

Rethinking perioperative oxygen therapy

Perioperatif oksijen kullanımı

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ABSTRACT

Oxygen administration is foundational in anesthesiology and perioperative medicine, yet growing evidence challenges the routine use of high inspired oxygen concentrations. While preventing hypoxia remains essential during induction, emergence, and perioperative urgencies, both hypoxia and hyperoxia carry significant risks—including inflammation, oxidative stress, vasoconstriction, and impaired organ perfusion. These effects are especially pronounced in high-risk surgical patients. Recent advances in noninvasive hemodynamic and oxygenation monitoring now allow dynamic, individualized titration of oxygen delivery (DO₂), moving beyond conventional SpO₂ targets. Guidelines from cardiovascular societies increasingly support focused oxygenation goals during perioperative cardiac and cerebro-vascular emergencies. In the context of perioperative complexity and management of high-risk patients, anesthesiologists are uniquely positioned to lead a shift toward goal-directed oxygen therapy. Recognizing oxygen as a dose-dependent drug offers an opportunity to optimize outcomes through a nuanced, physiology-informed approach to intraoperative and perioperative care.

Keywords: oxygen, oxygen delivery, hypoxia, hypoxemia, hyperoxia, surgery, hemoglobin, cardiac output, blood pressure, acute kidney injury, organ injury

ÖZ

Oksijen kullanımı perioperatif dönemin önemli öğelerinden birisidir. Ancak, son yıllarda yüksek inspiratuar oksijen konsantrasyonlarının rutin kullanımı sorgulanmaktadır. Perioperatif dönemde hem hipoksi hem de hiperoksi önemli riskler taşır — bunlar arasında inflamasyon, oksidatif stres, vazokonstriksiyon ve organ perfüzyonunun bozulması yer alır. Bu organ hasarları, özellikle kardiyak -torasik cerrahilerde ve yüksek riskli hastalarda daha belirgin olarak gözlenmiştir.

Noninvaziv hemodinamik ve oksijenizasyon monitörizasyonunda son gelişmeler oksijen sunumunun (DO₂) dinamik ve bireyselleştirilmiş şekilde ayarlanmasına olanak tanımakta, ve geleneksel SpO₂ hedeflerinin ötesine geçmektedir. O nedenle perioperatif kardiyak ve serebrovasküler girişimlerde hedeflenmiş oksijen sunumu yaklaşımı giderek önem kazanmaktadır. Oksijenin, dozu ayarlanan bir ilaç olarak görülmesi, intraoperatif ve perioperatif bakımda fizyolojik temellere dayanan bir yaklaşımla uygulanması hastalarımızın cerrahi sonuçlarının iyileşmesine daha faydalı olabilir.

Anahtar kelimeler: oksijen, oksijen sunumu, hipoksi, hipoksemi, hiperoksi, cerrahi, hemoglobin, kardiyak output, kan basıncı, akut böbrek hasarı, organ hasarı

Oxygen, defined as the ‘vital essence of life’ by Joseph Priestley in 1774, has long been central to medical practice. Over the centuries, our understanding of its physiological roles and therapeutic applications has expanded significantly. Recently, we started exploring when and how to adjust its dose and explore the outcomes of oxygen therapy. While oxygen is essential

for survival, the balance between insufficient oxygen (hypoxia) and excessive levels (hyperoxia) end up being critical. Both extremes -in other words, outside of the dose range- may cause tissue and organ damage, and situational - environmental factors may further exacerbate the damage.

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Oxygen debt

Hypoxia exacerbates inflammation by stabilizing nuclear factor- κ B and increasing the expression of Toll-like receptors, thereby attracting inflammatory cells. This cascade amplifies sterile inflammation, as seen in myocardial ischemia-reperfusion injury, resulting in collateral tissue damage (1).

Oxygen excess

Conversely, hyperoxia is increasingly recognized as harmful. Excess oxygen can trigger oxidative stress and endothelial dysfunction, inhibit nitric oxide synthase, and reduce nitric oxide availability (2,3). These effects lead to prominent vasoconstriction in cerebral and coronary arteries, reduced cardiac output, and impaired organ perfusion. Hyperoxia can facilitate neutrophil migration and exacerbate the reperfusion injury by promoting reactive oxygen species (ROS) production (4).

Perioperative period, inspired oxygen & oxygenation

In perioperative care, oxygen management is particularly critical. During intubation and extubation of the airway, high inspired oxygen concentrations are required to prevent hypoxia resulting from apnea or hypopnea. During surgery and maintenance of anesthesia, high oxygen concentrations may help to reduce surgical site infections (5,6). Perioperative pain may further decrease tissue oxygenation (7). Although there is some controversy (8), CDC and WHO recommend using high inspired oxygen concentrations during the perioperative period (9,10).

Diminished oxygenation during critical moments in surgery can impair cellular metabolism, leading to ischemia, mitochondrial dysfunction, and organ failure. For instance, low oxygen delivery (DO_2) during cardiopulmonary bypass has been associated with acute kidney injury, prolonged mechanical ventilation, and poorer outcomes (11). However, there is also emerging evidence linking supraphysiologic oxygen levels to pulmonary, renal, and myocardial injuries perioperatively (2).

Oxygenation in high-risk patients

Ensuring adequate oxygenation in high-risk patients is essential, as insufficient oxygen delivery and resulting tissue hypoxia during surgery can lead to cascading effects on multiple organ systems. Hypoxia not only compromises cellular energy production but also triggers inflammatory responses (1). These processes can accelerate organ dysfunction, increase perioperative morbidity, and prolong recovery times. Consequently, respected guidelines from international cardiovascular societies now emphasize the importance of maintaining adequate DO_2 levels during cardiac procedures (12). Expanding these principles to non-cardiac high-risk surgeries, such as major abdominal and orthopedic operations, could significantly mitigate complications and improve patient outcomes.

Perioperative monitorization of oxygen delivery

Technological advancements are enabling monitoring of DO_2 minimally invasively, offering an opportunity to minimize the risks of both hypoxia and hyperoxia. Real-time continuous monitoring tools, such as non-invasive pulse co-oximetry for hemoglobin monitoring and stroke volume-based minimally invasive cardiac output monitoring (13,14), allow clinicians to tailor oxygen therapy dynamically with specific focus on the oxygen delivery (DO_2). This integration of advanced monitoring enables precise adjustment of oxygen therapy to each patient's unique physiological needs, allowing clinicians to manage key determinants of oxygen delivery—such as cardiac output and oxygen content. This shift in focus moves us beyond simple oxygen dosing toward personalized, outcome-driven goals centered on optimizing tissue oxygenation.

Perioperative oxygen therapy cannot be considered in isolation. A complex interplay of factors like blood pressure (15,16), fluid management, and ventilation strategies also influence DO_2 both directly and indirectly. These interactions further emphasize the need for an individualized physiologic approach to care, especially for sicker patients undergoing high-risk surgeries (17).

Acute cardiac & cerebro-vascular events during surgery

Despite medical advancements, acute cardiac and cerebro-vascular events may occur during surgery, and it's important to adjust our oxygen therapy to respond to these acute events. Recent guidelines underscore the critical role of individualized oxygen therapy across various cardiovascular and cerebrovascular conditions. For acute myocardial infarction (MI), the American Heart Association (AHA) guidelines recommend withholding oxygen supplementation in normoxic patients with suspected or confirmed acute coronary syndrome in all care settings (18). In cases of acute heart failure, the European Society of Cardiology (ESC) guidelines advocate oxygen therapy for patients experiencing hypoxemia ($\text{SpO}_2 < 90\%$ or $\text{PaO}_2 < 60$ mmHg) while advising against its routine use in those

without hypoxemia (19). Following cardiac arrest, the AHA guidelines promote a titrated approach to oxygen therapy, targeting an SpO_2 range of 94–98% after the return of spontaneous circulation to balance the risks of hypoxia and hyperoxia (20). For ischemic stroke, the AHA guidelines recommend maintaining oxygen saturation above 94%, emphasizing the importance of oxygen therapy in optimizing tissue oxygenation and mitigating the risks associated with excessive oxygenation (21). In the perioperative period, these principles suggest maintaining SpO_2 between 94–98% while avoiding $\text{SpO}_2 > 98\%$ other than the intubation and extubation of the airway as well as other medical emergencies (e.g., anaphylaxis). These tailored approaches highlight the necessity of precision in oxygen therapy to improve patient outcomes and minimize complications (Table 1).

Table 1. Perioperative oxygen therapy

Oxygen Therapy	Pre-operative Period	Intra-operative Period	Post-operative Period
Benefits	- Optimizes oxygen saturation and reduces risk of hypoxia in high-risk patients	- Required before intubation and extubation of airway to prevent hypoxia Enhances tissue oxygenation during surgery - May decrease the risk of SSI	- May enhance wound healing - Reduces hypoxia related complications in vulnerable patients
Harms	- Potential for hyperoxia causing oxidative stress - May delay recognition of respiratory decline	- Hyperoxia causes vasoconstriction in coronary & cerebral vessels, decreases HR & CO, and may initiate oxidative damage - Increases risk of absorption atelectasis	- Prolonged use may cause dependency - May pose the risk of oxygen toxicity - May delay & limit mobilization
Opportunities	- Provides apneic oxygenation	- DO_2 targeted oxygen therapy may prevent intraoperative tissue-organ injury - Potential to reduce SSI	- Early weaning to minimize dependency - DO_2 optimization may enhance recovery by preserving organ functions

Suggested Oxygenation Goals During Acute Medical Problems in the Perioperative Period

Acute MI	Guidelines recommend withholding oxygen supplementation in normoxic patients with suspected or confirmed acute coronary syndrome in all care settings [Suggested perioperative SpO_2 goal $> 92\%$ and $< 99\%$]*
Heart Failure	Guidelines recommend oxygen therapy for patients with acute heart failure and SpO_2 of $< 90\%$ or PaO_2 of < 60 mmHg to correct hypoxemia. [Suggested perioperative SpO_2 goal $> 92\%$ and $< 99\%$]*
Cardiac Arrest	Guidelines recommend a titrated and individualized oxygen therapy strategy for patients after cardiac arrest with a target SpO_2 of 94–98% after the return of spontaneous circulation, and avoiding hyperoxia [Suggested perioperative SpO_2 goal $> 94\%$ and $< 99\%$]*
Ischemic Stroke	Guidelines recommend providing oxygen therapy to maintain an oxygen saturation level of $> 94\%$ [Suggested perioperative SpO_2 goal $> 94\%$ and $< 99\%$]*

DO_2 : oxygen delivery, SSI: surgical site infections, HR: heart rate, CO: cardiac output, FiO_2 : inspired oxygen concentration, MI: myocardial infarct, SpO_2 : pulse oximeter saturation. [Lower part of the visual (acute medical problems part) was inspired by Conrad & Eltzschig.] (26)

* These perioperative SpO_2 goals exclude the periods referring to induction of and emergence from general anesthesia and the other medical emergencies. Additionally, the upper levels of presented SpO_2 goals represent the author's opinion and suggestions.

Discussion

Given the growing complexity of surgical populations, particularly as more elderly and comorbid patients undergo major procedures, a personalized approach to oxygen therapy is increasingly needed. Oxygen therapy demands precision and caution (22,23). Advances in minimally invasive to noninvasive monitoring technologies and a deeper understanding of oxygenation physiology enable clinicians to deliver oxygen with greater efficacy and safety.

Treating oxygen as a therapeutic intervention rather than a universally benign agent marks a paradigm shift in perioperative medicine (24). Advances in monitoring and a deeper understanding of oxygen delivery physiology pave the way for safer, more effective practices (25). By embracing personalized oxygen therapy and integrating it into comprehensive perioperative strategies, clinicians can optimize outcomes for high-risk surgical patients and uphold the principles of evidence-based medicine.

Author contribution

Study conception and design: OA; data collection: OA; analysis and interpretation of results: OA; draft manuscript preparation: OA. The author(s) reviewed the results and approved the final version of the article.

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Conflict of interest

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