperative monitoring system. Recently, this phenomenon has been reported [8].

To investigate whether this phenomenon is true or not, we retrospectively compared the incidence of desaturation in patients without an abnormal RR with that in patients with an abnormal RR using our cohort population. To reduce the effect of selection bias, we compared the incidence of oxygen desaturation in propensity-matched pairs with or without an abnormal RR under RRa monitoring in a postoperative setting. We also retrospectively explored the factors that contribute to develop oxygen desaturation without an RR monitoring alert.

METHODS

Approval for access to the data stored on the RRa device pulse oximeter and the review of the clinical charts of postoperative patients with continuously monitored RRa was obtained from the NMU Institutional Review Board (No. 480-3 approved on April 14, 2014), while written informed consent for this historical study was waived. Data analysis was based on data from our previous report, which suggested a paradoxical increase in the incidence of postoperative desaturation without an RR monitoring alert [8].

STANDARD PERIOPERATIVE PATIENT TREATMENT

Cases requiring intensive care or similar treatment were excluded from RRa monitoring since mechanical ventilation or manual RR monitoring, such as intermittent auscultation every 1–2 h, was required for these cases. RRa monitoring was applied to extubated surgical patients who were outside of the intensive care units. The application was limited to elective cases, partially due to a shortage of RRa devices. In fact, patients who had undergone craniotomy, thyroidectomy, spinal surgery, laparotomy, laparoscopic surgery, and major orthopedic surgery were initially considered as candidates for RRa monitoring.

The methods of anaesthetic induction and maintenance, as well as tracheal intubation were not standardized for each patient. Anaesthesia was maintained with sevoflurane or propofol, while fentanyl or remifentanil was used for analgesia. Rocuronium was used for neuromuscular blockade, and sugammadex for the reversal of the neuromuscular blockade after evaluating the status of the neuromuscular blockade using a nerve stimulator. Fluid management was performed at the discretion of the attending anaesthetist and a transfusion was performed if necessary. Postoperative analgesia was provided with intravenous fentanyl (10–40 μg h^{-1}) or epidural ropivacaine (0.1–0.2%, 2–4 mL h^{-1}) combined with fentanyl (10–20 μg h^{-1}) using a patient-controlled analgesia (PCA) device (Coopdech Syrinjector PCA DeviceTM for i.v., Coopdech Balloonjector PCA DeviceTM for epidural, Daiken Medical Co. Ltd., Osaka City, Osaka, Japan). The PCA bolus sizes and lockout timings were set at 10–40 μg h^{-1} and 10 min for i.v. and 3 mL and 30 min for epidural, respectively. When PCA was used, a low dose droperidol (1.25–2.5 mg per day) was combined with a PCA device. Upon discharge from the operating room, an adhesive acoustic respiration sensor (RAS-125™ or RAS-125™ rev C, Masimo Corp.) and an oximetry sensor (LNCS Adtx, Masimo Corp.) were placed on the patient's neck and finger, respectively, and connected to an RRa device pulse oximeter to obtain the RR, SpO_2, pulse rate (PR), and perfusion index (PI) measurements. PI with a trending capability reflects the arterial pulse signal strength and may be used as a diagnostic tool during low perfusion [9]. A low PI is associated with an increased discrepancy between SpO_2 and arterial oxygen saturation (SaO_2) [10].

According to the manufacturer's instructions, the acoustic sensor was placed on the either side of the larynx, above the thyroid cartilage and below the jaw line. Patients were then transferred to a general surgical ward. The general hospital setting had a nurse to patient ratio of 1:7 and was comprised of a surgical population undergoing miscellaneous surgeries with opioid-based, patient-controlled analgesia. In the case of an RRa or SpO_2 alarm, the nurses at our institute were trained to deliver standard care and to pat a patient on the shoulder or chest while calling or orally encourage them to breathe deeply. However, the staff seldom adjusted the oxygen delivery rate. Patients were continuously monitored with an RRa device containing a pulse oximeter as per the standard of care, while the monitored data were stored in the internal memory. Oxygen (3–5 L min^{-1}) was administered for up to 8 h regardless of the postoperative analgesia used through an oxygen mask according to our institutional standard practice. RR, SpO_2, and PR alarms were set at RR < 8 or > 30 breaths per min, < 90% SpO_2 with supplemental oxygen, and PR > 130 or < 50 beats per min, respectively, according to the institutional protocol. The RRa device pulse oximetry data were temporarily and automatically stored in an internal memory for up to 72 h per 2 s resolution. Every time a Rad-87 monitoring was terminated, the data were transferred to a storage device using downloaded software (TrendCom ver 3460, Masimo Corp.) and were saved at our institute.

DATA HANDLING

Data were collected from May 1, 2012 to July 31, 2013. During this period, out of the 5,762 anaesthesia cases, 988

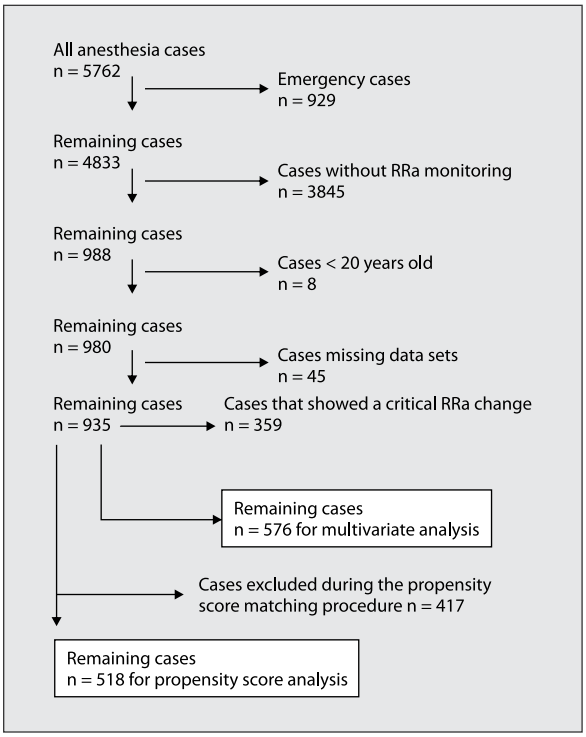

Figure 1. Study workflow

were monitored with an RRa device pulse oximeter. The cumulatively stored data were extracted, and those collected during the first preoperative 8 h were used for analysis. "Invalid" was marked on the artifactual periods in the stored data by sophisticated artifact detection algorithms. After pre-screening the raw data, data reliability was confirmed. The exclusion criteria for the current study and consequent reductions in the eligible patients were as follows: (1) emergency cases (n = 929); (2) cases without RRa monitoring (n = 3845); (2) cases < 20 years old (n = 8); and (3) cases with missing datasets or signal loss during the recording process (n = 45). Eventually, data from 935 patients were used in this study (Fig. 1).

Perioperative data were extracted from the patients' clinical charts. Based on the analyzed data, an event of oxygen desaturation was defined by a SpO_2 < 90% for 10 s or more, which was an arbitrary local rule, during 8 h of recording. To assess the data reliability, PI data were also extracted. Subsequently, the patients were divided into the following two groups: (1) a noncritical RR change group; and (2) a critical RR change group. Critical RR change was defined as an RR < 8 or > 30 breaths per min in 2 min or longer. Initially, we expected to prevent oxygen desaturation in advance by intervening when an abnormal RR was observed. However, upon implementation of the caregiver treatment under RRa monitoring, we found that it took at least 2 min for caregivers to intervene after the RR alarm had gone off.

STATISTICAL ANALYSIS

Continuous variables are presented as the mean and standard deviation (SD) if normally distributed or the median, and an interquartile range (IQR) if skewed. Categorical variables are presented as the number of patients and frequencies (%).

To minimize the effect of selection bias on the outcomes, we used propensity score matching to clinical characteristics to reduce distortion by confounding factors. Using a propensity score analysis, we generated a set of matched cases (critical RR change) and controls (noncritical RR change). A propensity score was generated for each patient from a multivariable logistic regression model based on the covariates using data from the recorded data and clinical chart as independent variables, with the group type (noncritical RR change vs. critical RR change) as a binary dependent variable.

As suggested by a review of statistical research on propensity score development, we used a structured, iterative approach to refine this model, with the goal of achieving covariate balance between the matched pairs [11]. The covariate balance was measured using the standardized difference, in which an absolute difference of > 0.1 indicated a meaningful covariate imbalance [9]. We matched the patients using a greedy matching algorithm with a calliper width of 0.001 of the estimated propensity score. A matching ratio of 1:1 was used. This procedure yielded 259 patients without critical RR changes propensity matched to 259 patients with critical RR changes. For statistical inference, methods that accounted for the matched nature of the samples were used. For the overall incident rate, the Cochran–Mantel–Haenszel test, stratified on the matched pair, was used to estimate the odds ratio and 95% CI of incidence (noncritical RR change vs. critical RR change).

If it was confirmed that absence of a critical RRa change increased oxygen desaturation, an analysis to identify cases that developed oxygen desaturation without a critical RRa change was performed. First, univariate analysis was used to identify factors associated with oxygen desaturation. Explanatory factors having a significant univariate association (P < 0.15) with oxygen desaturation were used to perform multivariable logistic regression analysis and stepwise backward elimination. All candidate variables were entered in the initial model and at each step; the variable with least significance (i.e., the highest P value of > 0.15) was eliminated and presented as adjusted odds ratios with 95% confidential intervals (CI). Interactions between variables were systematically searched and collinearity was considered for r or rho > 0.8 using the Pearson or Spearman coefficient matrix correlations, respectively. Discrimination of the final model for oxygen desaturation was assessed using the likelihood ratio test. Calibration of the model was

tested using the Hosmer-Lemeshow test. The area under the receiver operating characteristic (ROC) curve was computed as a descriptive tool for measuring model bias.

SAMPLE SIZE CALCULATION

For the purpose of a post hoc sample size calculation, we assumed a 25% incidence of desaturation in the postoperative patients based on a previous report (20–50%) [10, 12]. We estimated that 178 patients in each group were required to provide 95% power to detect a 15% difference in the incidence of oxygen desaturation between noncritical RR change and critical RR change, with a type I error probability of 0.05. Thus, our sample size was sufficient to detect a difference in the outcome. The MedCalc statistical package (Version 14.12.0, MedCalc Software BVBA, Ostend, Belgium) and R (version 3.0.3, R Foundation for Statistical Computing, Vienna, Austria) were used to perform all of the described analyses.

RESULTS

No patients died, required a code-blue call, or intensive care during the study period, while there were no reports of any critical complications. As the result of the propensity score matching, 417 patients were excluded. In the patients without and with critical RR changes, 317 and 100 patients were excluded, respectively. This procedure yielded 259 patients for cases propensity matched to 259 patients for controls. The clinical characteristics of the two matched groups extracted by a propensity analysis are presented in Table 1 (n = 259 in each group). The covariates were well balanced after matching. Notably, the imbalanced variables in the unmatched populations were balanced after matching. The patient outcomes are summarized in the bottom of Table 1. Oxygen desaturation occurred more frequently in those patients without critical RR changes compared to patients with critical RR changes after propensity matching (noncritical RR change vs. critical RR change: 39/220 [15.1%] vs. 16/243 [6.2%]). The odds ratio and 95% CIs for the noncritical RR change was 2.56 (1.38–4.55, $P = 0.002$).

We analyzed data from 576 patients in the entire population (n = 935) that did not show a critical RRa change during the recording period; of these, oxygen desaturation was observed in 76 (13.2%) patients, which was 8.1% of the overall study population. The median number of oxygen desaturation events was two (range 1 to 34). The median of the lowest SpO_2 level was 83% (range 36–89%) while that of the longest duration was 21 s (range 10 to 390 s). Patient data and perioperative characteristics were compared between the desaturation and non-desaturation groups (Table 2). Univariate analysis found that coexisting COPD (P = 0.098), low %VC ($P = 0.069$), transfusion requirement ($P = 0.059$), long duration of anaesthesia ($P = 0.051$) and surgery ($P = 0.042$), and intraoperative fluid balance ($P = 0.073$) were all associated with oxygen desaturation without a critical RRa change.

Multivariate analysis found that surgery duration (OR, 1.018 per 10 min increase; 95% CI, 1.002 to 1.035) was independently associated with oxygen desaturation without RR (Table 3). Discrimination of the final model assessed by the likelihood ratio test was significant ($P = 0.021$). Moreover, the Hosmer-Lemeshow test did not reject a logistic regression model fit ($P = 0.212$). The explanatory model based on these variables had an area under the ROC curve of 0.594 (95% CI, 0.553 to 0.634). Using the identified explanatory factor of surgery duration, ROC analysis was performed. The best cutoff value assessed by the Youden Index (sensitivity + specificity − 1) was 296 min [13]. The area under the ROC curve was 0.559 (95% CI, 0.517 to 0.600; sensitivity = 46.1%, specificity = 66.6%).

Post hoc power calculations were performed for these stepwise backward multivariate logistic regression models using five in the model itself. We followed standard methods to estimate the sample size for multivariate logistic regression, with at least ten outcomes needed for each included independent variable [14]. With a 13.2% (76/575) incidence of desaturation without a critical RR change in the overall study population, we required 378 patients without a critical RR change to appropriately perform multivariate logistic regression with five variables, respectively. This demonstrates that our sample sizes were sufficient to build the model.

DISCUSSION

Based on this propensity score analysis of the patient data, the incidence of desaturation occurred to a greater extent in patients without a critical RR change. Therefore, it was confirmed that the absence of a critical RR change paradoxically increased the incidence of desaturation in our postoperative monitoring setting.

The rate of postoperative oxygen desaturation has been reported to be highly variable (e.g., from 20% to 50%), although a comparison with the results of other studies remains limited due to different definitions of oxygen desaturation between each study [10, 12]. In addition, previous reports did not consistently base the primarily conclusions on the administration of supplemental oxygen to the patients. However, it has been reported that only less than 1% of the patients developed oxygen desaturation ($SpO_2 <$ 90%) when oxygen was administered [10]. Thus, our study rate of 6.2–15.1% appears to be high for settings under supplemental oxygen. Compared with the short postoperative transport period [10], the relatively long observation period in our study likely increased the number of patients that developed oxygen desaturation.

Table 1. Demographic and clinical characteristics after matching (n = 518)

Variables	Non RRa change (n = 259)	RRa change (n = 259)	*P*-value	Standardised difference
Age (year)	63.3 ± 14.7	62.4 ± 14.2	0.410	0.07
Gender (M/F)	114/145	117/142	0.859	0.01
Height (cm)	160.3 ± 9.7	160.3 ± 8.8	0.989	0.00
Body mass (kg)	58.7 ± 11.2	58.9 ± 12.8	0.848	0.02
Body mass index (kg m^{-2})	22.8 ± 3.7	22.8 ± 4.0	0.925	0.00
%VC (%)	104.2 ± 19.3	104.8 ± 17.4	0.756	0.03
$FEV_{1.0}$ (%)	77.5 ± 10.7	77.6 ± 10.1	0.904	0.01
Pulmonary dysfunction (Y/N)	87/172	78/181	0.456	0.05
ASA physical status (I/II/III)	47/191/21	43/193/23	0.8754	0.01
Hypertension (Y/N)	110/149	116/143	0.656	0.03
Ischemic heart disease (Y/N)	16/243	14/245	0.850	0.01
CHF (Y/N)	1/258	0/259	1.000	0
HD (Y/N)	5/254	5/254	1.000	0
Asthma (Y/N)	6/253	9/250	0.607	0.01
COPD (Y/N)	17/242	15/244	0.425	0.01
DM (Y/N)	52/207	51/208	1.000	0.00
Duration of surgery (min)	236 ± 119	243 ± 124	0.410	0.06
Duration of anaesthesia (min)	304 ± 127	312 ± 129	0.402	0.06
Surgical site Head and neck Abdominal Other	 85 161 13	 82 156 21	0.3439	0.07
Transfusion (Y/N)	33/226	36/223	0.775	0.02
Total fluid balance (mL)	1600 [–500–11120]	1550 [–60–5580]	0.841	–0.01
Anaesthetics Inhalational Intravenous	 195 64	 198 61	0.834	0.01
Rocuronium (mg)	90 [0–250]	90 [0–270]	0.449	–0.05
Remifentanil (µg)	1498 [0–16673]	1512 [0–10421]	0.772	–0.02
Fentanyl (µg)	300 [0–1000]	300 [0–1000]	0.526	–0.04
PCA (Y/N)	153/106	99/160	0.538	0.04
Basal fentanyl dose by PCA (µg h^{-1})	14 [0–45]	14 [0–45]	0.300	–0.07
Mean perfusion index	2.50 ± 1.76	2.52 ± 1.73	0.861	0.01

Primary outcome after matching

	Non RRa change (n = 259)	RRa change (n = 259)	Odds ratio (95% CI)	*P*-value	Effect size
Incidence of oxygen desaturation (n = Yes/No)	39/220 (15.1%)	16/243 (6.2%)	2.56 (1.38–4.55)	0.002	0.19

Values are mean ± SD, median [IQR], or number; FEV_1% — forced expiratory volume 1.0 (sec) %; %VC — % vital capacity; CHF — history of congestive heart failure; HD — on haemodialysis; COPD — chronic obstructive pulmonary disease, DM; diabetes mellitus, Rocuronium, Renmifentanil, and Fentanyl; total doses of these drugs used intraoperatively; PCA — patient controlled analgesia; Basal fentanyl dose by PCA — basal dose of fentanyl continuous administration delivered by a PCA device; RRa — acoustic respiratory rate

The reason for the phenomenon that the incidence of desaturation predominantly occurred in patients without a critical RR change may be due to the effectiveness of the caregiver treatment under RRa monitoring, rather than an increase in the incidence of desaturation due to the absence of a critical RR change. Such individuals could have developed the postoperative oxygen desaturation primarily in cases with a critical RR change as the absence of a critical RR change generally suggests a stable respiratory status. Therefore, despite being described as the "neglected vital sign," continuous RR monitoring may pro-

Table 2. Demographic and clinical characteristics for patients with desaturation and non-desaturation without a critical respiratory rate change

Variables	Desaturation (n = 76)	Non–desaturation (n = 500)	*P*-value
Age (year)	63.5 (14.3)	63.8 (14.0)	0.865
Gender (M/F)	40/36	283/217	0.516
Height (cm)	160.1 (9.7)	160.7 (9.7)	0.645
Body mass (kg)	58.1 (11.0)	58.8 (11.6)	0.587
Body mass index (kg m^{-2})	22.6 (3.5)	22.7 (3.6)	0.771
%VC (%)	100.7 (19.8)	104.9 (18.7)	0.069
$FEV_{1.0}$ (%)	76.4 (9.4)	78.1 (12.1)	0.234
Pulmonary dysfunction (Y/N)	25/51	150/350	0.609
ASA physical status (I/II/III)	10/62/4	89/379/32	0.535
Hypertension (Y/N)	36/40	218/282	0.538
Ischemic heart disease (Y/N)	3/73	22/478	0.857
CHF (Y/N)	0/76	5/495	0.381
HD (Y/N)	2/74	14/486	0.934
Asthma (Y/N)	2/74	19/481	0.613
COPD (Y/N)	8/68	28/472	0.098
DM (Y/N)	13/63	92/408	0.785
Duration of surgery (min)	291 (161)	256 (133)	0.042
Duration of anaesthesia (min)	362 (171)	327 (141)	0.051
Surgical site			
Head and neck	17	132	0.379
Upper Abdominal	10	74	
Lower Abdominal	34	165	
Laparoscopy	12	107	
Other	3	22	
Transfusion (Y/N)	19/57	81/419	0.059
Total fluid balance (mL)	1950 (1266 to 2941)	1783 (1080 to 2440)	0.073
Anaesthetics			
Inhalational	55	378	0.543
Intravenous	21	122	
Rocuronium (mg)	95 (70 to 110)	92 (60 to 127)	0.976
Remifentanil (μg)	1548 (802 to 2553)	1464 (590 to 2673	0.378
Fentanyl (μg)	300 (200 to 500)	300 (200 to 450)	0.420
PCA (Y/N)	54/22	338/162	0.548
Basal fentanyl dose by PCA (μg h^{-1})	15.0 (0–55)	14.0 (0–42)	0.732
Mean perfusion index	2.07 (2.33)	2.37 (1.68)	0.175

Variables are expressed as mean ± (SD), median (IQR), or number; $FEV_{1\%}$ — forced expiratory volume 1.0 (sec) %; %VC — % vital capacity; Pulmonary dysfunction — a case who had FEV1% < 70 or %VC < 80; ASA — American Society of Anesthesiologists; CHF — history of congestive heart failure; HD — on haemodialysis; COPD — chronic obstructive pulmonary disease; DM — diabetes mellitus; surgical site — "Upper abdominal" means supra-umbilical procedures, "Lower abdominal" means infra-abdominal procedures, and "Laparoscopy" means any laparoscopic procedures. Rocuronium, Renmifentanil, and Fentanyl — total doses of these drugs used intraoperatively; PCA — patient controlled analgesia; Basal fentanyl dose by PCA — basal dose of fentanyl continuous administration delivered by a PCA device

Table 3. Multivariate logistic regression model for desaturation without a critical acoustic respiratory rate change

	Odds ratio	95% CI	*P*-value
%VC per 10%	0.878	0.771 to 1.001	0.052
Duration of surgery per 10 min	1.018	1.002 to 1.035	0.033

%VC — % vital capacity; Coexisting COPD, total fluid balance, and transfusion requirement were excluded from the model during the stepwise backward elimination process

vide additional benefits for detecting hypoventilation before desaturation under oxygen administration [15]. In fact, we think that our postoperative monitoring system has nicely prevented developing desaturation in the majority of cases presenting an abnormal RR. However, it might be true that our system is weak in preventing desaturation in cases without presenting an abnormal RR or those unrelated with one's breathing pattern, which we initially supposed was a small minority.

Desaturation under oxygen administration without a critical RR change monitored by RRa devices was observed in 13.2% of all patients without a critical RR change. Surgery duration may be independently associated with oxygen desaturation without a critical RR change, although the logistic regression model fit was not ideal. In addition, the discriminatory power of the final model assessed by the c-statistic is only slightly better than chance. Moreover, the area under the ROC curve using the independently associated factor of surgery duration was 0.559 and had a weaker discriminatory power than the c-statistic value. In this context, the cut-off value of 296 min showed a sensitivity of 46.1% and a specificity of 66.6%, which is not a useful discriminatory tool for oxygen desaturation without a critical RR change monitored by RRa devices. It is likely that other confounding factors were present in this background. For example, this may have been due to delayed elimination of anaesthetic agents impairing the ventilatory response to hypoxemia rather than the duration of surgery itself.

Our study has several limitations. To minimize the effect of selection bias on the patient outcomes, we used propensity score matching to the clinical characteristics to reduce distortion by confounding factors. However, this study was retrospective in nature; thus, unmeasured variables could still have confounded our results. Second, acoustic waveforms obtained for patients exhibiting a critical RR change were not confirmed by the simultaneous listening of breathing sounds from the acoustic signal as specific software (TagEditor, Masimo Corp.) was necessary for the analysis. Therefore, some of the patients that were excluded during pre-screening may have shown a true positive critical RR change. In contrast, recording or reading errors in normal acoustic waveforms are rare. Thus, it is likely that a false negative critical RR change determined by RRa did not significantly affect our results. Another potential limitation of this study is that critical RR changes or oxygen desaturation might have occurred during the artifactual periods detected by the Masimo algorithms. However, a system status alert would have made the nurses aware of the problem, and likely did not alter the results of the study. Furthermore, the response of the healthcare providers may depend on the protocol of intervention, as well as the staff-to-patient ratio in the hospital. As another concern, namely the reliability of oximetry used in the present study, is one of the pivotal factors in the detection of desaturation. We used a Masimo oximetry sensor (LNCS Adtx, Masimo Corp.), which provides not only SpO_2 but also PR and PI values. Desaturation in some patients may have been due to inaccurate SpO2 measurements during impaired peripheral perfusion. However, in our study population, no significant difference in PI was observed between the group without a critical RR change and the group with a critical RR after propensity score matching. Therefore, we conclude that inaccuracy of measurements does not fully account for our findings. Finally, a considerable number of patients were excluded from the study although the application of RRa monitoring was limited due to a shortage of RRa devices.

CONCLUSIONS

Our propensity score analysis of the patient data confirmed the paradoxical phenomenon that the absence of a critical RR change increased the incidence of desaturation under our postsurgical monitoring settings. This might suggest that the absence of an abnormal RR does not always guarantee that patients did not develop desaturation under the postoperative management protocol based on RR monitoring. Although the duration of surgery may explain the possibility of postoperative oxygen desaturation in the absence of an abnormal RR, its discriminatory power is not particularly strong. While continuous RR monitoring by acoustic technology may contribute to patient safety, one needs to know that standard oxygenation and ventilation monitoring is not sufficient for a certain postoperative population.

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3. Conflicts of interest: none.

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