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Monitoring of perioperative tissue perfusion and impact on patient outcomes

Bin Li[1], Yuchen Dai[2], Wenlan Cai[2], Menghan Sun[1] and Jie Sun[1,2*]

Abstract
Monitoring perioperative tissue perfusion is crucial in clinical anesthesia to protect organs and ensure patient safety. Indicators like hemodynamic parameters, tissue metabolism, and microcirculation markers are used for assessment. Studies show intraoperative hypotension negatively impacts outcomes, though blood pressure alone may not reflect tissue perfusion accurately. Cardiac output is a more direct measure, with adequate levels generally indicating good perfusion. However, some conditions cause adequate cardiac output but inadequate perfusion. Non-quantitative markers like skin color and temperature, and quantitative indicators like tissue oxygen saturation and laser Doppler flowmetry, help assess microcirculation but can't fully evaluate systemic perfusion. Near-Infrared Spectroscopy (NIRS) monitors tissue oxygen metabolism, reflecting oxygen supply and consumption balance. Central venous oxygen saturation offers a better systemic overview but may not always indicate good perfusion, especially in sepsis. Lactic acid levels closely correlate with tissue perfusion and outcomes, with dynamic changes being more indicative than single measurements. Effective monitoring requires evaluating both macro- and microcirculation states and systemic metabolic levels to ensure optimal outcomes. Combining these measures provides a more accurate assessment of tissue perfusion and patient prognosis.

Keywords Perioperative, Tissue perfusion monitoring, Hemodynamic, Metabolic indicators, Patient outcomes

Introduction

The role of anesthesiologists has often been misunderstood by the public. While the primary purpose of anesthesia is to alleviate pain and induce narcosis, a crucial component of the anesthesiologist's work is perioperative monitoring to ensure the patient's homeostasis is maintained throughout surgery. Therefore, perioperative monitoring of the patient's vital functions is of paramount importance. During the perioperative period, the monitoring of tissue perfusion is essential for protecting vital organs and ensuring the patient's safety and recovery [1]. The indicators of tissue perfusion include hemodynamic parameters, like blood pressure, heart rate, cardiac output, as well as blood flow in specific organs. Indicators of tissue metabolism, e.g. venous oxygen saturation, tissue oxygen saturation, lactate levels and pH value, can also reflect tissue perfusion. This review will explore the clinical monitoring of tissue perfusion and its impact on patient outcomes.

The effect of blood pressure and tissue perfusion on patient outcomes

Study on the risk of blood pressure on organ injury and patient prognosis began in the early 1950s. In a previous study investigating risk factors for postoperative organ dysfunction, Fred Wasserman reported 25 cases of postoperative myocardial infarction and found that a decrease

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Table 1 Different perspectives on Perioperative Hypotension and adverse outcomes in recent years

Years (Authors)	Study Type	Blood Pressure Type	Conclusion
2017(Futier and colleagues)	Multicenter RCT	SBP	Among patients predominantly undergoing abdominal surgery who were at increased postoperative risk, management targeting an individualized systolic blood pressure, compared with standard management, reduced the risk of postoperative organ dysfunction.
2020(Sanchit and colleagues)	Post-hoc re-analysis of a large single-center retrospective cohort	Systolic, mean, diastolic pressures, along with pulse pressure (difference between systolic and diastolic pressures)	Absolute population risk thresholds were similar for myocardial and kidney injury on the lowest intraoperative pressure maintained for at least 5 min. The thresholds were roughly 90 mmHg for systolic, 65 mmHg for mean, 50 mmHg for diastolic, and 35 mmHg for pulse pressures. Among the components, systolic and mean pressures were most predictive, but only by small margins.
2021 (Wanner and colleagues)	Single-center RCT	MAP	Despite a 60% reduction in hypotensive time with MAP <65 mm Hg, no significant reductions in acute myocardial injury or 30-day MACE/AKI could be found.
2021 (Meng L)	Review	N/A	Hypotension does not always lead to organ hypoperfusion. Overall RCT evidence does not support the notion that a higher BP target always leads to improved outcomes.

Abbreviations: RCT, Randomized Controlled Trial; SBP, Systolic Blood Pressure; MAP, Mean Arterial Pressure; MACE, Major Adverse Cardiovascular Events; AKI, Acute Kidney Injury

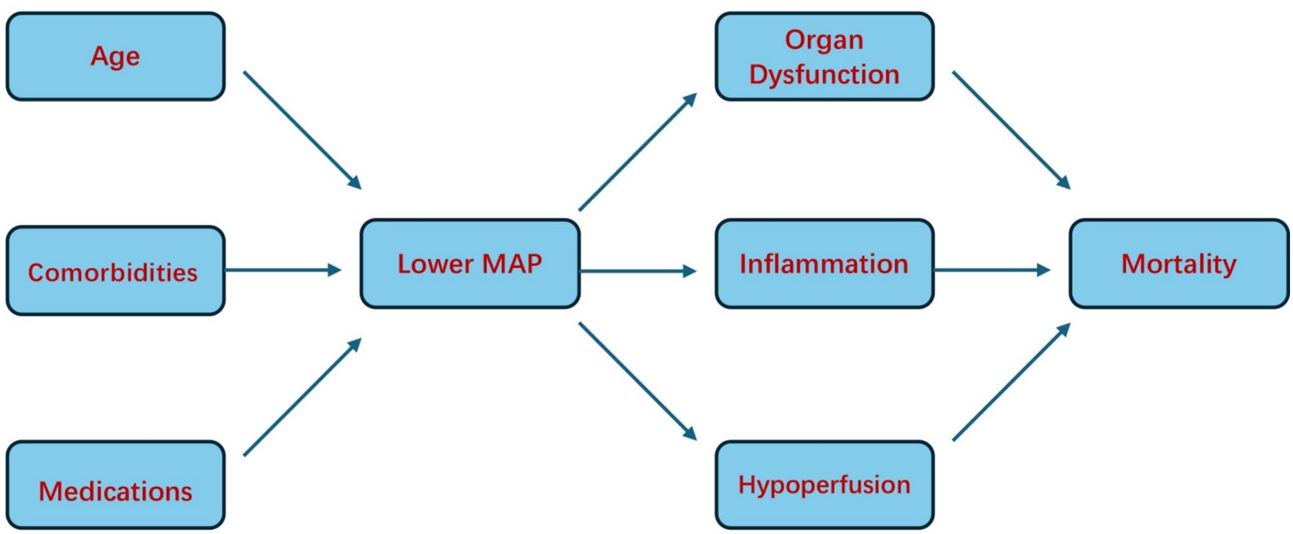

Fig. 1 Blood pressure and mortality relationship with potential confounding variables

in systolic blood pressure of 40 mmHg (or more) and a decrease in diastolic blood pressure of 20 mmHg or more intraoperatively, was associated with postoperative myocardial infarction [1]. Similarly, Lee Goldman found that a decrease in intraoperative systolic blood pressure (SBP) to less than 50% of preoperative levels or a decrease of 33% or more for more than 10 min was one of the independent correlates of perioperative cardiac complications [2]. In a retrospective study carried out by Terri G. Monk, intraoperative SBP below 80 mmHg was an independent risk factor for increased one-year mortality after noncardiac surgery [3].

Recent evidence underscores the complex relationship between perioperative hypotension (POH) and adverse outcomes. Various studies have proposed different definitions for clinically significant hypotension, including systolic blood pressure below 90 mmHg or a drop exceeding 20% of baseline mean arterial pressure (MAP). These discrepancies highlight the need for consensus on defining actionable thresholds to prevent adverse events. A summary of recent perspectives is provided in Table 1, showcasing emerging insights into the impact of POH on patient outcomes [4–7]. This highlights the complexity of managing perioperative hemodynamics and the necessity of personalized approaches to patient. These perspectives emphasize the importance of integrating advanced monitoring techniques to identify perioperative hypotension early and guide hemodynamic optimization strategies tailored to individual patient risk profiles.

In exploring the relationship between MAP and mortality, it is important to note that while lower MAP has been associated with increased mortality, causality cannot be assumed. A Directed Acyclic Graph (DAG) representation of the relationship between blood pressure and mortality highlights the potential confounding variables, such as underlying comorbidities, that could influence this relationship (Fig. 1). As shown in the DAG, while a direct relationship between lower MAP and increased mortality is evident, it is crucial to consider that this relationship may be influenced by unmeasured confounders. Thus, while the correlation between lower MAP and mortality is evident, further studies are needed to clarify whether this association is truly causal.

The effect of blood flow and tissue perfusion on patient outcomes

The relationship between blood pressure and blood flow is illustrated in Fig. 2. However, it is important to emphasize that blood pressure alone cannot fully reflect organ blood flow. For example, two cases with identical MAP show distinctly different tissue perfusion (as demonstrated in Supplemental Fig. 1). As Meng et al. have suggested, blood pressure is not always a reliable indicator of tissue perfusion [8]. In certain cases, hypotension, regardless of whether it is defined by low MAP or SBP, can cause organ damage, thereby increasing perioperative complications and mortality. Therefore, the relationship between blood pressure and blood flow should be understood as associative rather than causal, and other factors must be considered in assessing patient outcomes [8–10].

Cardiac output reflects organ blood flow more directly than blood pressure. In general, adequate cardiac output ensures sufficient tissue blood flow. On the contrary, low cardiac output, whether cardiogenic or noncardiogenic, leads to inadequate tissue perfusion, and poor patient outcomes [11–13]. Improving cardiac output with corresponding countermeasures can improve patient outcomes [14]. In the cases when cardiac output is mainly supported by medication, or in certain disease states such as sepsis, abdominal compartment syndrome and some heart failure states, cardiac output is relatively normal but tissue perfusion is severely insufficient, resulting in poor patient outcomes. Possible reasons include unstable cardiovascular function (heart failure with preserved ejection fraction), abnormal vascular access, abnormal cellular metabolism, elevated venous pressure, and others. A case of heart failure with preserved ejection fraction (HFpEF) is shown in Fig. 3, where cardiac output and blood pressure are within normal ranges, yet tissue perfusion is significantly inadequate. This highlights the importance of monitoring both cardiac output and tissue perfusion, as good hemodynamic status does not always correlate with optimal organ perfusion.

Recent studies, such as the OPTIMISE II trial [15], a large multicenter randomized controlled study, explored the effects of optimizing cardiac output using goal-directed therapy (GDT) in high-risk surgical patients. While the trial aimed to improve postoperative outcomes, such as mortality, morbidity, and length of stay, it did not show significant improvements despite optimizing cardiac output. This highlights a crucial point: blood pressure and cardiac output alone may not fully reflect organ blood flow or tissue perfusion, and focusing solely on these parameters may not always lead to clinical benefits. As the trial results suggest, optimizing cardiac output through traditional hemodynamic interventions may not account for other critical factors influencing patient outcomes, such as microcirculatory dysfunction, tissue oxygenation, and cellular metabolism. These factors may not be directly addressed by optimizing cardiac output alone, emphasizing the need for a more comprehensive approach. In line with this, integrating multiple monitoring techniques—such as near-infrared spectroscopy (NIRS), central venous oxygen saturation (ScvO2), and lactate levels—could provide a more complete picture of tissue perfusion and oxygen delivery. This broader approach could help identify at-risk patients more accurately and guide tailored therapeutic strategies, improving overall patient care.

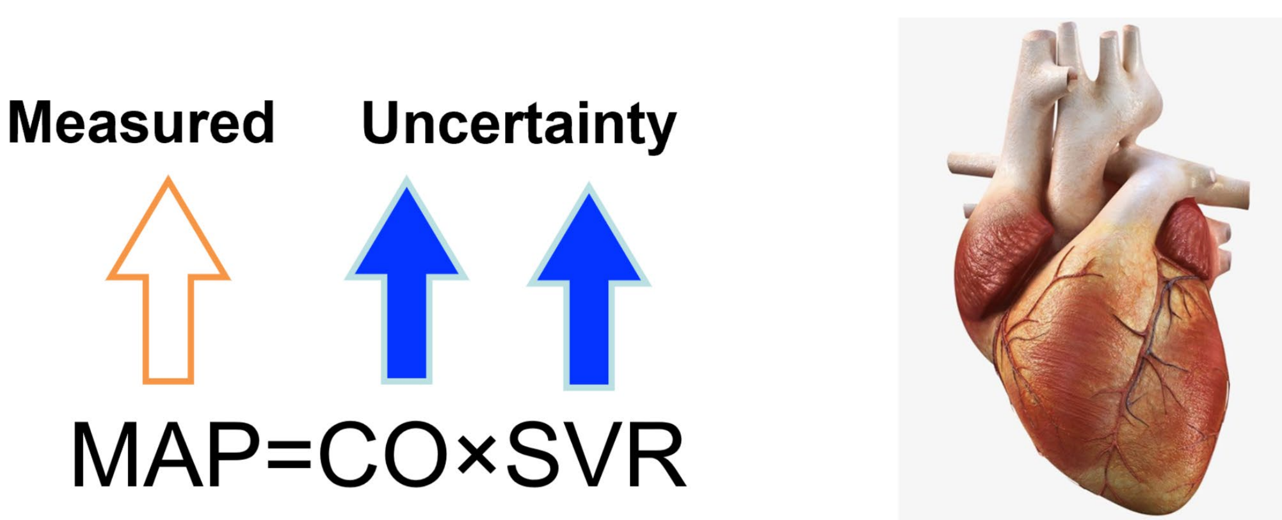

Fig. 2 The relationship between blood pressure and blood flow

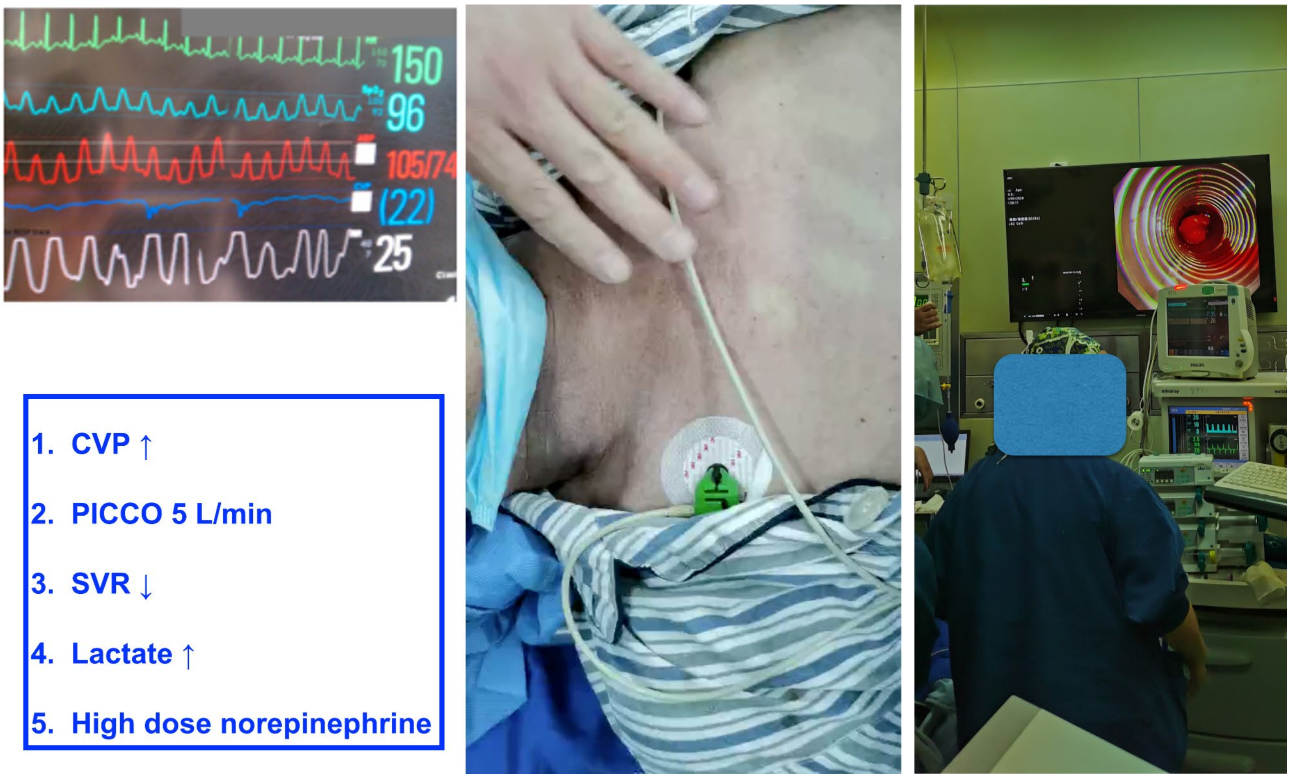

Fig. 3 Heart failure with preserved ejection fraction, with decent cardiac output and blood pressure, but inadequate tissue perfusion

The influence of microcirculation monitoring and tissue perfusion on patient outcomes

The non-quantitative markers of microcirculation monitoring included the color and temperature of skin and mucosa and peripheral vascular filling degree. In recent years, many quantitative and visual microscopic indicators have been invented, such as tissue oxygen saturation, transcutaneous oxygen pressure, Ppv-aCO2, pulse perfusion index, laser Doppler flowmeter, micro vessel illumination device, etc. In most studies with small sample size, these quantitative microcirculation indicators are closely related to the prognosis of patients [16–18]. Study on the microcirculation in sepsis found that: compared with the survival group, the heterogeneity index (HETERO), De Backer score, microcirculation flow index (MFI), perfusion vascular density (PVD), total vascular density (TVD) and other indicators representing microcirculation in the death group were significantly decreased, and further analysis showed that microcirculation indicators were closely correlated with the prognosis of patients. The hemodynamic parameters such as blood pressure, heart rate, perfusion pressure and central venous pressure had no significant correlation with microcirculation. The possible reason is that blood pressure does not represent blood flow, and cardiac output does not represent local blood flow. The effect of laser Doppler flowmeter, to monitor local superficial tissue blood flow, has been recognized in the area of microsurgery and burn and plastic surgery. Nevertheless, there were not many studies to observe the relationship between laser Doppler and prognosis. Most studies believed that peripheral perfusion index (PPI) was significantly related to the prognosis of patients. Some studies also found that low PPI was not necessarily related to tissue hypoperfusion. One possible reason is that PPI is measured based on preoperative pulse oximetry, which can be affected by peripheral circulation state and stability of pulse oximetry signal. In general, microcirculation monitoring seems to be a good way to monitor microcirculation. However, due to the different sensitivity and specificity of various methods, and all of them are local monitoring indicators they cannot be used to evaluate the systemic microcirculation state. Besides, it's far from enough to only use microcirculation markers to predict prognosis.

Monitoring tissue perfusion is crucial for understanding organ function and predicting patient outcomes. This involves evaluating the balance between oxygen supply and consumption throughout the body and its organs. Multiple methodologies are available to assess blood flow in different tissues, including clinical observation, hemodynamic monitoring, and more advanced, organ-specific techniques. As mentioned earlier, both systemic and organ-specific perfusion monitoring provide crucial insights for patient management in the perioperative period. Various methods are employed to assess perfusion across different anatomical regions, helping to evaluate the adequacy of perfusion and predict potential complications (Fig. 4).

Whole Body Includes clinical signs, hemodynamic monitoring, and DO_2/VO_2 balance indicators like SVO_2 or $ScVO_2$, along with metabolic markers such as lactate and pH.

Brain Focuses on assessing cerebral perfusion using tools like transcranial Doppler flow, CT, and MRI, as well as monitoring cerebral oxygenation via NIRS.

Heart Involves blood flow monitoring, ECG for rhythm disturbances, and myocardial enzymes to evaluate myocardial perfusion.

Kidney Utilizes organ blood flow techniques such as angiography and TEE, along with indirect markers like creatinine and β2-microglobulin to assess renal perfusion.

Other tissues Monitors clinical signs (e.g., skin color), Doppler flow, and transcutaneous oxygenation to assess perfusion in peripheral tissues.

In the perioperative period, monitoring tissue perfusion is particularly important for reducing adverse outcomes, especially in patients with significant comorbidities or those undergoing high-risk surgeries. Techniques such as near-infrared spectroscopy (NIRS) have expanded our ability to evaluate tissue-level oxygenation. However, ongoing debate persists regarding the optimal thresholds for intervention and the timing of therapeutic strategies.

The influence of oxygen supply and consumption balance index on patient outcomes

NIRS is an electromagnetic wave between visible light (Vis) and mid infrared (MIR), which was first found for monitoring tissue oxygen metabolism by Jöbsis in 1977 [19]. In recent years, NIRS has been widely used for cerebral oxygenation monitoring in infants, critically ill patients and patients undergoing different types of surgery, which reflects the balance between oxygen supply and consumption in tissue. Oxygen supply is positively correlated with tissue perfusion under the constant oxygen consumption. Low brain oxygen saturation detected by NIRS is significantly associated with brain injury and increased mortality in a variety of diseases. For example, in children supported by extracorporeal membrane oxygenation (ECMO), a decrease of regional cerebral oxygen saturation ($rScO_2$) by more than 20% of baseline or the average $rScO_2$ less than 70% was closely related to mortality [20]. The low tissue oxygen saturation monitored by NIRS was positively correlated with mortality in severe patients [21]. The low $rScO_2$ in perioperative period was also associated with postoperative cognitive dysfunction. In addition, during cardiopulmonary resuscitation (CPR), $rScO_2$ can reflect cerebral blood supply and the

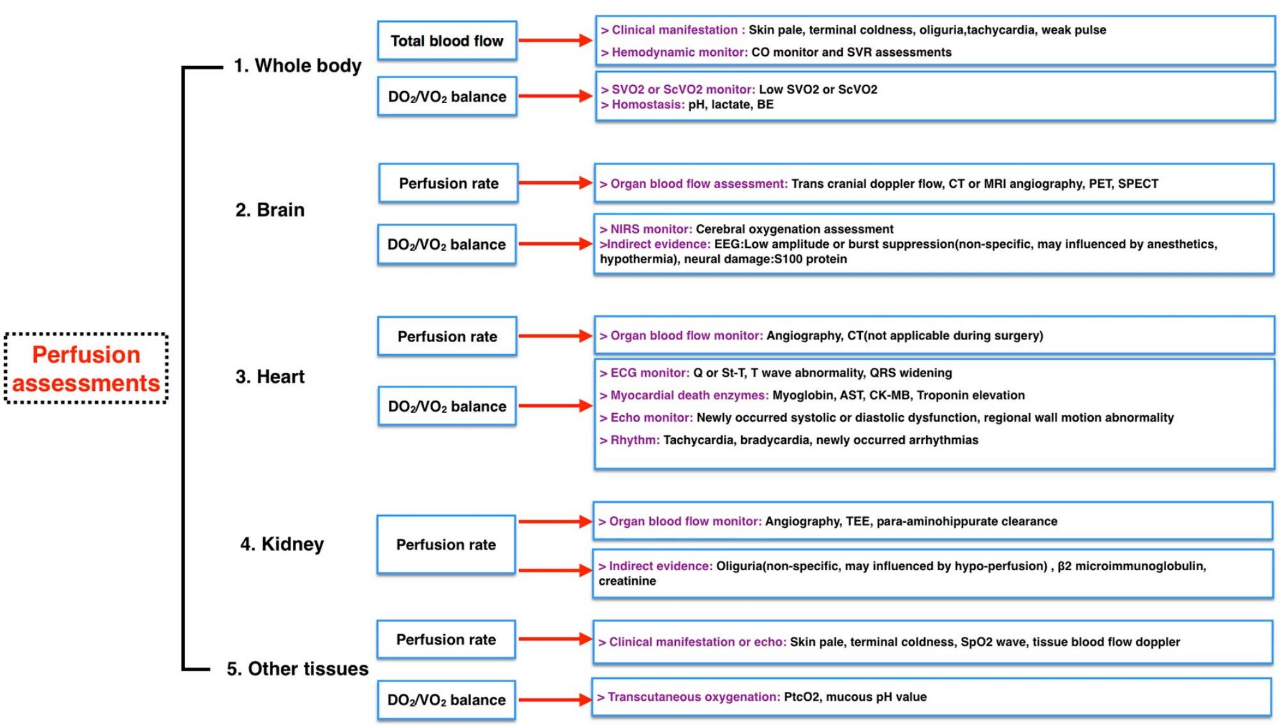

Fig. 4 Comprehensive assessment methods for tissue perfusion across organ systems

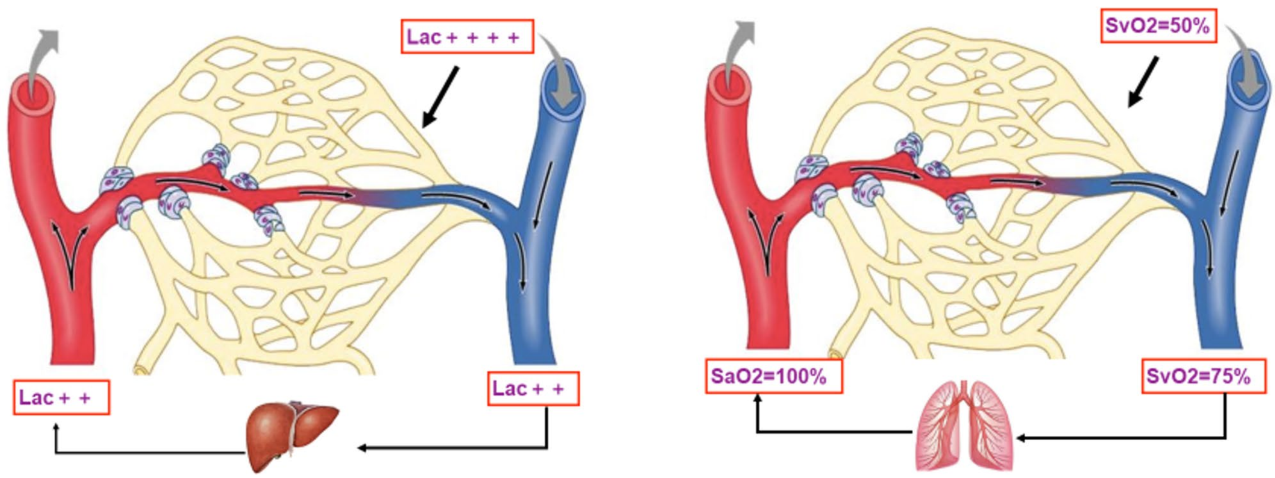

Fig. 5 Lactic acid can better reflect the abnormal perfusion of tissue, compared with the central venous oxygen saturation

effectiveness of cardiac resuscitation [22]. Although there is a definite correlation between blood oxygen saturation monitored by NIRS and systemic perfusion, tissue oxygen saturation is still an indicator of the balance between oxygen supply and oxygen consumption of local tissue, and does not fully represent the overall perfusion.

Compared with NIRS, central venous oxygen saturation can better reflect the balance between systemic oxygen supply and consumption and general tissue perfusion. A low central venous oxygen saturation is often the sign of tissue hypoperfusion, which is related to heart failure, dehydration and hypovolemia. Persistently low central venous oxygen saturation is significantly associated with mortality if the underlying cause remains unaddressed. Central venous oxygen saturation may be elevated in hemodynamic states characterized by high cardiac output and low systemic vascular resistance, such as sepsis and liver cirrhosis. However, this elevation does not necessarily indicate adequate tissue perfusion, as pre-capillary shunting and oxygen utilization disorders may still exist [18]. In these conditions, even when central venous oxygen saturation appears normal, significant hemodynamic abnormalities, tissue ischemia, and anoxia may persist. Therefore, in diseases like liver cirrhosis and sepsis, parameters that reflect microcirculatory blood flow or the balance between systemic oxygen supply and consumption may not reliably predict patient prognosis [23–25].

The influence of metabolism and tissue perfusion on patient outcomes

Lactic acid is primarily produced in muscles, intestines, red blood cells, brain, and skin, and is metabolized by the liver and kidneys. As a metabolic marker, lactic acid, along with pH value, is widely used to reflect tissue hypoperfusion, particularly in critically ill patients [26]. In septic shock, elevated lactate levels are closely linked to disease severity and mortality. Treatment strategies targeting lactate reduction have been shown to lower mortality rates in septic shock, cardiac surgery, and other shock states. This highlights the critical relationship between lactate levels, organ perfusion, and metabolism, and their impact on patient prognosis.

Compared with central venous oxygen saturation, lactate is a more specific indicator of anaerobic metabolism and tissue perfusion, as it is not affected by perfusion shunts or disorders in tissue oxygen utilization (Fig. 5). Lactate-directed early recovery strategies have significantly improved survival rates in sepsis patients [27, 28].

It is important to differentiate between the two main types of lactate acidosis: Type A lactate acidosis results from tissue hypoperfusion and hypoxia, as seen in septic shock, cardiogenic shock, or severe trauma. Type B lactate acidosis is caused by metabolic dysfunction without hypoperfusion, as seen in liver failure, certain medications, or malignancies. This review primarily refers to type A lactate acidosis, which is directly related to tissue hypoperfusion and systemic outcomes. Understanding this distinction is critical for guiding appropriate treatment strategies.

Additionally, elevated lactate levels during the disease course can often be reduced with timely intervention. Recent studies have also demonstrated that dynamic changes in lactate levels over time provide a better indication of patient outcomes than a single measurement [29].

Conclusion

Monitoring tissue perfusion is critical for understanding organ function and predicting patient outcomes during surgery. While traditional indicators like blood pressure and cardiac output are important, they don't always reflect tissue perfusion accurately. Blood pressure alone may not show the true blood flow to organs, and cardiac output doesn't guarantee adequate tissue perfusion in all cases. To improve assessment, techniques like near-infrared spectroscopy (NIRS), central venous oxygen saturation (ScvO2), and lactate levels provide more reliable insights into tissue oxygenation and metabolism. Microcirculation monitoring is useful but limited by its localized nature, as it can't fully assess overall systemic perfusion. Lactate levels are particularly useful for identifying tissue hypoperfusion and predicting outcomes, especially in critically ill patients. Tracking changes in lactate levels over time is often more informative than a single measurement. In conclusion, combining various monitoring methods—such as blood flow indicators, NIRS, and lactate levels—provides a clearer picture of tissue perfusion and helps improve patient care. A comprehensive approach that includes both systemic and localized assessments will lead to better management and outcomes for patients in the perioperative period.

Supplementary Information

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Supplemental figure 1: Same MAP with different CO and tissue perfusion

Author contributions

Bin Li wrote the main manuscript text. Yuchen Dai conducted literature review and data collection. Jie Sun provided critical insights and expertise in the field, guiding the structure and focus of the review. Wenlan Cai and Menghan Sun have played a key role in the revision process, specifically in the literature search and assisting with the creation of the figure. All authors contributed to drafting and revising the manuscript for intellectual content. All authors approved the final version for submission and publication..

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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