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EDITORIAL

Perioperative monitoring of the oxygen reserve: where do we stand?

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Abstract

The Oxygen Reserve Index (ORi) is an advanced plethysmography-derived variable that may help to quantify the degree of hyperoxia in patients receiving supplemental oxygen administration. ORi is a (relative) indicator of the actual partial pressure of oxygen dissolved in arterial blood (PaO_2). As such, it may help in the titration of oxygen administration or it may help to warn the clinician of a deterioration of oxygen status of the patient.

In this issue of the journal, Fadel et al. provide a 'classical' clinical validation study by assessing the correlation between ORi and PaO_2 in patients about to undergo open-heart surgery. Within the moderate hyperoxic range (100–200 mmHg PaO_2), there is a sound correlation between ORi and PaO_2. This editorial discusses the clinical implications of this validation study and elaborates on the possible role of ORi monitoring in addition to SpO_2 (peripheral arterial oxygen saturation) monitoring alone.

A fundamental goal for the anesthesiologist is to maintain oxygenation in patients undergoing any form of anesthesia, as firmly stated by the ASA basic anesthetic monitoring requirements: "*During all anesthetics, a quantitative method of assessing oxygenation such as pulse oximetry shall be employed"* [1]. Peripheral oxygen saturation (SpO_2) readily detects whether the oxygenation status of a patient changes from a non-hypoxic state to a hypoxic state, allowing clinicians to take appropriate measures for restoration of oxygenation [2]. In contrast, the difference between normoxia and hyperoxia is not easily made using SpO_2 monitoring alone: high-range SpO_2 values may relate to a wide range of associated PaO_2 values. Clinically, it is relevant to detect and quantify hyperoxia: (1) during certain perioperative phases, hyperoxia provides an 'oxygen reserve' that increases patient safety should oxygenation be at risk; and (2) on the other hand, hyperoxia is possibly associated with adverse postoperative outcome [3, 4].

The Oxygen Reserve index (ORi™) was developed ''*to provide insight into a patient's oxygen status in the moderate hyperoxic range ($PaO_2 > 100$ and ≤ 200 mmHg)*" according to the manufacturer (Masimo Corporation, Irvine, California, USA). The ORi value ranges between 0.0 and 1.0, was validated early after its introduction [5, 6] and several clinical studies using ORi monitoring for different purposes were conducted the last few years: for example, the detection of impending hypoxia during (induction of) general anesthesia [7–9], during tracheal surgery [10, 11], or one-lung ventilation [12, 13] and as a measure of the adequacy of preoxygenation [14–17]. Alternatively, it was used to assess the degree of hyperoxia [18–20], and subsequently to allow the titration of inspiratory O_2 fraction, either perioperatively [18, 20], on the ICU [19] or postoperatively [21].

In this issue of the journal, Fadel et al. provide a 'classical' clinical validation study by assessing the correlation between ORi and PaO_2 in patients about to undergo open-heart surgery [22]. ORi, PaO_2 and SpO_2 were determined before the induction of general anesthesia while patients were still breathing room air, and during a subsequential step-up hyperoxia phase in which FiO_2 was increased incrementally by 0.08 from 0.22 to 0.94. Most importantly, the authors observed a sound (linear) correlation between ORi and PaO_2 in the moderate hyperoxic range ($r = 0.819$,

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$p < 0.001$) – which is consistent with previous literature [5, 6].

As already expressed, ORi monitoring may be useful for two separate indications, the first being a warning tool for impending hypoxia. The study by Fadel et al. does not elaborate on this issue: in their study a fixed step-up titration of FiO_2 was performed, but it would have been clinically relevant to assess the ORi-PaO_2 relationship during a step-down FiO_2 protocol too, even though such a study would be even more time- and resource-consuming if conducted in a clinical setting. Although SpO_2 values of 96% or lower were consistently associated with low ORi values between 0.0-0.2 – see Fig. 3 of the study – this does not take into account the temporal dynamics of 'impending hypoxia' as has been assessed in a number of studies previously [10, 11]. Of note, there were even a few outliers with PaO_2 values between 125 and 150 mmHg at an ORi value below 0.2. For the second indication of ORi monitoring – aiding in the titration of FiO_2 – the study by Fadel et al. provides useful information to the clinician: at higher SpO_2 values, especially at 99–100% values, ORi values show a large variability, ranging from about 0.15 to 1.0, indicating that specifically in this range of SpO_2 values, ORi monitoring may be complementary to SpO_2 monitoring alone, by adding information about the actual oxygen reserve. To be more precise, an ORi value of 1.0 was always associated with a $PaO_2 > 150$ mmHg (Fig. 1) and in most cases PaO_2 levels ≥ 200 mmHg can be expected with an ORi value of 1.0. At a $PaO_2 > 250$ mmHg, the ORi was always 1.0. This is however in contrast to previous studies, showing a wide variability of ORi values (between 0.3 and 1) at a $PaO_2 > 250$ mmHg [5, 6]. The difference may partially be explained by differences in study designs. In fact, in a validation study conducted in healthy volunteers, less time elapsed from FiO_2 variations and blood gas analyses, compared to the Fadel study (2 versus 5 min), allowing less time for an equilibration between ORi readings, actual FiO_2 and subsequent arteriovenous oxygenation [5]. Instead, in another study conducted during surgery, blood gases were obtained when clinically indicated and, therefore, the oxygenation status and the clinical condition of the patient might not have been at a steady state at all [6]. The tight relationship between an ORi of 1.0 and a $PaO_2 > 200$ mmHg can inform the clinician of the presence of hyperoxia but also of a consistent oxygen reserve (e.g. during preoxygenation). On the other side, even at high PaO_2 – presumably with a 100% SpO_2 on the monitor – the ORi might sometimes be "falsely" low as can be seen in Fig. 3 and may therefore be less informative about the "real" oxygen reserve, with the possible exception of a tightly controlled setting as in the Fadel study.

There are some aspects of the study by Fadel et al. that the reader should take into account. Data were analyzed using (linear) correlation analysis without accounting for multiple measurements per patient – and it may be debated whether correlation analysis should have been adapted accordingly. Also, sensitivity and specificity of ORi and SpO_2 were compared at higher PaO_2 values. However, since SpO_2 is not intended to monitor hyperoxia and ORi is meant to *complement* (but not replace) SpO_2, we believe that this comparison is of limited clinical value.

In conclusion, the study by Fadel et al. adds clinically relevant information for the interpretation of ORi values in *addition* to SpO_2 monitoring alone. If hyperoxia was a concern, ORi values of 0.7-1 (generally reflecting a $PaO_2 > 150$ mmHg) may encourage a reduction of FiO_2. Instead, if hyperoxia is a clinical target (e.g. during preoxygenation), reaching an ORi of 1.0 can often guarantee a $PaO_2 > 200$ mmHg. Finally, intermediate ORi values (0.2–0.5, roughly corresponding to a PaO_2 of 100–150) might help rule out extreme hyperoxia, but also warn the clinician of a probably limited oxygen reserve in case of a suddenly impaired oxygenation. Especially this latter aspect requires further elucidation by carefully conducted studies, yet it would help the clinician if (future versions of) ORi would allow a consistent assessment of oxygenation beyond its current – narrow – sensitivity range.

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Declarations

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