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Research Article

Role of Clinical Laboratories in Early Detection of Sepsis

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Abstract:

Clinical laboratories play a pivotal role in the early detection of sepsis, a life-threatening condition caused by the body's response to infection. Quick and accurate laboratory diagnostics are essential for identifying the pathogens responsible for sepsis, as well as for assessing the host's response to infection. Common laboratory tests, including complete blood counts (CBC), blood cultures, and biochemical markers like C-reactive protein (CRP) and procalcitonin, help clinicians recognize the early signs of sepsis. The rapid turnaround time for these tests is critical, as early diagnosis and treatment significantly reduce morbidity and mortality associated with sepsis. By leveraging advanced techniques such as multiplex polymerase chain reaction (PCR) and next-generation sequencing, clinical laboratories can swiftly identify infectious agents and guide targeted therapy. Moreover, clinical laboratories are integral to the continuous monitoring of patients suspected of having sepsis. Ongoing assessments through repeated laboratory testing can provide invaluable insights into a patient's evolving condition and response to treatment. For instance, trends in laboratory markers can indicate whether a patient is improving or deteriorating, prompting timely adjustments to their management plan. The integration of laboratory data with clinical assessments enables healthcare teams to make informed decisions, improving sepsis outcomes. Overall, the collaboration between clinical laboratories and healthcare providers is critical in the fight against sepsis, emphasizing the importance of laboratory capabilities in enhancing patient care.

1. Introduction

Sepsis represents a dysregulated host response to infection, leading to systemic inflammation, organ dysfunction, and, if not promptly treated, septic shock and death. The pathophysiology of sepsis involves complex interactions between pathogens and the host immune system, resulting in a cascade of inflammatory and anti-inflammatory responses. This complexity makes sepsis challenging to diagnose, as its symptoms often overlap with other conditions. Therefore, laboratory tests are indispensable for confirming suspicion of sepsis, identifying the causative pathogen, and monitoring disease progression. The World Health Organization has recognized sepsis as a priority condition, urging for improved diagnostic capabilities and early intervention strategies [1]. Similarly, the Surviving Sepsis Campaign emphasizes the importance of early recognition and treatment, highlighting the role of laboratory parameters in sepsis bundles [2].

The incidence of sepsis is increasing worldwide due to factors such as aging populations, the rise of antimicrobial resistance, and the prevalence of chronic diseases. According to recent studies, sepsis affects approximately 49 million people annually, with 11 million deaths, accounting for nearly 20% of all global deaths [3]. In low- and middle-income countries, the burden is even higher, exacerbated by limited access to healthcare and diagnostic resources. Early detection and appropriate management can reduce sepsis mortality by up to 50%, underscoring the critical need for effective laboratory diagnostics [4]. Clinical laboratories contribute to this effort by providing rapid and accurate test results that inform clinical decisions. From routine blood tests to advanced molecular assays, laboratories offer a range of tools that aid in the early identification of sepsis.

The diagnosis of sepsis traditionally relies on clinical criteria such as fever, tachycardia, tachypnea, and altered mental status, combined with laboratory findings. However, these clinical signs are non-specific and can be absent in some patients, particularly the elderly or immunocompromised. Hence, laboratory tests become essential for objective assessment. Key laboratory indicators include markers of infection (e.g., leukocytosis or leukopenia), inflammation (e.g., C-reactive protein, procalcitonin), organ dysfunction (e.g., lactate, creatinine), and coagulation abnormalities (e.g., D-dimer, platelet count). These parameters help clinicians differentiate sepsis from other conditions, assess severity, and guide therapeutic interventions [5]. The integration of these tests into clinical algorithms enhances the accuracy and timeliness of sepsis diagnosis.

Clinical laboratories have evolved significantly over the years, incorporating automation, informatics, and novel technologies to improve diagnostic performance. In the context of sepsis, laboratories not only perform tests but also interpret results in the context of patient history and clinical presentation. This interpretive role is crucial for early detection, as it allows for the identification of subtle changes that may indicate incipient sepsis. Moreover, laboratories facilitate the monitoring of treatment response, enabling adjustments in therapy based on serial measurements. For instance,

trending procalcitonin levels can help determine the duration of antibiotic therapy, reducing unnecessary exposure and combating antimicrobial resistance [6]. Thus, laboratories are integral to the entire sepsis care pathway, from suspicion to recovery.

Despite advancements, challenges remain in the laboratory diagnosis of sepsis. These include pre-analytical variables such as sample collection and handling, analytical issues like test sensitivity and specificity, and post-analytical factors including result reporting and interpretation. Additionally, the turn-around time for tests is critical, as delays can compromise patient outcomes. Point-of-care testing (POCT) has emerged as a solution to provide rapid results at the bedside, but it requires careful quality control and integration with central laboratory systems [7]. Furthermore, the cost-effectiveness of novel biomarkers and technologies must be considered, especially in resource-limited settings. Research continues to address these challenges, aiming to optimize laboratory contributions to sepsis management.

The future of sepsis diagnostics lies in the development of multiplexed assays, omics technologies, and artificial intelligence (AI) that can analyze complex data patterns. Clinical laboratories are at the forefront of adopting these innovations, which promise to revolutionize early detection. For example, sepsis biomarkers derived from proteomics, metabolomics, and transcriptomics offer insights into the host response at a molecular level, enabling more precise diagnosis and risk stratification [8]. AI algorithms can integrate laboratory data with electronic health records to predict sepsis onset before clinical manifestation. As these technologies mature, clinical laboratories will play an even more central role in combating sepsis.

Sepsis, often termed the "hidden killer," is a medical emergency that requires immediate attention. Its definition has evolved over time, from focusing on systemic inflammation to emphasizing organ dysfunction. The current Sepsis-3 definition characterizes sepsis as life-threatening organ dysfunction caused by a dysregulated host response to infection [9]. This definition underscores the importance of identifying organ dysfunction early, which heavily relies on laboratory parameters such as serum lactate levels and Sequential Organ Failure Assessment (SOFA) score components, many of which are laboratory-based [10]. The SOFA score includes measures of respiration (PaO2/FiO2 ratio), coagulation (platelet count), liver (bilirubin), cardiovascular (mean arterial pressure or vasopressor use), central nervous system (Glasgow Coma Scale), and renal function (creatinine or urine output). Thus, clinical laboratories are fundamental in calculating SOFA scores and diagnosing sepsis.

The economic burden of sepsis is substantial, with high costs associated with hospital stays, intensive care, and long-term rehabilitation. In the United States alone, sepsis accounts for over $24 billion in annual healthcare expenses [11]. Early detection and intervention can reduce these costs by preventing complications and shortening hospital stays. Clinical laboratories contribute to cost-effectiveness by providing tests that guide appropriate resource utilization. For example, rapid pathogen identification allows for targeted antimicrobial therapy, reducing broad-spectrum antibiotic use and associated costs [12]. Moreover, laboratory tests help in risk stratification, identifying patients who require intensive care versus those who can be managed in general wards.

Historically, sepsis diagnosis relied heavily on clinical acumen, but with the advent of laboratory medicine, objective criteria have become standard. The development of biomarkers like C-reactive protein (CRP) and procalcitonin (PCT) has revolutionized sepsis diagnostics. CRP, an acute-phase protein, rises in response to inflammation, but it is not specific to infection. PCT, on the other hand, is more specific to bacterial infections and is widely used to differentiate sepsis from non-infectious inflammatory conditions [13]. Laboratories measure these biomarkers using immunoassays, providing results within hours. The incorporation of such biomarkers into clinical protocols has improved the accuracy of sepsis diagnosis.

In addition to biomarkers, microbiological cultures are cornerstone tests in sepsis. Blood cultures remain the gold standard for detecting bloodstream infections, but they have limitations such as long turnaround times and low sensitivity in patients on antibiotics. Clinical laboratories have implemented methods to expedite culture results, including automated blood culture systems and matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry for rapid pathogen identification [14]. These advancements reduce the time to identification from days to hours, enabling earlier targeted therapy.

The host immune response in sepsis involves a multitude of cellular and molecular pathways, which laboratory tests can capture. For instance, flow cytometry can analyze immune cell subsets, revealing patterns of immunosuppression that are common in sepsis [15]. Similarly, cytokine profiles measured by multiplex assays can indicate the severity of the inflammatory response. These specialized tests are often performed in clinical laboratories with advanced capabilities,

contributing to a deeper understanding of sepsis pathophysiology.

Laboratory testing for sepsis is not without challenges. Pre-analytical factors, such as the timing of sample collection and the volume of blood drawn, can affect results. For example, lactate levels must be measured promptly to avoid false elevations due to glycolysis in vitro [16]. Analytical variability between different assay platforms can also impact result interpretation. Laboratories must standardize procedures and participate in quality assurance programs to ensure reliability. Moreover, post-analytical communication of critical results is vital, requiring effective alert systems to notify clinicians of abnormal findings suggestive of sepsis.

The integration of laboratory information systems (LIS) with electronic health records (EHR) enhances the utility of laboratory data in sepsis detection. Automated alerts based on laboratory values, such as elevated lactate or low platelet count, can prompt clinical evaluation for sepsis [17]. Machine learning algorithms that incorporate laboratory data along with vital signs and clinical notes have shown promise in predicting sepsis onset earlier than traditional methods [18]. Clinical laboratories are key stakeholders in developing and implementing these decision support tools.

Global health organizations have launched initiatives to combat sepsis, emphasizing the role of diagnostics. The World Health Assembly adopted a resolution on sepsis in 2017, urging member states to improve prevention, diagnosis, and management [19]. This resolution specifically calls for strengthening laboratory capacity, especially in low-resource settings. Clinical laboratories are thus seen as essential components of health systems, and investments in laboratory infrastructure can yield significant benefits in sepsis care. For example, the installation of automated chemistry and hematology analyzers in rural hospitals can facilitate rapid testing of key parameters like lactate and complete blood count [20].The multidisciplinary nature of sepsis management requires collaboration between clinicians, microbiologists, pathologists, and laboratory technicians. Clinical laboratories serve as hubs for this collaboration, providing expertise in test selection and interpretation. Laboratory professionals contribute to antibiotic stewardship programs by reporting antimicrobial susceptibility patterns and guiding empiric therapy choices [21]. In sepsis, where every hour of delay in appropriate antibiotics increases mortality, laboratory input is crucial for timely decision-making.

Research into sepsis biomarkers is ongoing, with hundreds of candidates proposed in the literature. However, only a few have been validated for clinical use. Clinical laboratories play a role in validating and implementing new biomarkers through clinical trials and quality control measures. The process from discovery to routine use involves assessing analytical performance, clinical utility, and cost-effectiveness. Laboratories must balance innovation with practicality, ensuring that new tests add value to patient care [22].

2. Pathophysiology of Sepsis and Laboratory Indicators

Sepsis pathophysiology involves a complex interplay between the invading pathogen and the host immune response. Upon infection, pathogen-associated molecular patterns (PAMPs) such as lipopolysaccharide from gram-negative bacteria or peptidoglycan from gram-positive bacteria are recognized by pattern recognition receptors (PRRs) on immune cells. This recognition triggers the release of pro-inflammatory cytokines like tumor necrosis factor-alpha (TNF-α), interleukin-1 (IL-1), and interleukin-6 (IL-6), leading to systemic inflammation. Concurrently, anti-inflammatory responses are activated to dampen inflammation, but in sepsis, this balance is disrupted, resulting in organ damage [9]. Laboratory indicators reflect these pathophysiological changes. For example, elevated levels of cytokines can be measured in serum, although they are not routinely used due to assay complexity. Instead, downstream markers like C-reactive protein (CRP) and procalcitonin (PCT) are commonly assessed. CRP is produced by the liver in response to IL-6, and its rise indicates inflammation [10]. PCT, a precursor of calcitonin, is upregulated by bacterial infections and inflammatory cytokines, making it a more specific marker for sepsis [11]. Additionally, organ dysfunction manifests in laboratory abnormalities such as increased serum creatinine for renal dysfunction, elevated bilirubin for liver dysfunction, and thrombocytopenia for coagulation abnormalities. The Sequential Organ Failure Assessment (SOFA) score incorporates these laboratory parameters to quantify organ dysfunction, aiding in sepsis diagnosis and prognosis [12]. Thus, understanding pathophysiology guides the selection of laboratory tests for early detection.The host response in sepsis also involves endothelial activation and coagulation cascades. Endothelial damage leads to increased permeability, edema, and microthrombosis, contributing to organ hypoperfusion. Laboratory tests for coagulation, such as D-dimer and fibrin degradation products, indicate activated coagulation and fibrinolysis [13]. Moreover, lactate levels rise due to tissue hypoxia and anaerobic metabolism,

serving as a marker of cellular stress and guiding resuscitation efforts [14]. Clinical laboratories measure these parameters using automated analyzers, providing rapid results that inform clinical decisions. The integration of multiple laboratory indicators enhances the sensitivity and specificity of sepsis diagnosis, as no single test is perfect. For instance, the combination of PCT with clinical criteria improves the accuracy of diagnosing bacterial sepsis [15]. Therefore, laboratories must offer a panel of tests that capture the multifaceted nature of sepsis.

3. Traditional Biomarkers in Sepsis Detection

Traditional biomarkers for sepsis include leukocyte count, CRP, PCT, and lactate. The white blood cell (WBC) count is a routine test that often shows leukocytosis or leukopenia in sepsis. However, it is non-specific and can be influenced by many factors such as stress, steroids, or other illnesses [16]. CRP has been used for decades as an inflammatory marker. It rises within 6-12 hours of infection and peaks at 24-48 hours, but it lacks specificity for infection as it can be elevated in non-infectious inflammatory conditions like rheumatoid arthritis [17]. Despite this, CRP is valuable for monitoring response to therapy, as declining levels suggest effective treatment. PCT, introduced in the 1990s, has gained prominence due to its higher specificity for bacterial infections. PCT levels increase within 2-4 hours of infection, peak at 6-24 hours, and have a half-life of 24-36 hours, making it useful for early diagnosis and antibiotic stewardship [18]. Studies have shown that PCT-guided antibiotic therapy reduces antibiotic duration without compromising outcomes [19]. Lactate, measured from blood gas analyzers, is a critical biomarker for tissue hypoperfusion. Elevated lactate (≥2 mmol/L) in sepsis indicates shock and is associated with higher mortality [20]. The Surviving Sepsis Campaign recommends measuring lactate in patients with suspected sepsis and targeting resuscitation to normalize lactate levels [21]. These traditional biomarkers are widely available in clinical laboratories and form the backbone of sepsis diagnostics.In addition to these, erythrocyte sedimentation rate (ESR) is sometimes used but is less specific. Other traditional tests include blood cultures, which are essential for pathogen identification but are not rapid. Laboratories have improved blood culture techniques with automated systems that detect microbial growth continuously, reducing time to positivity [22]. Despite advancements, traditional biomarkers have limitations. For example, PCT may not be elevated in localized infections or viral sepsis, and lactate can be elevated in conditions like liver disease or metformin use [23]. Therefore, laboratories often combine multiple biomarkers to improve diagnostic accuracy. The use of biomarker ratios, such as PCT/CRP ratio, has been proposed to differentiate sepsis from non-infectious inflammation [24]. Clinical laboratories play a key role in validating and implementing such combinations in routine practice.

4. Emerging Biomarkers and Novel Technologies

The search for better sepsis biomarkers has led to the discovery of numerous candidates, including presepsin, soluble triggering receptor expressed on myeloid cells-1 (sTREM-1), and cell-free DNA. Presepsin, a fragment of the CD14 receptor, is released during bacterial phagocytosis and has shown promise in early sepsis detection. Studies indicate that presepsin levels rise earlier than PCT and correlate with sepsis severity [25]. sTREM-1 is involved in amplifying inflammatory responses and can be measured in plasma or bronchoalveolar lavage fluid. It has good diagnostic accuracy for bacterial infections [26]. Cell-free DNA, released from necrotic cells, increases in sepsis and can be quantified rapidly using fluorescent assays. It not only indicates infection but also reflects the extent of tissue damage [27]. These emerging biomarkers are being incorporated into commercial assays, and clinical laboratories are evaluating their utility in real-world settings.Novel technologies such as mass spectrometry, microfluidics, and biosensors are revolutionizing sepsis diagnostics. Mass spectrometry, particularly MALDI-TOF, allows for rapid identification of pathogens from positive blood cultures, reducing identification time from hours to minutes [28]. Microfluidic devices enable multiplexed detection of biomarkers from small sample volumes, facilitating point-of-care testing. Biosensors that use nanotechnology can detect pathogens or biomarkers with high sensitivity and specificity [29]. Additionally, omics technologies like proteomics, metabolomics, and transcriptomics provide comprehensive profiles of host response. For instance, metabolomic studies have identified distinct metabolic signatures in sepsis patients, which could lead to new diagnostic panels [30]. Clinical laboratories are adopting these technologies to enhance early detection, though challenges remain in standardization and cost.

5. Microbiological Diagnostics in Sepsis

Microbiological diagnostics are crucial for confirming infection and guiding antimicrobial

therapy. Blood cultures are the standard for detecting bacteremia and fungemia. Optimal blood culture practice involves collecting adequate blood volumes (20-30 mL per set) from different sites before antibiotic administration [31]. Automated blood culture systems use sensors to detect microbial growth, alerting technicians when bottles are positive. Once positive, Gram staining provides immediate information on morphology, followed by subculture and identification. MALDI-TOF mass spectrometry has revolutionized identification by analyzing protein spectra, providing species-level identification within minutes [32]. Antimicrobial susceptibility testing (AST) is then performed using methods like disk diffusion or automated systems, which determine the minimal inhibitory concentrations (MICs). However, AST results typically take 24-48 hours after identification.

To expedite results, laboratories have implemented rapid AST methods such as genotypic detection of resistance genes by PCR or fluorescence in situ hybridization (FISH) [33]. Additionally, direct testing from blood cultures using PCR panels can identify pathogens and resistance markers within hours. For example, the FilmArray Blood Culture Identification panel detects common bacteria, yeast, and antibiotic resistance genes [34]. These rapid methods enable earlier targeted therapy, improving outcomes. Besides blood cultures, other specimens like urine, sputum, or cerebrospinal fluid are cultured based on clinical suspicion. Molecular tests like PCR for specific pathogens (e.g., Streptococcus pneumoniae, Neisseria meningitidis) are also used, especially in culture-negative cases [35]. Clinical laboratories must balance speed with accuracy, ensuring reliable results for patient care.

6. Hematological and Coagulation Parameters

Hematological parameters provide insights into the host response in sepsis. Complete blood count (CBC) includes white blood cell count, hemoglobin, and platelet count. Sepsis often causes thrombocytopenia, which is associated with disseminated intravascular coagulation (DIC) and poor prognosis [36]. The platelet count is part of the SOFA score and can indicate coagulation abnormalities. Red blood cell distribution width (RDW) has emerged as a prognostic marker, with higher RDW correlating with mortality in sepsis [37]. Additionally, immature granulocyte count or the presence of left shift can suggest bacterial infection. Automated hematology analyzers flag these abnormalities, prompting further investigation.Coagulation tests are essential in sepsis due to the risk of DIC. Routine tests include prothrombin time (PT), activated partial thromboplastin time (aPTT), fibrinogen, and D-dimer. DIC is characterized by prolonged PT, low fibrinogen, and elevated D-dimer. The International Society on Thrombosis and Haemostasis (ISTH) criteria for DIC incorporate these laboratory parameters [38]. Thromboelastography (TEG) and rotational thromboelastometry (ROTEM) provide viscoelastic measurements of clot formation and lysis, offering real-time assessment of coagulation status in septic patients [39]. These point-of-care tests guide transfusion therapy. Laboratories perform these tests and interpret results in the context of clinical presentation, aiding in the management of coagulation disorders in sepsis.

7. Molecular Diagnostics and Genomics

Molecular diagnostics have transformed sepsis detection by enabling rapid pathogen identification and resistance gene detection. Polymerase chain reaction (PCR) based assays amplify specific DNA sequences from pathogens directly from blood samples. Multiplex PCR panels can detect multiple pathogens simultaneously, including bacteria, fungi, and viruses [40]. For example, the SeptiFast test identifies 25 common pathogens from blood, providing results within 6 hours [41]. Next-generation sequencing (NGS) offers even broader detection, sequencing all nucleic acids in a sample to identify pathogens without prior suspicion. Metagenomic NGS can detect rare or novel pathogens, making it valuable in immunocompromised patients [34]. However, NGS is costly and requires bioinformatics expertise, limiting its routine use.

Genomic approaches also study host response genes. Transcriptomic profiling of blood cells can classify sepsis subtypes and predict outcomes [35]. For instance, gene expression signatures of immunosuppression have been identified in septic patients. These molecular insights could lead to personalized therapy. Clinical laboratories are incorporating molecular diagnostics into their workflows, but challenges include contamination risk, interpretation of results, and integration with traditional methods. Despite this, molecular diagnostics represent a significant advancement in early sepsis detection.

8. Point-of-Care Testing (POCT) for Rapid Detection

Point-of-care testing brings laboratory testing to the bedside, reducing turnaround time and facilitating immediate decisions. In sepsis, POCT for lactate, PCT, and blood gases is widely used. Handheld

lactate meters provide results within seconds, allowing for rapid assessment of tissue perfusion [36]. PCT POCT devices are available, enabling measurement in emergency departments or intensive care units. These devices use immunoassay principles and provide results in 15-30 minutes [37]. Blood gas analyzers measure pH, pCO2, pO2, and lactate, giving insights into acid-base status and oxygenation.

The advantages of POCT include speed, convenience, and potential for improved outcomes. However, POCT must be integrated with central laboratory systems for quality control and result documentation. Training of non-laboratory personnel is essential to ensure accurate testing. Studies show that POCT for sepsis biomarkers can reduce time to antibiotic administration and length of stay [38]. As technology advances, more multiplexed POCT panels for sepsis biomarkers are being developed. Clinical laboratories oversee POCT programs, ensuring compliance with regulations and standards.

9. Integration of Laboratory Data with Clinical Decision Support

The volume of laboratory data in sepsis management requires effective integration and interpretation. Laboratory information systems (LIS) store and transmit test results to electronic health records (EHR). Clinical decision support systems (CDSS) use algorithms to analyze laboratory data alongside clinical parameters to alert clinicians to possible sepsis. For example, an automated alert based on elevated lactate and low blood pressure can trigger a sepsis protocol [39]. Machine learning models that incorporate sequential laboratory values can predict sepsis onset hours before clinical recognition [40].

These systems rely on accurate and timely laboratory data. Laboratories contribute by ensuring data quality and participating in the development of CDSS rules. The integration also facilitates antibiotic stewardship by linking culture results to antibiotic orders. However, alert fatigue can occur if too many alerts are generated. Therefore, CDSS must be refined to balance sensitivity and specificity. Clinical laboratories play a collaborative role in optimizing these tools for early sepsis detection.

10. Challenges and Limitations in Laboratory Diagnosis

Despite advancements, laboratory diagnosis of sepsis faces challenges. Pre-analytical issues include sample collection errors, such as insufficient blood volume for cultures or delayed processing of lactate samples [41]. Analytical variability between different assay platforms can lead to inconsistent results. For example, PCT values may differ between immunoassays, affecting clinical decisions [23]. Post-analytical challenges involve result interpretation and communication. Critical results must be communicated promptly to clinicians, but this relies on effective protocols.

Economic constraints limit access to advanced tests in resource-limited settings. Cost-effectiveness studies are needed to justify new biomarkers. Additionally, the overreliance on biomarkers can lead to misdiagnosis if used without clinical context. Laboratories must educate clinicians on the appropriate use and limitations of tests. Quality assurance programs are essential to maintain test accuracy. Addressing these challenges requires continuous improvement and collaboration.

11. Future Directions and Innovations

The future of sepsis diagnostics lies in personalized medicine and advanced technologies. Multiplexed panels combining traditional and emerging biomarkers will provide comprehensive profiles. Omics technologies will identify novel signatures for early detection and stratification. Artificial intelligence will analyze complex data patterns to predict sepsis earlier [40]. Wearable devices that monitor physiological parameters could integrate with laboratory data for continuous assessment.

Clinical laboratories will evolve to adopt these innovations, requiring investment in infrastructure and training. Point-of-care molecular diagnostics and digital pathology will become more prevalent. Global collaborations will standardize diagnostics across regions. Ultimately, the goal is to achieve rapid, accurate, and accessible sepsis detection worldwide, saving lives through early intervention.

12. Conclusion

In conclusion, clinical laboratories are indispensable for the early detection of sepsis. Through a wide array of tests, from traditional biomarkers to advanced molecular diagnostics, laboratories provide critical information that guides diagnosis and treatment. The integration of laboratory data with clinical decision support enhances timely recognition, while point-of-care testing offers rapid results at the bedside. Challenges remain, but ongoing innovations promise to improve diagnostic capabilities. As sepsis continues to pose a global health threat, the role of clinical laboratories will only grow in importance, underscoring the need for sustained

investment and collaboration in laboratory medicine.

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