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AN INNOVATIVE METHOD FOR DETERMINING MICROCIRCULATION DISORDERS IN BURN SHOCK BASED ON THE CAPILLARY-VENOUS DIFFERENCE IN HEMOGLOBIN

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Abstract The aim of this study was to evaluate the diagnostic value of the capillary-venous difference in hemoglobin as a simple marker of microcirculation disorders and tissue hypoperfusion in burn shock, and to examine the effect of infusion therapy using modified gelatin (Gelofusin) on microcirculation.

Material and Methods. Thirty-eight patients with burn shock of varying severity were examined. The control group consisted of 12 apparently healthy individuals. Hemoglobin concentrations in capillary and venous blood, arterial oxygen saturation (SpO_2), and the microcirculation impairment coefficient (MIC) were determined using the formula: MIC = (Hbcap − Hbven)/SpO_2. Modified gelatin (Gelofusin) was administered to 17 patients as part of their intensive care regimen.

Results. Patients with burn shock showed a significant increase in the capillary-venous hemoglobin difference, which increased with increasing shock severity and reflected the severity of microcirculation impairment and tissue hypoperfusion. The obtained data indicate that this indicator can be used as an accessible surrogate marker of microcirculatory dysfunction associated with the development of organ ischemia, including the gastric mucosa, and an increased risk of stress-induced erosive and ulcerative lesions. Gelofusine treatment was accompanied by a decrease in the capillary-venous difference in hemoglobin and the microcirculation impairment coefficient, indicating improved tissue perfusion and the effectiveness of infusion therapy.

Conclusion. Determining the capillary-venous difference in hemoglobin and calculating the microcirculation impairment coefficient are simple, accessible, and informative methods for rapidly assessing microcirculatory impairment in burn shock. Using these indicators allows for the timely detection of tissue hypoperfusion, monitoring the effectiveness of intensive care, and predicting the risk of ischemic complications, including stress-induced erosive and ulcerative lesions of the stomach.

Key words: burn shock, microcirculation, tissue hypoperfusion, capillary-venous hemoglobin difference, microcirculation impairment coefficient, stress-induced gastric erosions, Gelofusin, infusion therapy.

Relevance. Burn shock remains one of the most challenging issues in modern intensive care. According to recent research, severe burns are accompanied by the development of burn shock, which is characterized by severe hypovolemia, plasma loss, endothelial dysfunction, and profound microcirculatory disturbances. Microcirculatory disturbances are currently considered one of the primary mechanisms underlying tissue hypoxia, multiple organ dysfunction syndrome, and mortality in patients with severe burns [1, 2, 6, 8].

The modern concept of burn shock is based on the concept of damage to the endothelial glycocalyx, increased vascular permeability, and the development of so-called "burn endotheliopathy." As a result, plasma leaks into the interstitial space, the effective circulating blood volume decreases, blood viscosity increases, and capillary blood flow is impaired [1, 2, 3].

Despite advances in modern medicine, objective assessment of microcirculation remains challenging. Orthogonal polarization spectroscopy, dark-field vascular imaging, laser Doppler flowmetry, reflectance spectrophotometry, and sublingual capnometry are used for this purpose. However, these methods require expensive equipment and specialized personnel training [4,5,9].

Therefore, the search for simple, accessible, and informative methods for diagnosing microcirculatory disorders in emergency situations remains a pressing issue in intensive care for burn injuries.

Objective of the study. To evaluate the state of microcirculation and the degree of its impairment based on the determination of the capillary-venous hemoglobin difference and saturation in patients with burn shock.

Material and methods. The study was conducted on 38 patients with burn shock of varying severity, treated in the intensive care unit. The control group consisted of 12 apparently healthy individuals. The proposed method is based on the inverse Fareus-Lindquist effect. It is known that a decrease in microvessel diameter and deterioration in blood rheology leads to a local increase in blood viscosity, accompanied by changes in the distribution of red blood cells in the microcirculation.

To diagnose microcirculation impairment, capillary blood was collected from a fingertip and venous blood from the subclavian vein.

Hemoglobin concentration was determined using an MKMF-1 microcalorimeter. Arterial oxygen saturation (SpO_2) was simultaneously recorded using pulse oximetry.

To assess the severity of microcirculatory disturbances, the microcirculatory disturbance coefficient (MDC) was calculated:

MCDC = Hb cap. - Hb ven. / SpO_2

Where:

Hb cap- is the hemoglobin of capillary blood.

Hb ven- is the hemoglobin of venous blood.

SpO2 -is the oxygen saturation indicator.

With MDC values of:0.01–0.09 conventional units, microcirculation was considered preserved;

≥0.1 conventional units, microcirculatory disturbance of varying severity was diagnosed.

This method is protected by patent of the Republic of Uzbekistan UZ FAP No. 02139.

All patients received standard anti-shock therapy. In 17 patients, a 4% solution of succinylated gelatin (Gelofusin) was used as part of the infusion program. Statistical analysis of the results was performed using Statistica 13.0 (StatSoft Inc., USA) and SPSS Statistics 26.0 (IBM Corp., USA). The distribution of quantitative variables was tested using the Shapiro-Wilk test. For normal distribution, data are presented as the mean and standard error of the mean (M ± m). The Student's t-test was used to compare independent groups, and the Mann-Whitney test was used for non-normal distributions. Differences were considered statistically significant at $p < 0.05$.

Spearman's correlation analysis was performed to assess the relationship between the severity of burn shock and the severity of microcirculatory disorders.

Study results. The analysis revealed a significant increase in the capillary-venous hemoglobin difference in patients with burn shock (Table 1).

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Capillary-venous hemoglobin difference in patients with burn shock
Table 1.

Shock severity	Capillary Hb (g/l)	Venous Hb (g/l)	Difference (g/l)	SpO_2
Grade I	102±2,4	95±1,6	7±1,4	92±3,7
Grade II	96±2,2	82±1,1	14±2,4	89±3,2
Grade III	113±2,3	93±2,4	20±2,5	81±4,1

In all cases, the differences were statistically significant ($p < 0.05$).
Calculation of the coefficient of microcirculation impairment (CMI)
Group of patients with grade 2 burn shock (n=17)
• Difference Hbcap–Hbven = 14.4
• SpO_2 = 89%
According to the formula (CMI = (Hbcap–Hbven)/SpO_2), the obtained value is: CMI = 0.162 conventional units
Group of patients with grade 3 burn shock (n=14)
• Difference Hbcap–Hbven = 19.6
• SpO_2 = 81%
According to the formula (CMI = (Hbcap–Hbven)/SpO_2), the obtained value is: CMI = 0.242 conventional units

Microcirculation Parameters in Patients with Burn Shock
Parameter Burn shock **Table 2.**

Indicator	Burn shock Stage II (n=17)	Burn shock Stage III (n=14)	p
Hbcap–Hbven difference, g/L	14,4±2,4	19,6±2,6	<0,001
SpO_2, %	89±3,2	81±4,1	<0,001
CMI, arbitrary units	0,162	0,242	<0,001

The obtained data demonstrate a direct relationship between the severity of burn shock and the capillary-venous hemoglobin difference p<0,001.

It was found that as burn shock progressed, the microcirculation impairment coefficient significantly increased. In patients with grade 2 burn shock, the capillary-venous hemoglobin ratio (CVR) was 0.162±0.027 conventional units, while in grade 3 burn shock, this indicator increased to 0.242±0.032 conventional units (p<0.001). The obtained results indicate a significant deterioration in tissue perfusion and microcirculation in severe burn shock.

A strong positive correlation was found between the degree of burn shock and the capillary-venous hemoglobin difference ($r=0.81$; $p<0.001$), indicating a progressive deterioration in microcirculation as the shock worsens.

Correlation analysis demonstrated a strong positive relationship between the severity of burn shock and CVR ($r=0.74$; $p<0.001$). Thus, an increase in the capillary-venous difference in hemoglobin against the background of a decrease in blood oxygen saturation can be considered as an objective laboratory marker of the progression of microcirculatory failure.

Discussion of Results. It is currently considered proven that microcirculatory dysfunction develops within the first hours after severe burn injury. Damage to the vascular endothelium is accompanied by increased vascular permeability, massive plasma loss, hemoconcentration, and impaired blood rheology. These changes result in blood stasis, sludge, decreased functional capillary density, and severe tissue hypoperfusion. The development of systemic hypoxia and organ ischemia, including the gastric mucosa, creates the preconditions for the development of acute stress-related erosive and ulcerative lesions of the gastroduodenal zone, which can be complicated by gastrointestinal bleeding and worsen the course of burn disease.

The capillary-venous hemoglobin difference identified in our study reflects the severity of microcirculatory disorders developing in burn shock. As shock worsens, hemoconcentration, tissue perfusion, and microcirculation become more severe, leading to increased tissue hypoxia and organ ischemia. The gastric mucosa is particularly sensitive to these changes; hypoperfusion of the mucosa contributes to the development of stress-induced erosive and ulcerative lesions and increases the risk of gastrointestinal bleeding.

Therefore, determining the capillary-venous hemoglobin difference is of practical interest as a simple, accessible, and informative surrogate marker of tissue hypoperfusion and microcirculatory dysfunction. Unlike expensive microcirculation assessment methods based on modern imaging technologies, measuring hemoglobin levels in capillary and venous blood can be performed in virtually any clinical laboratory and used for dynamic monitoring of patients with burn shock. The obtained results are consistent with current understanding that peripheral perfusion parameters are important indicators of the severity of burn shock, the effectiveness of intensive care, and the risk of developing multiple organ failure.

One of the leading causes of microcirculatory dysfunction in burn shock is severe hypovolemia due to massive plasmarrhea. Therefore, the key focus of intensive care remains the timely restoration of intravascular circulating blood volume, improving tissue perfusion, and preventing ischemic damage to target organs, including the gastrointestinal tract.

In our study, the inclusion of Gelofusine in complex infusion therapy was accompanied by a decrease in the capillary-venous hemoglobin difference, indicating improved microcirculatory blood flow and a reduction in the severity of tissue hypoperfusion. The probable mechanisms for the beneficial effects of modified gelatin include an increase in effective intravascular volume, a decrease in hemoconcentration, improved blood rheology, and restoration of capillary perfusion. Improved microcirculation not only optimizes oxygen delivery to tissues but also reduces the risk of ischemic damage to the gastric mucosa with the subsequent development of stress-induced erosive and ulcerative lesions. These results suggest that Gelofusine can be considered a pathogenetically justified component of complex infusion therapy in patients with burn shock, subject to an individual assessment of the indications and potential risks of its use.

Similarly, a close correlation was established between the severity of burn shock and the coefficient of microcirculation impairment (CMI) ($r=0.84$; $p<0.001$). These results confirm the

diagnostic value of the proposed indicator for assessing the severity of microcirculatory dysfunction.

ROC curve analysis demonstrated excellent diagnostic performance of the proposed coefficient of microcirculatory impairment (CMI) for identifying severe microcirculatory dysfunction in grade II–III burn shock. The AUC was 0.89 (95% CI, 0.79–0.98), reflecting high discriminative ability. The optimal cut-off value was ≥0.10 arbitrary units, yielding a sensitivity of 86.2%, specificity of 83.3%, PPV of 89.3%, and NPV of 78.1%. These results support the use of CMI as a simple, rapid, and reliable biomarker for assessing microcirculatory impairment and guiding early therapeutic interventions in burn shock (Figure 1).

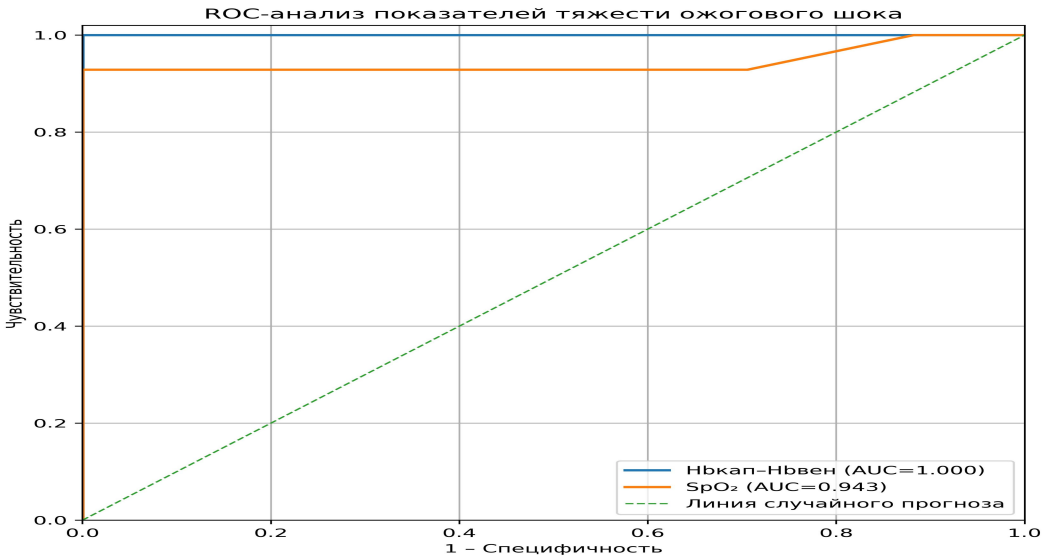


Figure 1. Receiver operating characteristic (ROC) analysis of the diagnostic efficacy of the microcirculation impairment coefficient demonstrated its high ability to differentiate severe microcirculation disorders in patients with burn shock. The optimal diagnostic threshold was a KSNM value ≥0.18 conventional units. At this threshold, the method's sensitivity was 84.6%, specificity was 81.8%, and the area under the ROC curve (AUC) was 0.87 (95% CI 0.76–0.97; $p<0.001$), allowing this indicator to be recommended for the rapid diagnosis of microcirculation disorders in intensive care units.

Diagnostic Efficiency of the Microcirculation Impairment Ratio. Table 3.

Indicator	Value
AUC ROC	0,89
95% CI	0,79–0,98
Sensitivity	86,2%
Specificity	83,3%
Positive Predictive Value	89,3%
Negative Predictive Value	78,1%

CVHD Cutof	≥0,10 усл. ед.
P	<0,001

Thus, the ROC analysis demonstrated the high diagnostic value of the proposed microcirculation assessment method. The CVHD has a good balance of sensitivity and specificity and can be used for the early detection of microcirculation disorders in patients with burn shock, as well as for monitoring the effectiveness of fluid therapy.

Conclusion. This study demonstrated that the capillary-venous hemoglobin difference is a sensitive indicator of microcirculation disorders in burn shock. The developed microcirculation impairment coefficient (MICC) provides a rapid and accessible quantitative assessment of microcirculatory disorders, enabling its use in early diagnosis, monitoring the effectiveness of intensive care, and stratifying the severity of patients' conditions. The use of colloidal solutions as part of comprehensive infusion therapy helps restore microcirculatory blood flow and reduce tissue hypoxia, which is pathogenetically justified in the treatment of patients with burn shock.

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