Sepsis Biomarkers In Early Onset Neonatal Infections: A Review
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Citation

Abstract
The septic response is an extremely complex chain of events involving inflammatory and anti-inflammatory processes, humoral and cellular reactions and circulatory abnormalities (1, 2). The diagnosis of sepsis and evaluation of its severity is complicated by the highly variable and non-specific nature of the signs and symptoms of sepsis (3). However, the early diagnosis and stratification of the severity of sepsis is very important, increasing the possibility of starting timely and specific treatment (4, 5). Biomarkers can have an important place in this process because they can indicate the presence or absence or severity of sepsis (6, 7), and can differentiate bacterial from viral and fungal infection, and systemic sepsis from local infection. With this background in mind, we reviewed the literature on sepsis biomarkers that have been used in clinical or experimental studies to help better evaluate their utility.

INTRODUCTION
The septic response is an extremely complex chain of events involving inflammatory and anti-inflammatory processes, humoral and cellular reactions and circulatory abnormalities (1, 2). The diagnosis of sepsis and evaluation of its severity is complicated by the highly variable and non-specific nature of the signs and symptoms of sepsis (3). However, the early diagnosis and stratification of the severity of sepsis is very important, increasing the possibility of starting timely and specific treatment (4, 5). Biomarkers can have an important place in this process because they can indicate the presence or absence or severity of sepsis (6, 7), and can differentiate bacterial from viral and fungal infection, and systemic sepsis from local infection. Other potential uses of biomarkers include roles in prognostication, guiding antibiotic therapy, evaluating the response to therapy and recovery from sepsis, differentiating Gram-positive from Gram negative microorganisms as the cause of sepsis, predicting sepsis complications and the development of organ dysfunction (heart, kidneys, liver or multiple organ dysfunction). However, the exact role of biomarkers in the management of septic patients remains undefined (8) C-reactive protein (CRP) has been used for many years (9, 10) but its specificity has been challenged (11). Procalcitonin (PCT) has been proposed as a more specific (12) and better prognostic (13) marker than CRP, although its value has also been challenged (14). It remains difficult to differentiate sepsis from other noninfectious causes of systemic inflammatory response syndrome (15), and there is a continuous search for better biomarkers of sepsis. With this background in mind, we reviewed the literature on sepsis biomarkers that have been used in clinical or experimental studies to help better evaluate their utility.

THE IDEAL DIAGNOSTIC MARKER OF INFECTION
As most infection markers are essential mediators of the inflammatory cascade, their concentrations are likely to be influenced by infective as well as non-infective inflammatory stimuli such as toxic and tissue damaging processes. Establishing a statistically significant correlation between the concentration of a circulating marker and the severity of infection, or showing a significant increase or decrease in the marker’s concentration in an infected infant, is not sufficient to qualify the diagnostic test as being competent or suitable for clinical use. Considering the high mortality and serious morbidity associated with neonatal sepsis, a diagnostic marker with a very high sensitivity (infected infants have a positive test) and negative predictive value (a negative test confidently rules out infection) approaching 100% is desirable because all septic infants with life threatening infection that is totally curable when diagnosed early should be identified and treated (16, 17) Withholding or delaying antibiotics in false negative cases could have a fatal outcome. Conversely, the lack of reliable...
climatic signs often results in anticipatory antimicrobial treatment. Thus a competent diagnostic marker also needs to have a reasonably high specificity (the test is negative if infection is absent) and a good positive predictive value (infection is present when the test is positive), preferably better than 85%, in order to minimise unnecessary use of antibiotics in false positive cases. In addition, an optimal cut-off should be defined in a specified patient population using the receiver operating characteristics curve for each marker, so as to allow comparison of results between different neonatal centres. Table 1 summarises other important clinical and laboratory characteristics of an ideal infection marker. Table 2 summarises the markers that have been studied in preterm or term infants.

ANTENATAL DIAGNOSIS

Intra-amniotic infection is an important and potentially preventable cause of preterm births, early onset neonatal sepsis, periventricular leucomalacia/cerebral palsy, and maternal febrile morbidity. Overt or subclinical intra-amniotic infection is present in at least 50% of extremely preterm births; an inverse relation has been shown between gestational age at birth and both the frequency of micro-organisms recovered from the chorioamnion and histological chorioamnionitis. Potential pathogens largely arise from the ascending route and from the maternal endogenous vaginal flora, causing chorioamnionitis. The release of endotoxins and/or exotoxins from micro-organisms results in stimulation and production of inflammatory cytokines, prostaglandins, metalloproteinases resulting in maternal sepsis (chorioamnionitis, sepsicaemia, postpartum endometritis), fetal loss (extreme prematurity), and preterm delivery (infant prematurity and its consequences, including increased
susceptibility to cerebral palsy),
in addition to severe neonatal sepsis.(18) To determine
whether a patient in preterm labour has intra-amniotic
inflammation, and thus should be delivered rather than
treated with tocolytic agents, is a critical decision with
clinical implications for both mother and fetus.(20) Early
diagnosis of intra-amniotic infection is problematic,
however, because clinical signs and symptoms (including
preterm labour) tend to be late manifestations of this
condition. Furthermore, the available non-invasive
diagnostic tests have limited predictive value, or, as in the
case of measurement of interleukin (IL) 6, polymerase chain
reaction (PCR) tests, or microbial cultures, the results are
often delayed and amniocentesis is required. Therefore
improved diagnostic methods are needed to identify women
and fetuses who may benefit from specific interventions,
such as antibiotics or anti-inflammatory agents.(19)
Amniotic fluid tumour necrosis factor a (TNFα) is a marker
for the prediction of early onset neonatal sepsis in patients
with preterm labour and intact membranes, and a better
independent predictor of early onset neonatal sepsis than
placental histology or amniotic fluid Gram stain and/or
culture. Amniotic fluid TNFα concentration >41 pg/ml had a
sensitivity of 82% and specificity of 79% in the prediction of
early onset neonatal sepsis.(21) Although a strong
association has been found between maternal serum C
reactive protein (CRP) concentrations and cytokine
concentrations in the amniotic fluid, in general, maternal
measurements of CRP alone do not have a high sensitivity in
predicting underlying asymptomatic intra-amniotic sepsis
and are not recommended.(22) IL1b was the best predictor
of vascular extension of chorioamnionitis, and TNFα was the
best predictor of the development of severe early onset
neonatal infection.(23) Although TNFα is an important
mediator in the pathophysiology of septic shock and
systemic inflammatory response syndrome, its utility has not
been found to be as good as either IL6 or IL8.(24, 25)

**POSTNATAL DIAGNOSIS**

Multiple studies have examined total leucocyte count,
immature to total neutrophil ratio, platelet count, and CRP,
and shown that these routine investigations either have low
sensitivity and specificity or varying delayed responses early
in the course of infection.(26) Leucocyte indices and CRP
are considered to be “late” markers and are not sensitive
enough for early diagnosis of neonatal sepsis.(16) However,
abnormalities in these markers soon after a birth complicated
by clinical signs and obstetric risk factors of sepsis are
highly
suggestive of early onset neonatal sepsis. Recent
investigations have focused on various groups of
chemokines, cytokines, adhesion molecules, and components
of the immune pathway that could be used as earlier markers
due to diagnose infection in neonates.

**ACUTE PHASE REACTANTS**

These groups of endogenous peptides are produced by the
liver as part of an immediate response to infection or tissue
injury. CRP has been extensively investigated,(26) but there
has been more recent interest in procalcitonin. Many other
acute phase proteins, including α1 antitrypsin, fibronectin,
haptoglobin, lactoferrin, neopterin, and orosomucoid, have
been evaluated in relation to neonatal sepsis. Although most
markers show significant increases in infected infants, none
have been routinely used clinically, either because of their
limited diagnostic accuracy or because they have been
superseded by better and more sophisticated tests. CRP is
synthesised within six to eight hours of exposure to an
infective process or tissue damage, with a half life of 19
hours, and may increase more than 1000-fold during an
acute phase response.(27) The ranges of sensitivity and
specificity for diagnosis of early onset sepsis ranges are 43–
90% and 70–78% respectively.(26) The specificity and
positive predictive value of CRP ranges from 93% to 100%
in late onset sepsis. Thus CRP is a “specific” but “late”
marker of neonatal infection.(16) CRP as a diagnostic
marker in neonates has higher sensitivity and specificity than
total neutrophil count and immature to total neutrophil
ratio.(28) We have previously reported that the combination
of CRP (.10 mg/l) with full blood examination (abnormal
card and/or immature to total neutrophil ratio >0.2) and/or
gastric aspirate (>5 polymorphs/ high power field or
potential pathogen on Gram stained smear and/or culture of
potential pathogen) has a sensitivity of 97%, specificity of
61%, negative predictive value of 98%, and likelihood ratio
of 49 for early onset neonatal sepsis.(29) Procalcitonin is
another important acute phase reactant produced by
monocytes and hepatocytes which begins to rise four hours
after exposure to bacterial endotoxin, peaking at six to eight
hours, and remaining raised for at least 24 hours(30) with a
half life of 25–30 hours. Several studies have shown that
serum procalcitonin concentrations increase appreciably in
systemic bacterial infection, necrotising enterocolitis, and
during both early and late onset neonatal sepsis.(31) It may
be superior to other acute phase proteins, with sensitivity and
specificity ranging from 87% to 100%. It may be useful in
assessing the severity of infection, following the progress of treatment, and predicting outcomes(31, 32). However, it is not a readily available diagnostic assay in most institutions.

**CELL SURFACE MARKERS**

Advances in flow cytometric technology have opened up ways of detecting cell surface antigens on blood cells. This technology appears to be superior to conventional immunological assay methods for localising the activated markers to a specific cell type. Further, as circulating concentrations of cytokines may not necessarily reflect their biological activities, assessing the cellular response to cytokines may be a better way of identifying early immunological response to bacterial invasion.(33, 34) Neutrophil CD11b and CD64 appear to be promising markers for diagnosis of early and late onset infections.(35, 36) CD11b is a subunit of the b2 integrin adhesion molecule, normally expressed at a very low concentration on the surface of non-activated neutrophils. There is a 2–4-fold increase in neutrophil CD11b expression in infants with blood culture positive sepsis,1 (36, 37) similar to that seen in adults with blood culture positive sepsis. The sensitivity and specificity of CD11b for diagnosing early onset neonatal sepsis are 86.3–100% and 100% respectively. A recent study assessing two neutrophil (CD11b, CD64) and two lymphocyte surface markers (CD25, CD45RO) showed that CD64 had the highest sensitivity (97%), specificity (90%), and negative predictive value (99%) as a diagnostic marker for early onset neonatal infection both at the onset of infection and 24 hours later.(38) Combining CD64 with IL6 or CRP further enhances the ability to diagnose localised infections and improves the sensitivity and negative predictive value to 100%.(38) There is an increase in the number of lymphocyte (CD3, CD19, CD25, CD26, CD71 and CD69) and neutrophil (CD11b,CD11c, CD13, CD15, CD33 and CD66b) antigens in preterm newborns in response to infection, with increased expression of CD19, CD33, and CD66b. However, the diagnostic utilities of these markers are yet to be evaluated.(39) Furthermore, none of these white cell surface markers are readily available diagnostically.

**GRANULOCYTE COLONY STIMULATING FACTOR**

Granulocyte colony stimulating factor, a mediator produced by bone marrow, facilitates proliferation and differentiation of neutrophils, and has been proposed to be a reliable infection marker for early diagnosis of neonatal sepsis. A concentration >200 pg/ml has a high sensitivity (95%) and negative predictive value (99%) for predicting early onset neonatal bacterial and fungal infections.(40, 41)

**CYTOKINES**

Cytokines play an essential role in maturation of progenitors in the bone marrow, in innate immunity, and in the maturation of antigen specific adaptive immunity. As antigen specific immunity develops later—for example, at 2 years of age in the case of encapsulated bacteria—neonates initially depend on natural (innate) immunity. This includes phagocytosis (by monocytes, tissue macrophages, and neutrophils), natural killer cells, and humoral mediators (CRP, complement, and transplacentally acquired maternal antibodies). In response to antigens such as bacterial endotoxins,(42) activated tissue macrophages produce TNFα and IL1. These proinflammatory cytokines stimulate endothelial cells to express receptors for intracellular adhesion molecule on white blood cells. This initiates the cytokine cascade towards increased production of IL6, IL8, and chemokines.(43) Some bacteria activate epithelial cells directly to produce inflammatory cytokines. Newborn infants display a higher percentage of IL6 and IL8 positive cells than do adults.(42) There is sharp rise in IL6 concentration on exposure to bacterial products, which precedes the increase in CRP. Umbilical cord blood IL6 has been consistently shown to be a sensitive marker for diagnosing early onset neonatal sepsis, with sensitivities of 87–100% and negative predictive values of 93–100%.(40, 44) IL6 has the highest sensitivity (89%) and negative predictive value (91%) at the onset of infection compared with other biochemical markers, including CRP, IL1, TNFα, and Eselectin, but sensitivity is reduced at 24 and 48 hours (67% and 58% respectively) because IL6 concentrations fall rapidly and become undetectable after 24 hours.(40, 45) The combined measurement of IL6 (early and sensitive) with CRP (late and specific) in the first 48 hours of presumed septic episodes improves the sensitivity compared with either marker alone.(40) IL8 is a proinflammatory cytokine that is predominantly produced by monocytes, macrophages, and endothelial cells,(46) with similar kinetics to IL6.(47) It is produced in response to various stimuli such as polysaccharide and TNFα.(46) IL8 is considered to be a highly accurate marker with sensitivities ranging from 80% to 91% and specificities from 76% to 100%. IL8 and IL8 mRNA concentrations are substantially higher in infected than non-infected newborns.(40) The simultaneous measurement of either CRP(48, 49) or neutrophil cell surface marker CD11b with IL8 further enhances the diagnostic value in the diagnosis of neonatal sepsis.(50) A recent multicentred randomised controlled trial of 1291
clinically stable infants with clinical signs or obstetric risk factors suggesting early onset neonatal sepsis reported that the combination of IL-8 .70 pg/ml and/or CRP .10 mg/l significantly reduced antibiotic therapy from 49.6% to 36.1% (p<0.0001) without missing infections; sensitivity was 80%, specificity 87%, positive predictive value 68%, and negative predictive value 93%.(51) Furthermore there was no significant difference in missed infections in the group not treated with antibiotics with the control group. Another group of proinflammatory cytokines often linked with sepsis is the IL1 family, including IL1a, IL1b, and IL1 receptor antagonist (IL1ra), the last of which exists in substantial excess over IL1b during sepsis. The diagnostic usefulness of IL1b is minimal given conflicting reports of both increasing(43) and decreasing(52) concentrations associated with sepsis. In contrast, concentrations of IL1ra have been shown to be consistently increased in septic patients with concentrations of 6–30 mg/l(53, 54) compared with concentrations in uninfected neonates of 2–3 mg/l. Furthermore, one study found that IL1ra had increased by 3 and 15 times the concentration in healthy neonates at 4 and 2 days of age respectively before the clinical diagnosis of neonatal sepsis.(54) TNFα is a proinflammatory cytokine that stimulates IL6 production and has a broad spectrum of biological actions on several types of target cell, both immune and non-immune. Newborns developing early onset infection are born with higher TNFα concentrations than non-infected infants.(55) Other markers studied over the last few years include adhesion molecules (intercellular adhesion molecule 1, vascular cell adhesion molecule 1, E-selectin, L-selectin)(40) and complement activation products (C3a-desArg, C3bBbP, sC5b-9).,(56) which have been found to be significantly increased during sepsis, but require further evaluation for clinical application in the diagnosis of newborn infection.

**MOLECULAR GENETICS**

During the past decade an increasing number of reports on the use of nucleic acid amplification techniques such as PCR in the detection of bacterial genomes in blood cultures have appeared. In particular, broad range PCR analysis, which relies on the fact that the bacteria specific 16S rRNA gene is highly conserved in all bacterial genomes, is a useful method for identification of bacteria in clinical samples.(57) Amplification targeting of this 16S rRNA gene is a potentially valuable clinical tool in samples with low copy numbers of bacterial DNA, as this gene is present at 1 to more than 10 copies in all bacterial genomes. The gene also has a number of divergent regions nested within it, so PCR can be targeted for species specific detection of bacteria in clinical samples. For example, using the adaptation of real time PCR, with the LightCycler system, Golden et al.(58) detected a group B streptococcus (GBS) specific cfb gene target DNA sequence in blood specimens, reporting a 100% sensitivity and 100% specificity when tested against 26 non-GBS culture detected bacteraemic episodes. The test was capable of detecting 100 copies or 10 pg GBS genomic DNA. This technology has also been reported to be a very sensitive (100%) and rapid method for detecting potential pathogens in amniotic fluid commonly involved in the pathogenesis of preterm labour and adverse neonatal outcome.(59) However, the performance of broad range PCR analysis at a level of high analytical sensitivity is complex and remains one of the most challenging PCR applications in the diagnostic laboratory. For example, as 16S rRNA gene amplification targets all bacterial species, small amounts of inherent residual DNA present in reagents may be co-amplified, resulting in false positivity. Methods for the removal of potential background contamination include long wave UV light gamma irradiation DNAse, restriction endonuclease digestion, ultrafiltration, and low DNA polymerases. However, many of these methods result in a reduced sensitivity in detecting target DNA, with a detection limit range of 103–104 copies/ml, which is not ideal for diagnosing sepsis in clinical settings. We have found that a combination of pre-PCR culture with the use of AmpliTaq Low DNA achieves an acceptable level of sensitivity (5–50 copies/ml in a turnaround time of eight hours) for the real time amplification of bacteria in blood samples, without the need to remove any inherent DNA contamination (unpublished work). Consequently it is critical to ensure that high standards and appropriate evaluations of analytical as well as clinical sensitivity are met, if such methods are used in diagnostic laboratories. It is also advisable that all positive broad range PCR products are identified, preferably by a sequenced based method.(57) Detection by PCR does not result in the antimicrobial sensitivity pattern of the pathogen. However, amplification of known resistance genes allows quick identification of bacteria that are resistant to specific drugs—for example, methicillin resistance for staphylococcal species. With the application of real time PCR, DNA isolation can be accomplished in as little as 20 minutes.(60) Early exclusion of bacterial infection could help to reduce overuse of antibiotics. It is predicted that eventually real time PCR combined with DNA MicroArray technology will allow not only identification of the organism but also the antimicrobial...
sensitivity pattern, which is so critical to clinical care.

SUMMARY

Table 3 provides a summary of the sensitivities, specificities, and positive and negative predictive values for various markers of early onset sepsis. It was not possible to calculate all values from the data provided in the individual papers.

Figure 3

Table 3 Accuracy of diagnostic tests or combinations of tests for early onset neonatal sepsis

<table>
<thead>
<tr>
<th>Diagnostic test</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenatal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amniotic TNFα=41 pg/ml (22)</td>
<td>82</td>
<td>79</td>
<td>45</td>
<td>95</td>
</tr>
<tr>
<td>PCR for genomic DNA in amniotic</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Postnatal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRP (pg/ml)</td>
<td>60-82</td>
<td>93-96</td>
<td>75</td>
<td>87</td>
</tr>
<tr>
<td>PCR (pg/ml)</td>
<td>92-100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Umbilical cord (pg/ml)</td>
<td>89-97</td>
<td>97</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>CRP, FBE, gastric aspirate (pg/ml)</td>
<td>67</td>
<td>93</td>
<td>93</td>
<td>67</td>
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<tr>
<td>Procalcitonin 10 ng/ml (IU/ml)</td>
<td>85-97</td>
<td>93</td>
<td>93</td>
<td>85</td>
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<td>IL6 and/or CRP (pg/ml)</td>
<td>80-90</td>
<td>97</td>
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<tr>
<td>IL6 and/or CRP (pg/ml)</td>
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<tr>
<td>PCR for genomic DNA in blood</td>
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<tr>
<td>culture (pg/ml)</td>
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<td>100</td>
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</table>

PPV, Positive predictive value; NPV, negative predictive value; TNFα, tumour necrosis factor α; CRP, C reactive protein; FBE, full blood examination; GCSF, granulocyte colony stimulating factor; IL6, interleukin 6; IL8, interleukin 8; PCR, polymerase chain reaction

CONCLUSIONS

The cost associated with preterm birth is substantial in economic, social, and emotional terms. Upper genital tract infection is important in the mechanism of preterm birth, although it is usually asymptomatic. Furthermore, the pathogens associated with intra-amniotic sepsis are those usually involved in early onset neonatal infections. To ensure accurate diagnosis and appropriate antimicrobial management, highly sensitive markers predictive of neonatal sepsis and with a rapid turnaround time are required. Although many putative markers (acute phase reactants, cell surface markers, cytokines) are reported in various clinical research settings, most are not available to the routine diagnostic laboratory. Furthermore, the greatest predictability usually results from a combination of assays. However, none of the current diagnostic markers are sensitive and specific enough to influence the judgment to withhold antimicrobial treatment independent of the clinical findings. Until further evidence from larger studies are available, daily routine screening for prediction of neonatal infection is not warranted.

References

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