Abstract

Biomarkers, or biological markers, have been tested in the clinical laboratory for decades. More recently, there has been a surge in research studies aimed at identifying biomarkers of infection and inflammation. One of the foremost motivators in this expansion of research is the quest to find ideal biomarkers for sepsis. Traditional, yet still relevant, laboratory markers of infection and inflammation consist of the white blood cell count, erythrocyte sedimentation rate, and C-reactive protein. Newer biomarkers that are currently available in the clinical laboratory and used for the evaluation of sepsis include lactate and procalcitonin, while two promising emergent biomarkers for the evaluation of sepsis, pentraxin 3 and presepsin, are presented. Beyond sepsis, promising emergent biomarkers for chronic wound infections, pneumonia, and invasive fungal infections are also discussed.
LEARNING OBJECTIVES:

1. Define the term “biomarker”.

2. Describe the traditional, newer, and future biomarkers of sepsis discussed in this article.

3. Identify the emergent biomarkers of chronic wound infections, pneumonia, and invasive fungal infections discussed in this article.
ABBREVIATIONS:

BDG - 1,3-β-D-glucan, CD - cluster of differentiation, CRP - C-reactive protein, ESR - erythrocyte sedimentation rate, FDA - Food and Drug Administration, GM - galactomannan, HNE - human neutrophil elastase, IL - interleukin, MALDI-TOF - matrix-assisted laser desorption ionization time of flight, PCT - procalcitonin, PTX3 - pentaxin 3, WBC - white blood cell
INDEX TERMS:

Biomarker, infection, inflammation, sepsis
INTRODUCTION TO BIOMARKERS

Identification of microorganisms and their antimicrobial susceptibility patterns are the primary objectives of a microbiology department. Other laboratory departments (in particular clinical chemistry and hematology) have played a supportive role in the diagnosis of infection with the detection and quantification of circulating markers, known as biomarkers. As the microbiology department has evolved due to technological advances, we have also seen a boom in research to discover superior biomarkers of infection and inflammation.

The term biomarker can have different meanings depending upon the context, thus in 2001 it was standardized as “a characteristic that is objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention”. With this definition, biomarkers encompass results of laboratory testing, imaging techniques (e.g., magnetic resonance imaging), and recordings of physiological tests (e.g., blood pressure, electrocardiogram). Biomarkers are often classified by their application for diagnostic, predictive, and prognostic purposes, monitoring of treatment, pharmacodynamic response, and safety. Diagnostic biomarkers detect the presence of disease while prognostic biomarkers are used in identifying the probability of disease recurrence or progression. Predictive biomarkers aid in identifying those who will respond to therapy. Monitoring of treatment biomarkers are used to assess the status of a disease. Biomarkers that change in concentration upon exposure to a medical product are known as pharmacodynamic response biomarkers. Lastly, safety biomarkers indicate the presence or risk of an adverse event due to medical intervention.

BIOMARKERS IN THE CLINICAL LABORATORY
For this review, the definition of a biomarker provided by the National Cancer Institute (part of the National Institutes of Health), “a biological molecule found in blood, other bodily fluids, or tissues that is a sign of a normal or abnormal process, or of a condition or disease” will be used as it is more specific to laboratory testing. BI0. Biomarkers have been detected since the beginning of the twentieth century, yet the term is relatively new.6,10 Examples of established biomarkers include pancreatic enzymes (amylase and lipase), acute myocardial infarction markers (creatine kinase-MB and cardiac troponin), kidney metabolites (creatinine and urea), liver enzymes (alanine aminotransferase and aspartate aminotransferase), and tumor markers (prostate-specific antigen and cancer antigen 125).6,10 Biomarker research has expanded over the past few decades due to their potential to improve success rates in drug development and advances in –omic (genomics, transcriptomics, proteomics, peptidomics, and metabolomics) technologies.11 Nevertheless, the number of biomarkers cleared by the United States Food and Drug Administration (FDA) has not increased. According to Pavlov (2013), this is due to the lengthy and challenging process of going from biomarker discovery to FDA clearance for clinical testing.11

The FDA has a pathway for developing disease-related biomarkers that consists of a multistep process.4 A simplistic description would be to describe the pathway occurring in four main phases. The first phase is discovery and consists of exploratory studies that are performed to identify promising biomarkers.4,11 The second phase is analytical validation that includes analysis of performance metrics ensuring the test is reliable, reproducible, and of adequate sensitivity and specificity. The next phase is clinical validation that focuses on how well the test measures a clinical feature of the disease, disease outcome, or outcome of treatment. The final phase is clinical utility and is established by how well the test either confirms a diagnosis,
improves patient outcomes, determines appropriate treatment, or monitors treatment. Assay development is interwoven within the phases as it is a continuous process that begins after discovery but can be modified throughout any phase of the process.

The multi-phase process described above is a long and arduous journey that can take up to 10 years from discovery phase to clearance by the FDA. Researchers encounter many challenges throughout this lengthy process. Major challenges include relatively high false-positive rates, lack of rigorous validation studies, or scarcity of data showing significant contribution to clinical practice. With each phase, the financial burden increases and often industry enters after the second phase to provide financial support. Industry involvement presents new challenges, such as ownership of intellectual property.

This article focuses on biomarkers of infection (primarily bacterial infections) and inflammation. Biomarkers of inflammation are included as they typically rise in response to an infection. The presentation of these biomarkers will begin with a brief review of conventional laboratory makers of infection and inflammation (Table 1), followed by a review of more recent biomarkers used for the diagnosis and prognosis of sepsis (Table 2). Finally, emergent or promising biomarkers for bacterial and fungal infections that are prevalent in the literature will be succinctly presented (Table 2).

TRADITIONAL LABORATORY MARKERS OF INFECTION AND INFLAMMATION

Traditional or established laboratory markers consist of hematological parameters of infection, inflammatory response markers, and serological markers of bacterial and viral infections. Hematological parameters, such as the white blood cell (WBC) count, have long been used as biomarkers of infection and inflammation. As the role of leukocytes is to protect the host against infectious agents and provide an immune defense, an elevated WBC count is often an
早期的感染标志物。\textsuperscript{12,13} 白细胞分类，血液计数的另一个组成部分，也提供了对传染病状态的洞察。\textsuperscript{12}

传统的感染和/或炎症标志物包括红细胞沉降率 (ESR) 和 C-反应蛋白 (CRP)。ESR 由 Westergren 在 1921 年引入，仍然是血液科部门的常规测试，并测量了红细胞在垂直柱中在一定时间内下降的速率。\textsuperscript{14-16} 它是急性期反应的间接衡量，且在炎症时增加。ESR 是非特异性的，且可能受多种因素的影响，例如急性期蛋白的存在、红细胞的数量以及血浆蛋白的水平。\textsuperscript{12,15} 不论如何，ESR 升高的常见原因是感染。\textsuperscript{12} ESR 的临床价值一直受到争议，由于其缺乏特异性，但仍然是一个常见的测试。\textsuperscript{17-20}

C-反应蛋白是一种急性期血浆蛋白，是 pentraxin 蛋白家族的成员。\textsuperscript{15} CRP 在宿主防御 (先天免疫) 中起着重要作用，通过识别细菌并激活补体级联或触发吞噬作用来对抗病原菌。\textsuperscript{15,21} 血清中 CRP 的浓度会迅速上升，对感染 (细菌性和寄生性) 或组织损伤 (创伤性坏死和恶性肿瘤)。\textsuperscript{21} 上升可以是正常值的 1000 倍，并且可能与炎症过程的强度成正比。\textsuperscript{15,21,22} 由于其快速响应的急性炎症过程，它是一个急性反应的有价值指标。\textsuperscript{21} CRP 被认为是一个更好的指标，因为它对急性反应的敏感性和快速检测的改变对疾病。\textsuperscript{23}

血清标志物是确定感染性疾病病因或感染的已建立生物标志物。
Serodiagnosis is based on “the principle that the reaction between an antibody and an antigen will result in a recordable event” with a goal of identifying “an antigen or antibody in order to help determine the etiologic importance of a particular microorganism”. For brevity, serological markers will be discussed globally in relation to bacterial and viral infections.

Serological testing may be used to directly identify bacterial agents, such as Treponema pallidum, Borrelia burgdorferi (causative agent of Lyme disease), Coxiella burnetii, and Rickettsia and Streptococcus species. In addition, serological testing, often in the form of an immunoassay, is commonly used in the diagnosis of viral infections caused by hepatitis viruses and the human immunodeficiency virus. For many years, serological testing was primarily performed in the microbiology department; however, due to advances in technology most serological assays are performed today on automated clinical chemistry analyzers.

NEWER BIOMARKERS OF INFECTION AND INFLAMMATION: SEPSIS

Febrile illness resulting from bacterial infection is a common cause of hospitalization and is a contributing factor in the growth of biomarker research. The overwhelming concern of any bacterial infection is progression to sepsis due to its high mortality rate. Worldwide sepsis is responsible for 30 million cases resulting in 8 million deaths. To date, there is not a gold standard test for sepsis, yet several researchers are looking at emergent biomarkers with optimism. The quest for an ideal biomarker of bacterial infection, especially sepsis, is a marker that allows for early diagnosis, aids in prognosis, and/or provides guidance in treatment.

To date, approximately 200 biomarkers have been studied in the evaluation of sepsis, with CRP, procalcitonin (PCT), and lactate being the most commonly ordered. PCT has been an orderable test for years but it was recently re-discovered as a biomarker for bacterial infections. PCT is a prohormone or precursor to calcitonin (the hormone that regulates
calcium concentration) and it is not normally released into the bloodstream unless stimulated by infection and inflammation.\textsuperscript{34,35} PCT production is stimulated directly by bacterial endotoxins or indirectly by inflammatory mediators, and rises quickly after the onset of infection.\textsuperscript{35-37} PCT levels increase significantly in systemic infections, such as sepsis, thus it is a reliable biomarker for early diagnosis of sepsis and/or for response to therapy.\textsuperscript{35} PCT does have a major limitation; it is elevated in pneumonia and other infectious diseases including those of the lower respiratory and urinary tracts, as well as in post-surgical and abdominal infections.\textsuperscript{35,37,38}

Lactate is another common biomarker for sepsis. Elevated serum lactate levels (hyperlactatemia) are often seen in patients with severe sepsis, thus it is often measured to monitor patients that are at high risk of impending septic shock.\textsuperscript{31} Lactate formation during sepsis is often due to inadequate oxygen delivery resulting in tissue hypoxia, but there are other etiologies (e.g., underlying disease, drug, toxins) that can contribute to elevated levels that must be taken into consideration.\textsuperscript{39} Elevated lactate levels indicate tissue hypoperfusion and are correlated with an increased mortality rate in patients with sepsis.\textsuperscript{39-41}

Both PCT and lactate have been included as recommended biomarkers in the \textit{Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock: 2016}.\textsuperscript{42} The initiative of this campaign is to decrease the mortality of patients due to sepsis.\textsuperscript{42} In the quest for ideal biomarkers for sepsis it is becoming more apparent that no single, gold-standard biomarker may exist as biomarkers are now often studied in groups (panels of multiple biomarkers) due to increased sensitivity and specificity for disease detection when measured collectively.\textsuperscript{3,43}

\textbf{FUTURE BIOMARKERS OF INFECTION AND INFLAMMATION: SEPSIS}
As numerous biomarkers are being studied for the diagnosis and prognosis of sepsis, only two promising biomarkers, pentraxin 3 and presepsin, will be presented. Pentraxin 3 (PTX3) is an acute phase protein and member of the pentraxin superfamily of proteins. PTX3 is stored in the granules of neutrophils and released in inflammatory conditions.\(^4\) During inflammatory processes, PTX3 can be produced by a variety of cells including endothelial cells, mononuclear phagocytes, and dendritic cells.\(^4\)-\(^6\) PTX3 aids in pathogen recognition, promotion of phagocytosis, and complement activation.\(^7\) In sepsis, PTX3 levels significantly increase often within 24 hours of infection, making it a valuable diagnostic biomarker.\(^6\)-\(^9\) In addition, research studies have found that PTX3 levels will remain elevated if treatment is not effective and will continue to rise if the infection worsens (severe sepsis and septic shock), thus indicating the prognostic value of this biomarker.\(^6\)-\(^9\)

Presepsin is the soluble form of cluster of differentiation 14 (CD14) that has been investigated for almost two decades as a biomarker for sepsis.\(^3\),\(^5\) CD14 is expressed on the membrane of monocytes and macrophages, and is a pattern recognition molecule (aiding in pathogen recognition) of the innate immune system.\(^5\),\(^2\) After recognition, soluble CD14 is released resulting in presepsin formation and levels in circulation may reflect systemic inflammation.\(^5\),\(^2\),\(^3\) Presepsin is normally present in low concentration in healthy individuals and has been shown to increase in bacterial infections with significant increases observed in systemic bacterial infections.\(^5\),\(^2\) Some studies indicate that presepsin might have better sensitivity and specificity than currently used biomarkers for sepsis.\(^5\),\(^3\) Additional studies are evaluating the utility of presepsin as a biomarker for other bacterial infections, for example, pneumonia and bacterial meningitis.\(^5\)
Numerous research studies have focused on cytokines required to initiate and maintain the inflammatory response. Many of the inflammation-promoting cytokines (e.g., interleukin-3, interleukin-6, interleukin-8, interleukin-27, interleukin-37) are being studied as possible biomarkers for bacterial infections, specifically sepsis. Additionally, innate immune system cells, such as neutrophils and monocytes, are being further evaluated as promising biomarkers that would be used in conjunction with more traditional biomarkers. In comparison to traditional biomarkers, the use of biomarkers in sepsis is in its infancy and more research is required.

**FUTURE BIOMARKERS OF INFECTION AND INFLAMMATION: OTHER INFECTIONS**

Biomarkers are being investigated for a variety of other bacterial and fungal infections. Chronic wound infections are a growing problem worldwide and a life-threatening complication for patients. Early identification of bacterial wound infections, especially in patients that do not have the classic clinical signs of inflammation and purulent secretions, can prevent progression to severe infection and/or sepsis. Quantifying enzyme activity in wound fluid is being investigated as it could allow for early detection of bacterial infection. Two potential enzyme biomarkers are being studied; the human neutrophil elastase (HNE) and cathepsin G. These enzymes are secreted into the wound as an immune mediated response to infection. Neutrophil elastase and cathepsin G are proteases stored in neutrophil azurophilic granules that are released during inflammation and help degrade bacteria during phagocytosis. Researchers are also investigating other enzymes and proteins as possible emergent biomarkers of bacterial wound infections.
Pneumonia is one of the most common lower respiratory tract infections and is a leading cause of mortality worldwide.\textsuperscript{67-69} For bacterial pneumonia, timely antibiotic treatment is important for prognosis. The ideal biomarker for bacterial pneumonia should either indicate inflammation or is released from the lung due to infection.\textsuperscript{67} The most widely used biomarkers for diagnosis and prognosis of bacterial pneumonia include CRP and PCT, although both can be elevated in other bacterial infections and conditions.\textsuperscript{67,68} PCT is often used to guide the initiation and duration of antibiotic treatment.\textsuperscript{70} Novel biomarkers for pneumonia are continually sought with several studies investigating the potential of interleukin-6 (IL-6), a cytokine in the acute phase response that is elevated in patients with pneumonia.\textsuperscript{67,71-73}

Invasive fungal infections are of worldwide importance due to an increasing immunosuppressed population and increasing numbers of transplant recipients.\textsuperscript{74} Current methods of diagnosis of invasive fungal infections are routinely used but have limitations. The major limitation of traditional microbiological methods of diagnosis is the time necessary for fungal culture growth whereas traditional serological methods (including immunodiffusion and fungal antigen detection) can have low sensitivity and/or specificity.\textsuperscript{74,75} Matrix-assisted laser desorption ionization time of flight (MALDI-TOF), a more recently utilized identification technique, also requires growth in culture first.\textsuperscript{75} Due to the limitations of traditional and current testing, the development of alternative rapid tests (that do not need growth in culture), such as biomarkers and molecular based tests, are growing.\textsuperscript{75}

For more than two decades research has been ongoing for two fungal biomarkers, galactomannan (GM) and 1,3-β-D-glucan (BDG).\textsuperscript{75,76} Galactomannan is a cell-wall polysaccharide that is released from hyphae of \textit{Aspergillus} spp. and other fungi in body fluids. There are FDA-approved immunoassays for the detection of GM in serum and bronchoalveolar
Another circulating biomarker of fungal infection is BDG, a cell wall glucose polysaccharide found in the majority of fungi. The BDG assay can detect a variety of clinically important fungi except for Cryptococcus spp., Blastomyces dermatitidis, and the Mucorales group as they either lack BDG entirely or produce it at minimal levels. Both biomarkers have limitations so it is recommended to use them in conjunction with clinical symptoms and other test results. Possible future biomarkers for invasive fungal infections include D-arabinitol, a metabolite of most pathogenic Candida species, and gliotoxin, a metabolite released by Aspergillus fumigatus.

**SUMMARY**

Biomarker detection can identify disease states while also providing information about the progression of infection and prognosis for recovery. Biomarkers have been tested in clinical laboratories for decades but due to the push for personalized medicine and the advances in –omics technology biomarker research has seen significant growth despite the limited number of biomarkers cleared by the US FDA. Biomarker assays need to be available at a relatively low cost, reliable, reproducible, sensitive, specific, and provide information that is not already available from a clinical assessment. Finding a single biomarker or a multiple biomarker panel that meets the above criteria are still being sought for infection and inflammation.

Worldwide health concerns, in particular sepsis, have seen significant research into finding the gold standard biomarker(s). To date, only PCT and lactate are recommended for clinical testing, however, hundreds have been investigated for their potential as an emergent sepsis biomarker including pentraxin 3 and presepsin. Emergent biomarkers have also been identified for other disease states including pneumonia, wound infections, and fungal infections. This review has pertained primarily to biomarkers of infection and inflammation yet it is worth
noting from the literature review conducted that biomarkers are being investigated for a multitude of diseases and conditions.
REFERENCES


Table 1. Traditional biomarkers used in infection and inflammation

<table>
<thead>
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<th>Detection Of</th>
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<tr>
<td>WBC Count</td>
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<tr>
<td>ESR</td>
<td>Inflammation</td>
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<tr>
<td>CRP</td>
<td>Bacterial infection and inflammation</td>
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<tr>
<td>Serological markers</td>
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**Detection Of**
- Bacterial infection
- Inflammation
- Bacterial infection and inflammation
- Bacterial and viral infection
Table 2. Newer biomarkers for sepsis and future biomarkers of infection and inflammation

<table>
<thead>
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<td>Pneumonia and other bacterial infection</td>
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<tr>
<td>Lactate</td>
<td>Bacterial infection</td>
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<td>Presepsin</td>
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<td>Gliotoxin</td>
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<td>Aspergillus fumigatus</td>
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