

## MICROCIRCULATION MONITORING IN THE INTENSIVE CARE UNIT: MODERN METHODS AND CLINICAL PERSPECTIVES

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### **Abstract**

Microcirculation monitoring in the intensive care unit represents one of the key areas of modern critical care medicine, as disturbances in tissue perfusion and oxygenation are fundamental to the development of multiple organ failure in critically ill patients. Despite achieving target macrocirculatory parameters, a significant proportion of patients exhibit the so-called “hemodynamic incoherence” between macro- and microcirculation, which necessitates the implementation of methods for direct assessment of the microvascular bed.

This paper presents a review of current methods for microcirculation monitoring, including videomicroscopy techniques (SDF, IDF), laser Doppler flowmetry, transcutaneous oxygen tension measurement (TcPO<sub>2</sub>), capillaroscopy, and near-infrared spectroscopy (NIRS). Their diagnostic capabilities, advantages, and limitations in intensive care settings are discussed. Particular attention is given to the clinical application of these methods in sepsis, various types of shock, diabetic foot syndrome, and acute cerebral insufficiency.

Analysis of the literature indicates that the integration of microcirculatory parameters into intensive care protocols allows for more accurate risk stratification of adverse outcomes, optimization of fluid therapy and vasoactive support, and evaluation of treatment effectiveness. However, the widespread implementation of these technologies is limited by the lack of standardized protocols, variability in data interpretation, and technical challenges.

Thus, microcirculation monitoring is a promising tool for personalized intensive care, capable of improving treatment outcomes in critically ill patients. Future research should focus on the standardization of methods, development of clinical algorithms, and integration of microcirculatory parameters into existing monitoring systems.

### **Keywords**

microcirculation; intensive care unit; critical conditions; tissue perfusion; tissue oxygenation; sepsis; shock; multiple organ failure; SDF videomicroscopy;

IDF technology; laser Doppler flowmetry; TcPO<sub>2</sub>; NIRS; capillaroscopy; hemodynamics; personalized therapy

### **Introduction:**

Modern intensive care is focused on the timely identification and correction of disturbances in systemic and tissue perfusion, which are key components in the pathogenesis of critical conditions. Traditionally, hemodynamic monitoring in intensive care units is based on the assessment of macrocirculatory parameters such as arterial blood pressure, cardiac output, central venous pressure, and lactate levels. However, accumulating evidence indicates that normalization of these parameters does not always lead to the restoration of adequate microcirculation, resulting in the phenomenon of “hemodynamic incoherence” and a persistent risk of tissue hypoxia.

Microcirculation is a complex network of arterioles, capillaries, and venules that ensures the delivery of oxygen and nutrients to cells, as well as the removal of metabolic byproducts. In conditions such as sepsis, various types of shock, severe trauma, acute cerebral insufficiency, and diabetic foot syndrome, significant structural and functional alterations occur in the microvascular bed, including endothelial dysfunction, impaired blood rheology, activation of inflammatory cascades, and microthrombosis. These processes lead to reduced capillary density, impaired tissue perfusion, and the development of organ dysfunction.

In recent years, there has been significant progress in the development and implementation of methods for direct visualization and quantitative assessment of microcirculation. Videomicroscopy techniques (SDF, IDF), laser Doppler flowmetry, transcutaneous oxygen tension measurement (TcPO<sub>2</sub>), and near-infrared spectroscopy (NIRS) enable real-time acquisition of objective data on microvascular blood flow. These methods provide new opportunities for early detection of perfusion disturbances, assessment of disease severity, and monitoring of treatment effectiveness.

**However, despite its high potential, the use of microcirculatory monitoring in clinical practice remains limited.** This is due to the lack of standardized measurement and data interpretation protocols, the high cost of equipment, and insufficient integration of obtained parameters into existing intensive care algorithms.

**The aim of this study** is to analyze modern methods of microcirculation monitoring in the intensive care unit, to evaluate their diagnostic and prognostic significance, and to determine the prospects for their implementation in clinical practice from the perspective of personalized medicine.

## Materials and Methods

This study was conducted as an analytical review of contemporary scientific literature devoted to microcirculation monitoring in patients in the intensive care unit. The analysis included publications from 2015 to 2025 indexed in international databases (PubMed, Scopus, Web of Science, eLIBRARY), as well as current clinical guidelines and meta-analyses related to tissue perfusion and critical conditions.

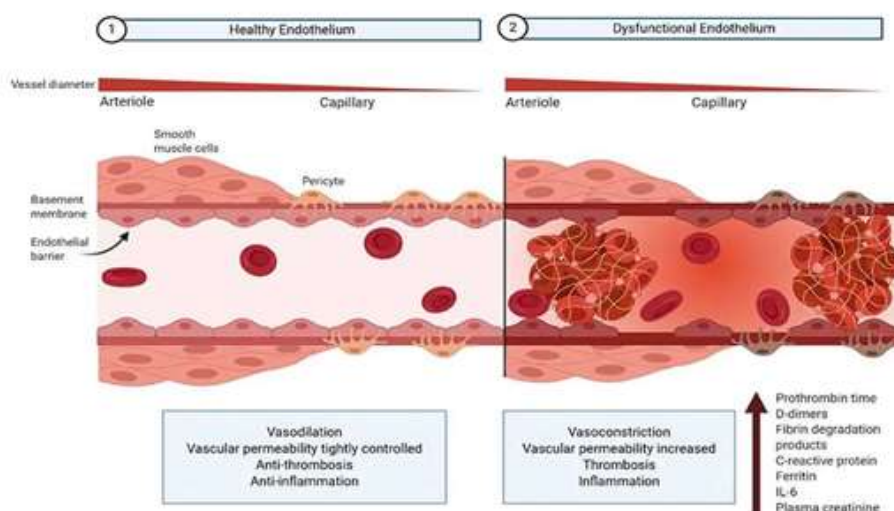
Inclusion criteria were: original studies, randomized controlled trials, systematic reviews, and meta-analyses addressing microcirculation assessment methods in adult patients with sepsis, various forms of shock, severe trauma, acute cerebral insufficiency, and diabetic foot syndrome. Exclusion criteria included studies with insufficient methodological quality, animal studies, and publications lacking clearly defined quantitative microcirculatory parameters.

The following microcirculation monitoring methods were analyzed:

- videomicroscopy techniques (Sidestream Dark Field – SDF, Incident Dark Field – IDF);
- laser Doppler flowmetry;
- transcutaneous oxygen tension measurement (TcPO<sub>2</sub>);
- near-infrared spectroscopy (NIRS);
- capillaroscopy.

To assess clinical significance, the following parameters were evaluated: perfused vessel density (PVD), microvascular flow index (MFI), perfusion heterogeneity, tissue oxygenation level (StO<sub>2</sub>), as well as the dynamics of these indicators in response to therapy.

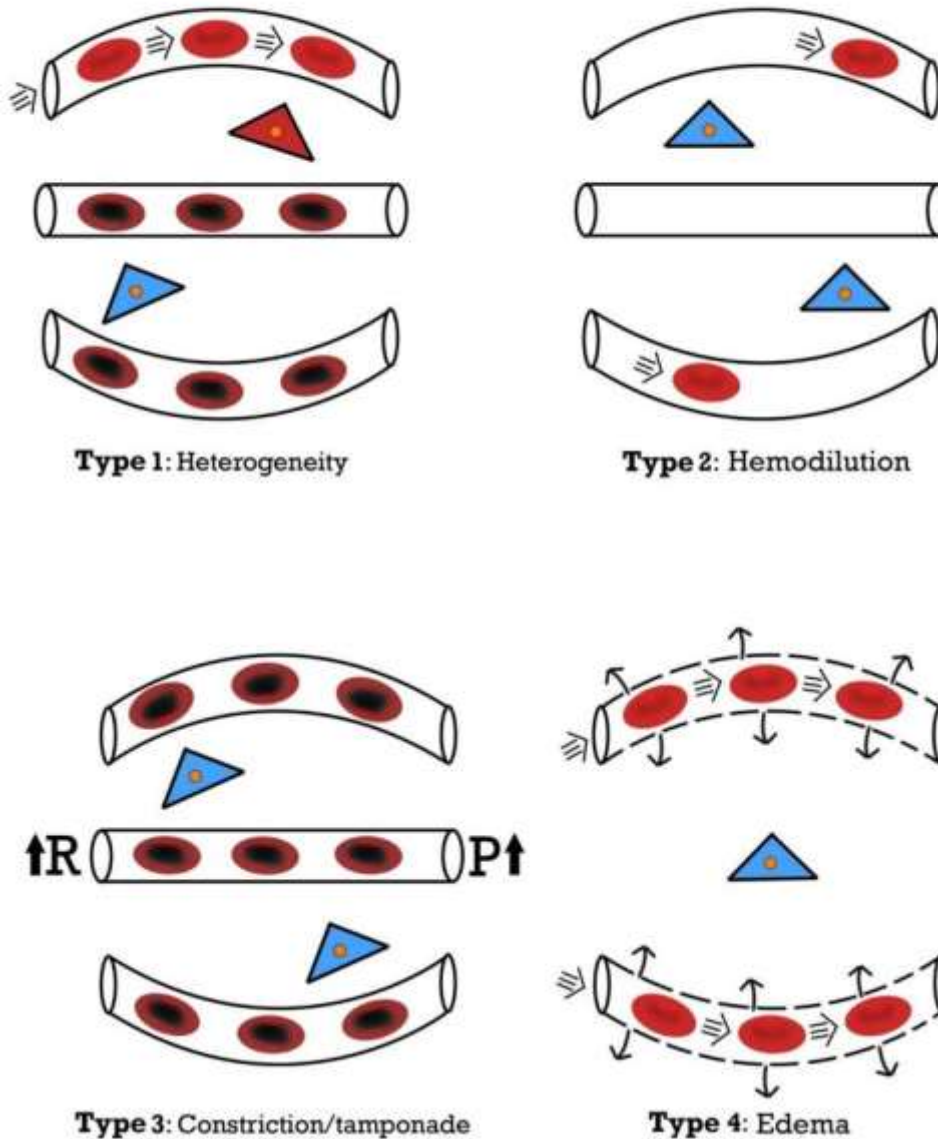
**Figure 1. Pathogenesis of Microcirculatory Disorders**



Statistical analysis of the literature data was descriptive in nature. Methods of comparative analysis, data synthesis, and generalization were used for result

interpretation. Where applicable, statistical significance indicators ( $p < 0.05$ ) reported in the original studies were taken into account.

**Microcirculatory alterations associated with loss of hemodynamic coherence.**



Thus, the applied methodological approach made it possible to comprehensively evaluate modern technologies for microcirculation monitoring, their diagnostic value, and prospects for implementation in intensive care clinical practice.

**Results**

The analysis of current literature data demonstrated that microcirculatory disturbances are one of the key pathogenetic mechanisms in critical conditions and are closely associated with adverse clinical outcomes. It has been established that in patients with sepsis, various types of shock, and severe trauma, pronounced

microcirculatory dysfunction persists even after normalization of macrocirculatory parameters, confirming the presence of the phenomenon of “hemodynamic incoherence.”

The use of videomicroscopy techniques (SDF, IDF) revealed a significant decrease in perfused vessel density (PVD), a reduction in the microvascular flow index (MFI), and increased perfusion heterogeneity in patients with sepsis. It has been shown that a decrease in MFI below 2.6 and marked flow heterogeneity are associated with increased mortality. During treatment, improvement in these parameters correlates with clinical recovery and a reduced risk of multiple organ failure.

**Table 1. Main Methods of Microcirculation Monitoring**

Method	Principle	Main Parameters	Advantages	Limitations
SDF / IDF videomicroscopy	Visualization of capillaries	PVD, MFI, heterogeneity	Direct assessment of microcirculation	Requires expertise, expensive
Laser Doppler flowmetry	Reflection of laser from erythrocytes	Perfusion index	High sensitivity	Low reproducibility
TcPO <sub>2</sub>	Measurement of tissue oxygen tension	mmHg	Prognostic value	Dependent on skin/temperature
NIRS	Infrared spectroscopy	StO <sub>2</sub> (%)	Non-invasive, dynamic	Limited penetration depth
Capillaroscopy	Visualization of capillaries	Density, structure	Simplicity	Limited anatomical areas

Laser Doppler flowmetry demonstrated high sensitivity in assessing changes in skin microcirculation; however, its informativeness is limited by variability and the influence of external factors. In contrast, transcutaneous oxygen tension measurement (TcPO<sub>2</sub>) showed high prognostic value: values below 30 mmHg are associated with severe tissue hypoxia and poor prognosis, especially in patients with diabetic foot syndrome.

**Table 2. Critical Threshold Values of Microcirculation**

Parameter	Normal	Critical Value	Clinical Significance
MFI	≥ 2.9	< 2.6	High mortality risk
PVD	High	Decrease	Hypoperfusion
TcPO <sub>2</sub>	> 40 mmHg	< 30 mmHg	Tissue hypoxia
StO <sub>2</sub>	75-85%	< 70%	Impaired oxygenation
Lactate	< 2 mmol/L	> 4 mmol/L	Severe shock

**Table 3. Microcirculatory Changes in Different Conditions**

Condition	Main Disturbances	Features
Sepsis	Flow heterogeneity, ↓ MFI	Microthrombosis
Hypovolemic shock	↓ capillary density	Centralization of circulation
Cardiogenic shock	↓ perfusion	Stasis
Diabetic foot syndrome	↓ TcPO <sub>2</sub> , endothelial dysfunction	Chronic ischemia
Acute cerebral insufficiency	↓ cerebral microcirculation	Brain hypoxia

NIRS methods enabled real-time assessment of regional tissue oxygenation (StO<sub>2</sub>). A decrease in StO<sub>2</sub> below 70% was associated with impaired perfusion and an increased risk of organ dysfunction. Moreover, the dynamics of StO<sub>2</sub> during vascular occlusion tests demonstrated high sensitivity to changes in microcirculation and treatment effectiveness.

Capillaroscopy demonstrated its value in detecting structural changes in the microvascular bed, including reduced capillary density and signs of endothelial dysfunction; however, its use in intensive care settings is limited by technical constraints.

Overall, it has been established that the integration of microcirculatory parameters (PVD, MFI, TcPO<sub>2</sub>, StO<sub>2</sub>) with traditional macrocirculatory indicators allows for a more accurate assessment of patient severity, timely detection of tissue hypoperfusion, and optimization of intensive care management strategies. The most informative approach was found to be the combined use of multiple monitoring methods simultaneously.

Thus, the obtained results confirm the high clinical significance of microcirculation monitoring as a tool for early diagnosis, prognostic assessment, and evaluation of treatment effectiveness in the intensive care unit.

### Conclusions

1. Microcirculatory disturbances are a key pathogenetic component in critical conditions (sepsis, shock, acute cerebral insufficiency, diabetic foot syndrome) and are directly associated with the development of tissue hypoxia and multiple organ failure.
2. It has been established that normalization of macrocirculatory parameters does not guarantee restoration of microcirculation, confirming the existence of the “hemodynamic incoherence” phenomenon and the need for direct monitoring of tissue perfusion.
3. Modern methods for microcirculation assessment (SDF/IDF videomicroscopy, TcPO<sub>2</sub>, NIRS, laser Doppler flowmetry) have high diagnostic and prognostic value, enabling early detection of perfusion disturbances and evaluation of treatment effectiveness.
4. The most informative microcirculatory indicators are the microvascular flow index (MFI), perfused vessel density (PVD), tissue oxygenation level (StO<sub>2</sub>),

and transcutaneous oxygen tension (TcPO<sub>2</sub>), whose changes reliably correlate with clinical outcomes.

5. A comprehensive approach that includes simultaneous assessment of macro- and microcirculatory parameters improves risk stratification accuracy, optimizes fluid and vasoactive therapy, and enhances clinical outcomes in intensive care patients.

6. Despite its high potential, the widespread implementation of microcirculation monitoring is limited by the lack of standardized protocols, complexity of data interpretation, and technical challenges.

7. Future prospects of this field are associated with the development of unified monitoring algorithms, integration of microcirculatory parameters into clinical protocols, and the implementation of personalized intensive care principles.

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