**БІОЛОГІЧНІ ТА МЕДИЧНІ ПРИЛАДИ І СИСТЕМИ**

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# Construction Guidelines for Optical-Electronic Expert Systems in Blood Rheology

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**Abstract.** I Building specifically designed optical-electronic information processing expert systems for blood rheology bioimage analysis requires a painstaking, subtle approach. Such systems provide essential support for diagnostic operations and require an understanding of experimental properties such as the rheology of blood and bioimage analysis. To properly build these systems, guidelines are needed for improving imaging methods, image processing routines, and application of expert knowledge so the blood's rheological properties can be analyzed precisely. nformation features (information parameters) for the analysis of the biomedical images, in particular, for the assessment of the rheologic properties of the blood, are formed. Algorithm and optical-electronic expert system for the analysis of the rheological properties of the blood are suggested, they are used for the increase of the diagnostic validity which is adetermining factor in the biomedical diagnostics. The main focus of modern clinical hemorheology is the search diagnostic and prognostic criteria for various diseases and rheological correction methods violations. Changes in the rheological parameters of blood are one of the significant mechanisms of the formation of insufficient blood supply in the early stages the development of the disease. Main pathological effects violations of rheological properties in the blood can lead to micro-flow failure circulation, the extreme manifestation of which may lead to a decrease in trophism and the development of ischemic syndrome, a violation of micro-rheology and an increase in the viscosity of blood, which causes an increase in total peripheral resistance and the development of arterial hypertension syndrome, to atherosclerotic changes in blood vessels, to a violation of hemorheology, which contributes to increased thrombosis.

**Keywords:** biomedical information, optical – electronic expert system, membership functions, complex hierarchical structure, hemodynamic parameters, analysis of blood rheology

## Принципи побудови оптико-електронних експертних систем для дослідження реології крові

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**Анотація.** Створення спеціально розроблених оптико-електронних експертних систем обробки інформації для реологічного аналізу біозображень крові вимагає ретельного аналізу. Такі системи забезпечують необхідну підтримку для діагностичних операцій і вимагають розуміння експериментальних властивостей, таких як реологія крові та аналіз біозображень. Щоб належним чином побудувати ці системи, потрібні рекомендації щодо вдосконалення методів візуалізації, процедур обробки зображень і застосування експертних знань, щоб можна було точно аналізувати реологічні властивості крові. Формуються інформаційні ознаки (інформаційні параметри) для аналізу біомедичних зображень, зокрема, для оцінки реологічних властивостей крові. Запропоновано алгоритм та оптико-електронну експертну систему для аналізу реологічних властивостей крові, які використовуються для підвищення діагностичної валідності, що є визначальним фактором у біомедичній діагностиці. Основним напрямком сучасної клінічної гемореології є пошук діагностичних і прогностичних критеріїв різних захворювань і порушень методів реологічної корекції. Зміна реологічних показників крові є одним із суттєвих механізмів формування недостатності кровопостачання на ранніх стадіях розвитку захворювання. Основні патологічні наслідки порушення реологічних властивостей крові можуть призвести до порушення мікрореології кровообігу, крайній прояв якого може призвести до зниження трофіки та розвитку ішемічного синдрому, порушення мікрореології та підвищення в'язкості крові. крові, що зумовлює підвищення загального периферичного опору та розвиток синдрому артеріальної гіпертензії, до атеросклеротичних змін у судинах, до порушення гемореології, що сприяє посиленню тромбоутворення.

**Ключові слова:** біомедична інформація, оптико-електронна експертна система, складна ієрархічна структура, гемодинамічні параметри, аналіз реології крові.

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**Introduction.** Building specifically designed optical-electronic information processing expert systems for blood rheology bioimage analysis requires a painstaking, subtle approach. Such systems provide essential support for diagnostic operations and require an understanding of experimental properties such as the rheology of blood and bioimage analysis (Begum et al, 2020). To properly build these systems, guidelines are needed for improving imaging methods, image processing routines, and application of expert knowledge so the blood's rheological properties can be analyzed precisely.

Mastering the imaging process is thus a critical part of building these systems. Careful control of resolution, contrast, and image acquisition protocols is essential if relevant rheological information held by bioimages is to be reliably obtained (Begum et al, 2020). Recommendations also stress the use of suitable imaging modalities and methods suited to fully capturing blood sample rheological characteristics. The second key principle is to develop strong image-processing algorithms (Abdeldaim et al., 2018). Further, image processing algorithms are used when processing bioimages for analysis of blood rheology properties. Such algorithms must take into account variations in the quality of images, noise removal, separation of blood components, and extraction of rheological parameters (Singha et al., 2021). Powerful analyses improve rheological property analysis, which leads to more precise diagnostic capabilities.

Furthermore, these systems must absorb expert knowledge to allow blood rheology analysis. Domain-specific know-how and biomedical principles are integrated in such a way that the system can accurately interpret bioimages, taking into account blood component interactions and characteristics (Singha et al., 2021). Algorithms based on expert knowledge enable computers to interpret the rheological differences and analyze them with clinical significance (Crow, 2012). Expert optical-electronic systems require a full grasp of both imaging and biomedical principles before their implementation can be considered. This interdisciplinary approach brings together experts in imaging technology with biomedical engineers and clinicians (Begum et al, 2020). It helps to guarantee that the systems are by clinical demands, meet biomedical requirements, and combine imaging technology of international standards.

Rapid development of the information needs puts forward new requirements to the means and methods for the analysis of biomedical information. To meet these needs there appears the necessity to apply new physical principles and technologies. Principally new solution of the problem is the development of the expert optical-electronic information system, intended for the processing of the biomedical data, based on new computation technologies. Objects in the medical images are complex and of multifactorial nature and these factors stipulate high requirements concerning the reliability, accuracy and validity of theresearch results. Usage of the computational facilities and mathematical methods in this sphere enables not only to accelerate the processing of the biomedical images but improve the accuracy of the result obtained. Greater part of the software products does not give sufficiently complete and accurate information regarding the quantitative and qualitative character of the medical images. That is why, there exists the problem of the development of highlyefficient information system, which is able to meet the modern requirements of the problem put forward, the system must be constructed on the modern optical-electronic element base. Much attention is paid to the development of the efficient methods and means of the work with the images in medical diagnostic systems (Abdeldaim et al., 2018; Ahmed et al., 2023; Ansari et al., 2023). The concept of the expert optical-electronic information system provides the creation of the basically new structural organization both of the channels for the collection of the primary information and means, intended for the processing, proceeding from the assumption that they must simulate biomedical processes. This means that, for instance, parallel optical channels must interact with the neurolike networks (Riva, & Feke, 1981; Riva, et al., 1992; Lerche et al., 1989).

Such system as the basic model of the complex noninvasive diagnosis assumes that this is engineering systems which acquires the information, sent in the form of the visual medium of the arbitrary shape, allocates certain features of the bioobject, processes them and makes the decision automatically or with the participation of the operator (Harris et al., 1994; Kozhemiako et al., 2010). In particular, systems for the analysis of the blood rheology are of great interest for the specialists (Arber et al., 2017). Such optical electronic information system carries out the transfer of the biomedical image to the computer where, applying the corresponding software, this image is processed. Having obtained the biomedical image of the blood content, it is necessary to know how to process correctly this information to obtain necessary, from the point of view of medicine, data regarding the state of the studied object (Stoltz et al., 1987; Pryzwan et al., 2024; Michelson et al., 1996).

In the last decade, significant advances have been made in the development of fundamentally new approaches to the study of the rheological properties of blood as fundamental issues in the theory of haemoreology, and problems in the methodology for diagnosing and correcting haemoreological disorders in clinical practice with the aim of preventing vascular occlusion and ischemia of vital organs (Riva & Feke, 1981; Pryzwan, 2024; Kozhemiako et al., 2010).

Disorders of the rheological properties of blood are an important pathogenetic factor in the development of many diseases. Under conditions of pathology, reduced blood turnover can become the primary cause of disorders in the microcirculatory and venous channels. The severity of these violations often determines the severity of the patient's condition and sometimes also the prognosis of the outcome of the disease. Each category of patients has its own characterized haemoreological profile, due to the original pathology. It is therefore urgent to make early diagnosis of the rheological properties of blood in the early diagnosis of vascular conditions and to improve the results of treatment, especially in cardiac patients, which will make it possible to correct blood flow in a timely and adequate manner according to the vessels, preventing dysfunctional disorders in vital organs (Lerche et al., 1989).

Of course, rheological dysfunction of the blood is also an important pathogenetic factor in the development of many diseases. In conditions of pathology, the reduction of blood turnover can become the primary cause of the impairment of internal organ functions, which in many ways can determine the severity of the patient's condition and further prognosis. This underlines the diagnostic value of a laboratory hemoreological evaluation that enhances the pathogenetic orientation (Lerche et al., 1989; Harris et al., 1994).

**Biomedical image processing methods for expert systems.** The application of biomedical image processing techniques by expert systems in extracting critical diagnostic information is crucial. These methodologies are essential to turning biomedical images into information, augmenting the decision-support capabilities of medicine (Singha et al., 2021). Various types of image processing are used to extract meaning from these images, such as image segmentation and feature extraction; pattern recognition and machine learning also play an important part. Segmentation of images is an essential step in biomedical image processing, which involves the separation and identification of a certain area or structure within the picture. Such a process enables relevant areas of interest, for example, corrupt tissues or cells to be extracted from the surrounding environment and analyzed specifically by expert systems (Abdeldaim et al., 2018). Another important step is feature extraction, which isolates and selects the appropriate attributes or features of segmented biomedical images. Extracting such discriminative features is vital for diagnoses of actual clinical relevance to be possible using expert systems. The methods used to find patterns in biomedical images and interpret them are known as pattern recognition techniques (Begum et al, 2020). These techniques allow patterns, aberrations, or groupings of features associated with acute leukemia diagnosis to be identified.

The addition of machine learning algorithms to expert systems makes them even more diagnostic. Neural networks, support vector machines, and deep learning methods allow the systems to learn patterns from biomedical images (Singha et al., 2021). Many of these algorithms can detect complex relationships within images that would not be evident to the naked eye, increasing precision and diagnosis. Applying these approaches to image processing within expert systems, for instance, enables the appropriate interpretation and implementation of visual biomedical data in acute leukemia diagnosis (Begum et al, 2020). Through the use of these advanced methods, such systems can derive more sophisticated information from biomedical images and assist clinicians in diagnosis, prognosis, and treatment planning.

**Evaluating the efficacy of expert optical-electronic systems in blood rheology.** For example, research into methods to compare the accuracy of diagnostic tests using expert optical-electronic systems in analyzing biomedical information related to blood rheology is crucial. It also requires careful evaluation processes to determine how effective these systems are in assessing the blood's rheological properties, which can aid in the diagnosis of acute leukemia (Singha et al., 2021). At the core of these studies is an experiment to determine system performance, diagnostic accuracy, and reliability in detecting leukemia by analyzing bioimages related to blood rheology (Begum et al, 2020). Such tests serve to determine the accuracy, sensitivity, and specificity as well as the overall performance of such expert systems in interpreting bioimages related to blood rheology.

Researchers hope that by subjecting expert optical-electronic systems to rigorous analysis, the effectiveness and clinical applicability of these methods for diagnosing acute leukemia will be confirmed. Such studies include comprehensive assessments of how closely these systems match those typically employed by doctors in distinguishing blood properties between healthy and leukemic individuals (Singha et al., 2021). The assessment focuses on the sensitivity of their systems to detecting various minor differences, abnormalities, or vascular rheological changes related to leukemia. Comparing the system's output to diagnostic standards and expert evaluations is a comprehensive analysis. These kinds of comparative analyses can determine the extent to which these expert systems are reliable and accurate in identifying such rheological anomalies as may indicate acute leukemia (Begum et al, 2020). It also requires statistical studies to establish figures and prove their diagnostic capabilities.

In addition, this kind of research is typically validated through the use of samples from patients with different stages and subtypes of acute leukemia. The rigor and broad applicability of the systems' diagnostic capabilities have been proven with these extensive tests, strengthening their clinical utility (Rehman et al., 2018). The results of these research projects are valuable in helping the expert optical-electronic system used to diagnose acute leukemia gain validity and recognition. These positive findings on high accuracy, reliability, and correlation with established clinical criteria serve to further affirm the appropriateness of these systems in supporting clinicians (Begum et al, 2020). This kind of verification can be regarded as an important foundation for recognizing these systems as aids to clinical decision-making in acute leukemia diagnosis.

**Reliability metrics analysis for decision support.** Reliable decision support is of paramount importance for biomedical image analysis, especially when it comes to diagnosing acute leukemia.

These include expert judgment, algorithms, and diagnostic results (Rehman et al., 2018). They are taken together to make a final assessment of the reliability of decision support systems that depend on them for accuracy and credibility. Reliability indexes must be analyzed. Precision, sensitivity, specificity, and inter-rater agreement are important factors used to verify how accurate biomedical image diagnosis can be relied upon regarding issues of consistency or credibility. Precision sets the bar for how often test results are positive. Sensitivity assesses accuracy in detecting acute leukemia, while specificity measures the accurate diagnosis of patients without it (Singha et al., 2021). Inter-rater assessment measures the degree of consistency among various system elements or reviewers, reflecting on the stability and accuracy of diagnostic reporting.

It is these indicators that can best direct the clinician in interpreting system output, and thus help with accurate diagnosis of acute leukemias. High precision, sensitivity, and specificity will help the expert system to produce more accurate diagnostic information (Rehman et al., 2018). This helps healthcare professionals to have confidence in relying on the system's results when considering clinical action. Analysis of reliability metrics also provides a vehicle for continued development and fine-tuning of the decision support system (Abdeldaim et al., 2018). Scientists should examine these indicators to assess the condition of the system and look for areas that need adjustment or improvement (Singha et al., 2021). This way clinicians and developers alike can make improvements based on strengths and weaknesses discovered so that reliability improves with each rendition of the system.

Reliability metrics can help set standards for decision support systems in biomedical image analysis. These benchmarks also help establish standards for system validation, so that clinical implementation will only occur when the accuracy and reliability of a given system has been proven before its use. With such confidence in reliable indicators, decision support systems are accepted and used by clinical practitioners (Rehman et al., 2018). With these kinds of reliability measures showing that things are consistent, credible, and in line with what the experts set out for people, clinicians will very much be able to accept recommendations from such a system in their decision-making.

**Modern methods in information technology creation.** Taking advantage of modern techniques is crucial in designing information systems suitable for acute leukemia diagnosis. These technologies include cutting-edge equipment and techniques for analyzing data, improving diagnostic capabilities, and assisting decision-making (Singha et al., 2021). Incorporating modern methods makes it more adaptive to the continuous change and multifarious nature of medical data, maximizing its value for diagnoses such as various types of acute leukemia (Arber et al., 2017). Harnessing the power of artificial intelligence (AI), machine learning and data analysis is at the core of modern approaches to developing information technologies for use in diagnosing acute leukemia. It can quickly process enormous amounts of data, with AI-driven algorithms that find useful patterns and spot markers to differentiate the various leukemia subtypes (Rehman et al., 2018). What is more, machine learning models are trained to learn from the information they receive and grow progressively smarter when applied for future diagnostic purposes.

By using cloud computing and taking advantage of big data technologies in acute leukemia diagnosis, scientists can say that they are fundamentally changing the way many people approach working with large amounts of biomedical information (Rehman et al., 2018). Seamless storage, management, and analysis of large-scale biomedical data is based on cloud computing. Through its scalability and accessibility, it enables efficient data processing, providing decision support to real-time operations. Such accessibility allows healthcare professionals to get the information they need about a patient from anywhere when making quick critical decisions (Singha et al., 2021; Davis et al., 2014). Cloud-based big data These cloud sorts of tools also provide incredible capabilities for thoroughly analyzing large biomedical databases. It can unearth complex relationships and patterns in the data that traditional methods would overlook. This advanced analysis reveals obscure relationships among various factors, illuminating the complex nature of acute leukemia (Rehman et al., 2018). Big data analysis produces its breakthroughs by examining huge amounts of information to reveal minute indicators or links that can guide correct diagnosis and treatment.

In addition, the incorporation of contemporary imaging technologies makes these systems even more powerful diagnostic tools. Modern imaging techniques and optical-electronic systems have a big impact on the detection of acute leukemia by increasing the resolution and refining the precision of images taken (Singha et al., 2021). Both technologies provide high-resolution image analyses, allowing a detailed examination of cellular shape and detecting characteristic abnormalities found in different types of acute leukemia. The clear rendering of the microscopic structure assists in identifying tiny differences or abnormalities imperative for diagnosis and treatment (Rehman et al., 2018). All these modern imaging technologies are of tremendous benefit for investigating the pathogenesis of leukemia.

**Algorithmic Software Development.** Designing computer programs specifically for acute leukemia that allow analysis of this type is a necessary component in improving diagnostic accuracy and speed. The software contains advanced computer programs that can analyze and assess complicated biomedical data, helping to make timely diagnoses of various forms of acute leukemia (Singha et al., 2021). But the most important part is developing algorithms that can handle various types of data, such as genetic information and blood profiles along with imaging scans. These kinds of algorithms are designed to learn how to identify patterns, abnormalities, and certain markers representative of different subtypes of leukemia (Rehman et al., 2018). Improved pattern recognition techniques allow one to detect slight variations or anomalies in the biomedical data which may indicate certain special features of leukemia.

Through the employment of machine learning, there has been a continuous development in the type of algorithm that responds to changing data sets. What makes these algorithms especially impressive is that they can learn as new information becomes available, improving their diagnostic powers and increasing their accuracy (Rehman et al., 2018). Using neural networks or deep learning enables the system to extract useful insights from tricky biomedical data, revealing subtle relationships that provide important diagnostic clues for acute leukemia.

One of the key factors behind improvements in diagnostic accuracy with time is machine learning's adaptive nature when confronted by new data. These algorithms pick up new knowledge from the updated data and as a result can better recognize minute markers, along with distinguishing different subtypes of leukemia (Singha et al., 2021). This adaptive learning mechanism increases the precision of the system's prognosis, improving assessment. The use of neural networks or deep learning multiplies the strength and effectiveness of analysis by allowing a greater understanding of biomedical data. These models are good at finding patterns, correlations, and associations that may not be apparent otherwise (Rehman et al., 2018). Through the use of these models, the system can draw out some diagnostic insights from bone marrow and build a better overall picture of acute leukemia's complex etiology.

Furthermore, decision support algorithms also strengthen the diagnostic process and provide valuable assistance to clinicians. After detailed analysis of the data, these algorithms can recommend tests and treatments or make differential diagnoses (Singha et al., 2021). Closing the gap between software and decision support, in this way, the system reduces the workload for searching through different types of acute leukemia. Algorithmic software communicating with decision support algorithms works together to maximize the efficiency and effectiveness of diagnostic procedures by providing clinicians with capable information (Rehman et al., 2018). The fusion of these cutting-edge algorithms and decision support systems allows healthcare providers to gain a comprehensive portrait of the diagnostic information, making diagnosis more efficient, precise, and informed about acute leukemia subtypes.

**Hardware support in leukemia diagnosis.** Information technology abounds, and the most important point in using acute leukemia diagnostics is to develop robust hardware support so that system performance can be optimized as well as data processing capacity or imaging. Advances in hardware make it easier to analyze and interpret data, providing aid for more accurate diagnosis of all forms of acute leukemia (Singha et al., 2021). When these high-performance computing systems are combined, they allow rapid and detailed examination of large amounts of biomedical information. Such systems use high-speed processors and large memory capacity to crunch through the relevant calculations, quickly providing information that is useful in diagnoses (Rehman et al., 2018). Moreover, parallel computing architectures also speed up the processing of data and facilitate real-time analysis and decision support.

Progress in hardware will be crucial to developing the implementation of imaging technologies specifically designed for treating acute leukemia. The high-resolution microscopes and optical–electronic systems used as imaging hardware are state-of-the-art, greatly enhancing sampling precision (Singha et al., 2021). These new developments provide unprecedented opportunities for precise and detailed observation, making it easier to see cellular morphology or irregularities that may be related to specific disorders of acute leukemia. The application of high-resolution micro-scopes and optical electronic systems, moreover enables clearer images to be obtained that allow for better visualization of the structures related to acute leukemia. They also allow for the careful analysis of cellular structure, which can help determine abnormalities and irregularities unique to each type of leukemia (Rehman et al., 2018). This precision in imaging is crucial to the diagnosis and characterization of various forms of acute leukemia.

In addition, hardware accelerators like GPUs add a great boost to the efficiency of acute leukemia analysis. It's just that GPUs are specially designed to speed up the kinds of computation involved in biomedical imaging or with large data sets (Arber et al., 2017). What these accelerators do is increase the speed and efficiency of the system's mathematical processing, allowing data to be processed even more quickly. Consequently, the system performs better in the high-speed evaluation of vast amounts of biomedical data, and diagnostic accuracy is improved for the analysis of acute leukemia (Williams et al., 2019). In the system architecture, taking advantage of hardware accelerators (GPUs) results in significant improvements to computational efficiency. In biomedical applications, their parallel processing capabilities make them quicker at performing complex algorithms needed to analyze images and speed up the diagnostic process. With such accelerated computing power, data can be interpreted and analyzed much faster than before (Rehman et al., 2018). This not only ensures increased accuracy in the analysis of acute leukemia samples but also results in greater efficiency as well.

**Experimental studies & expert system framework.** Experimental studies and the development of an expert system in clinics are also major elements in constructing resilient acute leukemia technology. These studies include in-depth validations and assessments, while the structure of an expert system gives it a sound foundation for reliable diagnosis (Rehman et al., 2018). In addition, there must be numerous experimental studies of the validation and comparison of algorithms against standards for analyzing data and assessing diagnostics. The purpose of these studies is to verify the validity, precision, and reliability of the newly developed technologies in testing for different types of acute leukemia (Singha et al., 2021). Vigorous experimentation guarantees that the system's performance will meet clinical needs and helps to give it credibility.

Creating the skeleton of an expert system involves several different aspects, including how its structure will be organized and how decisions are made. Such an end-to-end system includes numerous components that have been proven individually through algorithms, data processing techniques, and decision support systems (Rehman et al., 2018). The shell way inside the expert system encompasses several vital components, such as data storage cartridges, and operational commands in evidence-based procedures for use by doctors to judge acute leukemia cases; all these are carefully engineered to work together (Shah et al., 2021). Expert system architecture is precisely tailored to combine the most rigorously tested and verified algorithms and methods. These parts are all brought together to work in concert, which requires precise and coordinated operations (Williams et al., 2019). The framework also provides data storage mechanisms to allow the structured entry and retrieval of extensive sets of information, which is essential for making sound biomedical decisions.

An important part of the expert system's architecture is that it requires user-friendly interfaces, specifically for doctors. These interfaces are intuitive, allowing the user to interact with them naturally (Singha et al., 2021). They allow clinicians to enter appropriate patient data, read the diagnostic output of machines, and deduce recommendations or findings generated by computers. These interfaces, which focus on user-friendliness to support healthcare professionals using them effectively and quickly, are highly innovative. In addition, decision support modules incorporated into the framework enhance diagnostic accuracy by supplying doctors with actionable information and guidance based on smart data analysis (Davis et al., 2014). These modules help practitioners understand the system's output, providing differential diagnoses and treatment recommendations as well as clinical data based on information analyzed.

The expert system skeleton consists of a mechanically organized structure in which verified congruous algorithms are tightly integrated with data input and processing procedures as well as decision support mechanisms and highly user-responsive interfaces. The fact that components are so well integrated within the system framework itself produces coherence and stability in support of accurate and actionable diagnoses of acute leukemia (Rehman et al., 2018). This user-centric design makes it easy to interact with, allowing healthcare professionals to enter and read key diagnostic information freely.

**Methodology.** By the blood rheology (hemorheology) we mean the study of the biophysical features of the blood as the viscous fluid. The blood viscosity is characterized by the conventional viscosity factor, which is referred to the certain conditions of the fluid flow (for instance, pressure, velocity).

Macrology treats blood as an integer, devoid of structure, although it is a dispersed system that is viscous, with a number of characteristics: viscosity of whole blood, viscosity of plasma, concentration of hemoglobin). Microrheology examines the rheological behavior of blood according to the properties of its components in particular erythrocytes, which is also characterized by a number of indicators: erythrocyte aggregation, erythrocyte deformation. In the area of the Newtonian current in the arterial channel, where the speeds are high (250÷270 $s^{-1}$), the red blood cells are completely disaggregated - it is in this zone that their deformation begins giving them the shape of ellipsoids. The cardiac function and the mechanical properties of the vascular walls are decisive for blood flow. In arterioles and pre-capillaries (70 $s^{-1}$), large aggregates are first broken down into separate chains - coin bars that navigate along the flow, reduce their length in accordance with the increase in speed, not too strong, aggregates rapidly disintegrate, The largest aggregates are delayed (Riva & Feke, 1981; Kozhemiako et al., 2010).

In capillaries, the red blood cells move one after another. In the region of the Kesson current, in the venous channel (2,5÷10 $s^{-1}$) the most intensive aggregate formation takes place, after which partial aggregates are destroyed, in the heart at the rate of shift «0» practically all the erythrocytes are assembled in aggregates (Riva & Feke, 1981).

Dependence of the viscosity force on the velocity gradient becomes non-linear (Kozhemiako et al., 2010):

$$F\,\boldsymbol{visc} = f((\eta \frac{dV}{dZ})^2), \tag{1}$$

where $dV/dZ$[1/s] – is the velocity gradient that shows how the velocity$V$ changes at the change by the unit of the distance in the direction of the transition from the layer to layer, otherwise the shift velocity; $\eta$ [Pa·s] is the coefficient of the dynamic viscosity of the fluid, that characterizes theresistance of the fluid to the displacement of the layers.

The properties of such environmentfirst of all depend of the fluid. The system in general will have other, greater viscosity that depends on the form and concentration of the particles. For the case of small concentrations of $C$ particles, the formula (Riva & Feke, 1981) is valid:

$$\eta = \eta (1+KC), \quad (2)$$

For the ellipsoids K increases and is determined by the values of its semi axes and their relations. If the structure of the particles changes (for instance, when the conditions of the process change), the coefficient *K* in (3) and the viscosity of such suspension changes.

To study the viscosity of blood and plasma, the method of rotational or capillary viscometry is most often used (Arber et al., 2017; Riva & Feke, 1981) with the determination of viscosity in the range of shear rates from 1 to 200 $s^{-1}$. The choice of working shear rates is determined by the fact that in this range all the effects of nonlinear blood behavior are observed. The data obtained are indicated as apparent viscosity $\eta$ .

**Realization of expert optical-electronic information system for the processing of the biomedical information.** The main problem, solved by the expert optical-electronic information system for the processing of the biomedical information is the automatic allocation of the arbitrary objects, their counting and calculation of the morphologic parameters. The system performs the processing of the biomedical images, in particular, counting of the number of the red blood cells (RBC) on the biomedical image (Fig.1). The search of the objects is performedcompletelyin the automatic mode. The automatic mode operates with a certain error (practical error on the images of rather large area is approximately 10%).

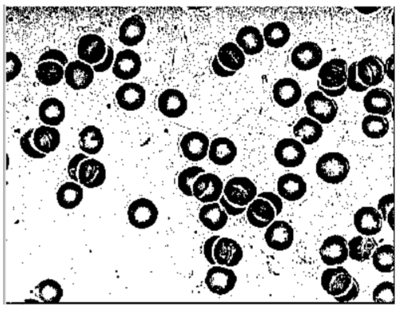


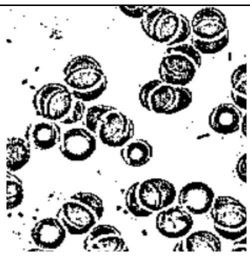
**Figure 1.** Biomedical image of the blood rheology

Hemodynamicindices of the blood flow are defined by the biophysical parameters of the cardiovascular system activity (for instance, stroke volume), structural characteristics of the vessels (their radius and flexibility) and directly by the properties of the blood itself (viscosity) (Riva & Feke, 1981; Kozhemiako et al., 2010).

By the blood rheology (hemorheology) we mean the study of the biophysical features of the blood as the viscous fluid. The blood viscosity is characterized by the conventional viscosity factor, which is referred to the certain conditions of the fluid flow (for instance, pressure, velocity).

Macrology treats blood as an integer, devoid of structure, although it is a dispersed system that is viscous, with a number of characteristics: viscosity of whole blood, viscosity of plasma, concentration of hemoglobin). Microrheology examines the rheological behavior of blood according to the properties of its components in particular erythrocytes, which is also characterized by a number of indicators: erythrocyte aggregation, erythrocyte deformation. In the area of the Newtonian current in the arterial channel, where the speeds are high (250÷270 $s^{-1}$), the red blood cells are completely disaggregated - it is in this zone that their deformation begins giving them the shape of ellipsoids. The cardiac function and the mechanical properties of the vascular walls are decisive for blood flow. In arterioles and pre-capillaries (70 $s^{-1}$), large aggregates are first broken down into separate chains - coin bars that navigate along the flow, reduce their length in accordance with the increase in speed, not too strong, aggregates rapidly disintegrate, The largest aggregates are delayed (Riva & Feke, 1981; Kozhemiako et al., 2010).

One of the main characteristics of the rheological properties of blood is the aggregation of red blood cells, which is determined the nature of superficial intererythrocyte interaction. States of erythrocytes spontaneous aggregation are classified (Riva & Feke, 1981): the formation of aggregates of two red cells; the formation of linear aggregates; the formation of multidimensional (fig. 2).

| Formation of aggregates of two red cells | Formation of linear aggregates | Formation of multidimensional aggregates |
|---|---|---|
|  |  |  |

a) b ) c)

**Figure 2.** States of erythrocytes spontaneous aggregation

Erythrocyte aggregates is also divided of types (Riva & Feke, 1981; Lerche et al., 2010): $D_1$ – linear aggregates; $D_2$ - grid aggregation; $D_3$ - lump aggregation; $D_4$ - echinocyte aggregation (fig.3).

| $D_1$ – linear aggregates | $D_2$ - grid aggregation | $D_3$ - lump aggregation; | $D_4$ - echinocyte aggregation |
|---|---|---|---|
|  |  |  |  |

a) b) c) d)

**Figure 3.** Types of erythrocyte aggregates

Normal physiological aggregation has the character of linear chains in the form of coin columns consisting of 4-5 cells of Fig. 3,a.

On average, human blood samples are disaggregated at shift speeds of $50^{-1}$ seconds, allowing for complete hydrodynamic disaggregation of erythrocytes in the vascular bed. At very low shear speeds, even the normal red blood cells are almost entirely grouped into 3.b coin bars.

At a certain rate of shift, the coin bars are completely destroyed and a suspension flow from individual cells is observed (Riva & Feke, 1981; Lerche et al., 2010). The main feature of a pathological aggregation is a lump aggregation with increased adhesion strength between erythrocytes maintain aggregation even at ($\gamma$ = $250^{-1}$ seconds). Lump assemblies are preserved even at high shear speeds, which makes normal blood flow impossible in micro-vessels (fig. 3.c). The resulting stable assemblies are dropped through a system of shunts past the capillary channel into the venous system, thus ensuring continuity of blood flow. This leads to a discrepancy between the volumetric blood flow through the main vessels and the level of microcirculation and the formation of plasma capillaries free of erythrocytes. A direct consequence of the pathological aggregation of red blood cells is the centralization of blood flow and the insufficiency of tissue perfusion (Riva & Feke, 1981; Stoltz et al., 2010).

Changing the shape from discoid to spherical leads to the impossibility of free packing of red blood cells, i.e., to an increase in the area of contact (aggregation). Echinocytic transformation significantly increases the strength of aggregates (Fig. 3, d).

**Realization of the optical-electronic system for the analysis of blood rheology.** In general case, the input variables, used in the expert system, can be presented either in qualitative or quantitative form. By means of optical-electronic expert system (OEES) the introduction of the input variables, conversion of the quantitative variables into qualitative is performed. The given expert system on the base of the fuzzy logic introduction also realizes the functions of the collection, storage, correlation analysis and usage of knowledge, obtained by the experts in order to analyze the rheologic properties of the blood (Posudin, 2014; Kostruba et al., 1996; Saldan et al., 2017).

Structure scheme of the fuzzy-expert optical-electronic system for the analysis of blood rheology is shown in Fig. 4. OEES consists of the optical block, photosensitive matrix for the registration of the biomedical object of the research, unit for the image preprocessing of biomedical information, block for select of image fragment, blocks for performance of algorithms based on object selection, spatial filtering algorithms, static segmentation algorithms and algorithms based on comparison with references, results proceeding block, customization block, block of standards for evaluation of geometric parameters of the rheological properties of blood, system of results inference and decision-making Unit of the fuzzy processing and output, used in the expert system allows to process complex hierarchical structures of the input variables, which can be presented in the form of the tree.

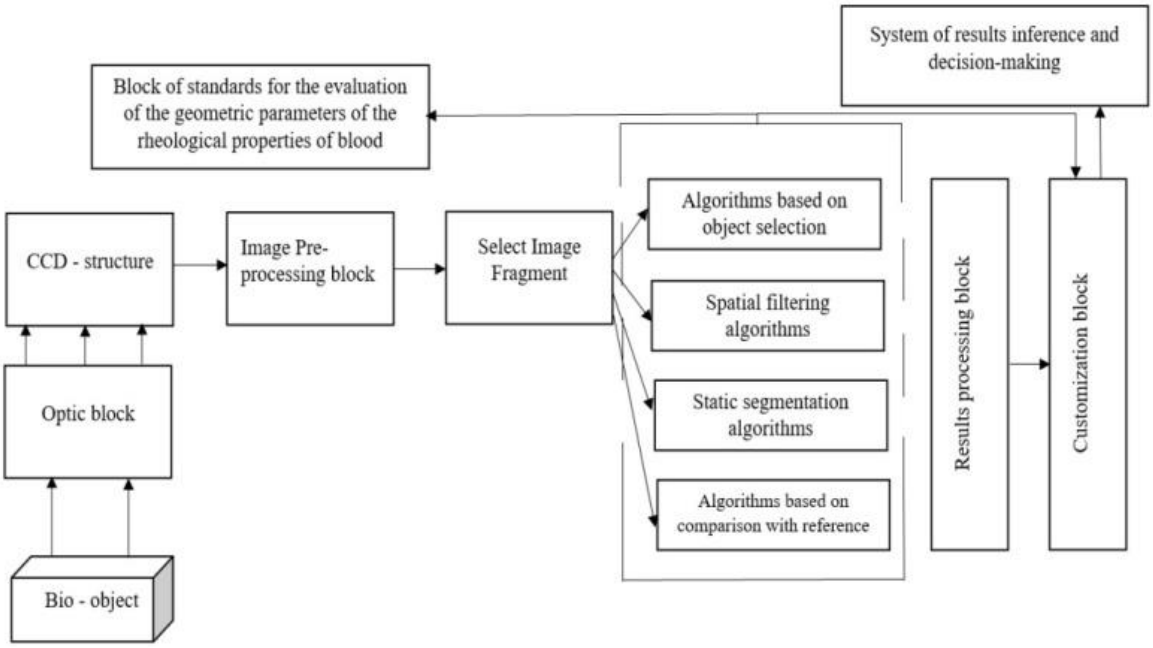
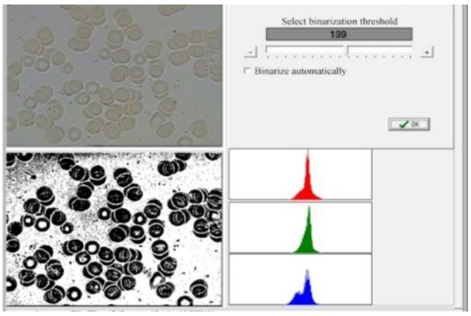



**Figure 4.** Structure scheme of the fuzzy-expert optical-electronic system for the analysis of blood rheology

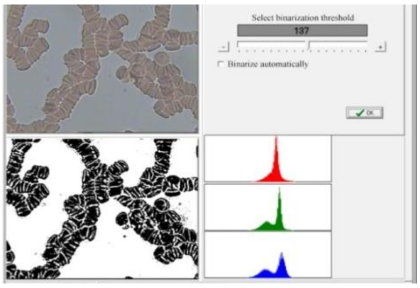
**Results and Discussion.** For instance, after the examination by means of optical-electronic expert system, of the patients with the possible pathological changes, the results, shown in Fig. 5 are fixed.

To a great extent it is connected with the fact that the blood has the internal structure, that is the suspension of the formed elements in the solution – plasma. As 93% of the formed elements are the red blood cells, in case of the simplified model examination the blood is the suspension of the red blood cells in the psychological salt solution.

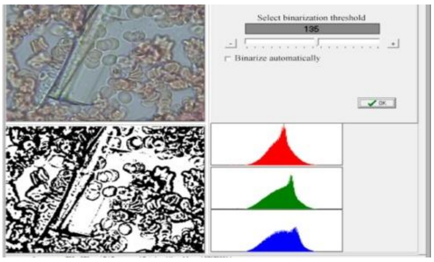
Changes in the rheological parameters of blood are one of the significant mechanisms of the formation of insufficient blood supply in the early stages the development of the disease. Main pathological effects violations of rheological properties in the blood can lead to micro-flow failure circulation, the extreme manifestation of which may lead to a decrease in trophism and the development of ischemic syndrome, a violation of micro-rheology and an increase in the viscosity of blood, which causes an increase in total peripheral resistance and the development of arterial hypertension syndrome, to atherosclerotic changes in blood vessels, to a violation of hemorheology, which contributes to increased thrombosis (Riva & Feke, 1981).



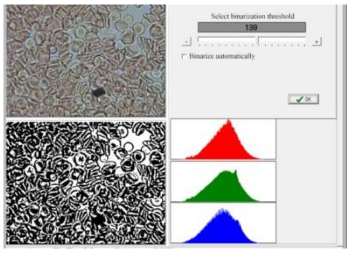

a) Norm – $D_1$




b) Pathology of the 1$^{st}$ level – $D_2$




c) Pathology of the 2$^{st}$ level – $D_3$



d) Pathology of the 2$^{st}$ level – $D_3$

**Figure 5.** Results of the biomedical images processing

**Conclusion.** It enabled to perform complex efficient diagnostics and increase by 10% the validity and speed of the diagnostics. Information features (information parameters) of the analysis of the biomedical images, in particular, for the assessment of the rheologic properties of the blood, are formed. Algorithm and optical-electronic fuzzy expert system for the analysis of the rheological properties of the blood are suggested, they are used for the increase of the diagnostic validity which is a determining factor in the biomedical diagnostics. Changes in the rheological parameters of blood are one of the significant mechanisms of the formation of insufficient blood supply in the early stages the development of the disease. In this way, the main focus of modern clinical hemorheology is the search diagnostic and prognostic criteria for various diseases and rheological correction methods violations.

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**Conflicts of Interest.** The authors declare no conflict of interest.

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