Clinical chorioamnionitis at term VI: acute chorioamnionitis and funisitis according to the presence or absence of microorganisms and inflammation in the amniotic cavity

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Abstract

Objective: Neonates born to mothers with clinical chorioamnionitis at term are at an increased risk of infection. Acute subchorioamnionitis, chorioamnionitis, and funisitis are considered placental histologic features consistent with acute inflammation according to the Society for Pediatric Pathology. The objectives of this study were to examine the performance of placental histologic features in the identification of: 1) microbial-associated intra-amniotic inflammation (intra-amniotic infection); and 2) fetal inflammatory response syndrome (FIRS).

Methods: This retrospective cohort study included women with the diagnosis of clinical chorioamnionitis at term (n=45), who underwent an amniocentesis to determine: 1) the presence of microorganisms using both cultivation and molecular biologic techniques [polymerase chain reaction (PCR) with broad range primers]; and 2) interleukin (IL)-6 concentrations by enzyme-linked immunosorbent assay (ELISA). The diagnostic performance (sensitivity, specificity, accuracy, and likelihood ratios) of placental histologic features consistent with acute inflammation was determined for the identification of microbial-associated intra-amniotic inflammation and FIRS.

Results: 1) The presence of acute histologic chorioamnionitis and funisitis was associated with the presence of proven intra-amniotic infection assessed by amniotic...
fluid analysis; 2) funisitis was also associated with the presence of FIRS; 3) the negative predictive value of acute funisitis ≥ stage 2 for the identification of neonates born to mothers with intra-amniotic infection was <50%, and therefore, suboptimal to exclude fetal exposure to bacteria in the amniotic cavity; and 4) acute funisitis ≥ stage 2 had a negative predictive value of 86.8% for the identification of FIRS in a population with a prevalence of 20%.

**Conclusion:** Acute histologic chorioamnionitis and funisitis are associated with intra-amniotic infection and the presence of FIRS. However, current pathologic methods have limitations in the identification of the fetus exposed to microorganisms present in the amniotic cavity. Further studies are thus required to determine whether molecular markers can enhance the performance of placental pathology in the identification of neonates at risk for neonatal sepsis.

**Keywords:** Acute histologic chorioamnionitis; fetal inflammatory response syndrome (FIRS); interleukin-6 (IL-6); microbial-associated intra-amniotic inflammation; neonatal sepsis.

**Introduction**

Clinical chorioamnionitis is a heterogeneous syndrome [1] characterized by maternal fever accompanied by at least two of the following signs: maternal or fetal tachycardia, maternal leukocytosis, uterine tenderness, or foul-smelling amniotic fluid [2–14]. This syndrome is associated with proven intra-amniotic infection in almost 60% of cases, and is a major risk factor for neonatal sepsis [12, 15–23]. The rapid and accurate diagnosis of maternal intra-amniotic infection is important to guide the management of neonates exposed to intrapartum fever [24–34]. The gold standard for the diagnosis of intra-amniotic infection is amniotic fluid analysis with the use of cultivation and molecular microbiologic techniques to identify the presence of bacteria [35–52] and to assess the inflammatory response [13, 35–37, 53–59].

When information about the amniotic fluid microbiology and inflammatory state is not available, pediatricians must rely on clinical risk factors (e.g., maternal fever, rupture of membranes, etc.) [26–28, 60], signs of neonatal sepsis and laboratory tests, such as neonatal white blood cell and differential counts [61–80], immature to mature ratio of neutrophils [77, 80–83], interleukin (IL)-6 [84–118], IL-8 [81, 91, 100, 101, 104, 106, 109, 113, 119], C-reactive protein (CRP) [68–70, 72, 78, 103, 104, 113, 118, 120–125], procalcitonin [118, 123, 124, 126–128], blood [26, 30, 82, 129–134], and cerebro-spinal fluid cultures [135–144], as well as other biomarkers. Despite intensive investigation, the accurate identification of early-onset sepsis in neonatology remains a conundrum [26–28, 32, 34, 145].

Examination of the placenta, the largest human biopsy, can provide information about fetal exposure to intra-amniotic inflammation or infection [146–169]. Chorioitis and acute histologic chorioamnionitis are histologic lesions that represent a maternal response to inflammatory stimuli in the amniotic cavity, such as bacteria, viruses and fungi, or non-infectious insults, such as danger signals (alarmins resulting from cell stress, apoptosis, and pyroptosis) [156, 158, 163, 170–173]. Inflammation of the umbilical cord or chorionic vessels represents a fetal response and is indicative of a fetus’s exposure to inflammatory stimuli before birth [154].

As early as 1959, Benirschke proposed that the examination of the umbilical cord using a frozen section could be a rapid and accurate method to identify newborns exposed to infection in utero [146]. Decades later, this idea has been revisited [174–176]. However, a major limitation of all clinical studies performed to date in patients with clinical chorioamnionitis at term is that the presence of bacteria in the amniotic cavity remains unknown, and therefore, accurate ascertainment of intra-amniotic infection is not feasible. The objective of the current study was to examine the diagnostic performance of placental histologic features of acute inflammation in the identification of: 1) microbial-associated intra-amniotic inflammation (also termed intra-amniotic infection), and 2) fetal inflammatory response syndrome (FIRS). The latter outcome was selected because there is evidence that both FIRS [98, 177–191] and neonatal systemic inflammation [192–209] are associated with adverse neonatal and infant outcomes.

**Materials and methods**

This retrospective cohort study included women with the diagnosis of clinical chorioamnionitis at term, who underwent an amniocentesis to identify microorganisms in the amniotic cavity. Patients were identified by searching the clinical database and Bank of Biological Samples of Wayne State University, the Detroit Medical Center, and the Perinatology Research Branch (NICHD/NIH/DHHS). The criteria for entry were: 1) singleton gestation, 2) gestational age of ≥ 37 weeks, 3) sufficient amniotic fluid obtained by transabdominal amniocentesis for molecular microbiologic studies, and 4) absence of fetal malformations. These patients were included in prior studies, which provide a detailed description of sample collection, microbiological studies, and determination of amniotic fluid IL-6 concentrations and other cytokines [1, 3, 9–11].
All patients provided written informed consent. The use of biological specimens as well as clinical and ultrasound data for research purposes was approved by the Institutional Review Boards of NICHD, Wayne State University, and Sótero del Río Hospital, Santiago, Chile.

Clinical definitions

Microbial invasion of the amniotic cavity was defined according to the results of amniotic fluid culture and PCR/ESI-MS (broad-range PCR coupled with electrospray ionization mass spectrometry) (Thermo Fisher Technology, Athogen, Carlsbad, CA, USA) [1, 65–67, 210]. Microbial-associated intra-amniotic inflammation (also termed intra-amniotic infection) was diagnosed when microorganisms were identified in the amniotic fluid using cultivation or molecular microbiologic techniques and elevated amniotic fluid IL-6 concentrations (>2.6 ng/mL), as described in detail elsewhere [1, 13, 35–37, 39, 50, 53, 54, 56–59, 211–213].

Clinical chorioamnionitis was diagnosed by the presence of maternal fever (temperature >37.8°C) accompanied by two or more of the following criteria: 1) maternal tachycardia (heart rate >100 beats/min), 2) uterine tenderness, 3) foul-smelling amniotic fluid, 4) fetal tachycardia (heart rate >160 beats/min), and 5) maternal leukocytosis (leukocyte count >15,000 cells/mm³) [2, 4–8, 12, 214]. FIRS was diagnosed when umbilical cord plasma IL-6 concentrations were >11 pg/mL [178, 187–189, 215–217].

Placental pathology

Tissue samples were obtained from each placenta – one roll from the chorioamniotic membranes and one from the umbilical cord. Two sections were taken from both the chorionic and basal plates. Tissues were formalin-fixed and embedded in paraffin. Five-micrometer-thick sections were taken from both the chorionic and basal plates. Tissues and the slides were examined by perinatal pathologists masked to the results of amniotic fluid culture and PCR/ESI-MS (broad-range PCR coupled with electrospray ionization mass spectrometry) (Thermo Fisher Technology, Athogen, Carlsbad, CA, USA) [1, 45–47, 210]. Microbial-associated intra-amniotic inflammation (also termed intra-amniotic infection) was diagnosed when microorganisms were identified in the amniotic fluid using cultivation or molecular microbiologic techniques and elevated amniotic fluid IL-6 concentrations (>2.6 ng/mL), as described in detail elsewhere [1, 13, 35–37, 39, 50, 53, 54, 56–59, 211–213].

Clinical chorioamnionitis was diagnosed by the presence of maternal fever (temperature >37.8°C) accompanied by two or more of the following criteria: 1) maternal tachycardia (heart rate >100 beats/min), 2) uterine tenderness, 3) foul-smelling amniotic fluid, 4) fetal tachycardia (heart rate >160 beats/min), and 5) maternal leukocytosis (leukocyte count >15,000 cells/mm³) [2, 4–8, 12, 214]. FIRS was diagnosed when umbilical cord plasma IL-6 concentrations were >11 pg/mL [178, 187–189, 215–217].

Results

Clinical characteristics of the study population

The descriptive characteristics of the study population stratified by the presence or absence of microbial-associated intra-amniotic inflammation (intra-amniotic infection) were previously reported [3]. Microorganisms most frequently identified in the amniotic cavity were Ureaplasma spp. and Gardnerella vaginalis [1]. Briefly, patients with clinical chorioamnionitis at term with microbial-associated intra-amniotic inflammation had a significantly higher median amniotic fluid white blood cell count, amniotic fluid IL-6, and umbilical cord plasma IL-6 concentration than those without microbial-associated intra-amniotic inflammation (P < 0.001, P < 0.001, and P = 0.03, respectively) [3]. The frequencies of FIRS and acute inflammatory lesions of the placenta were also significantly greater in patients with clinical chorioamnionitis at term with microbial-associated intra-amniotic inflammation than in those without microbial-associated intra-amniotic inflammation [FIRS: 36% (9/25) vs. 5% (1/20), P = 0.03; and acute inflammatory lesions of the placenta: 70.8% (17/24) vs. 25% (5/20), P = 0.02] [3].
The frequency of neonates with FIRS was 22.2% (10/45). Among them, 90% (9/10) and 66.7% (6/9) were born to mothers with intra-amniotic infection and with placental histologic lesions consistent with acute amniotic fluid infection respectively, [acute subchorionitis/ histologic chorioamnionitis (n=5) or inflammation of the umbilical cord (n=5)] (Table 1). Among neonates with FIRS, whose mothers had placental histologic features consistent with acute inflammation, 83% (5/6) had stage 2 acute histologic chorioamnionitis/funisitis (Table 1). The descriptions of clinical characteristics, bacteria isolated from the amniotic cavity, amniotic fluid and umbilical cord plasma IL-6 concentrations, as well as placental histologic lesions in mothers whose neonates had FIRS, are shown in Table 1.

Overall, 33% (15/45) of neonates born to mothers with clinical chorioamnionitis had suspected neonatal sepsis. Among these neonates, 53.3% (8/15) and 20% (3/15) were exposed to intra-amniotic infection and intra-amniotic inflammation without detectable bacteria, respectively. The remaining 26.7% (4/15) were born to mothers who had no intra-amniotic inflammation. All neonates with suspected neonatal sepsis (diagnosis based on clinical signs and laboratory findings) had negative blood cultures for microorganisms.

**Diagnostic performance**

The diagnostic performance of placental histologic features consistent with acute inflammation for the identification of microbial-associated intra-amniotic inflammation (also termed intra-amniotic infection) is shown in Table 2. The sensitivity of placental histologic features of acute inflammation ranged from 16.7% to 70.8%. Specifically, acute histologic chorioamnionitis and funisitis ≥ stage 2 had sensitivities of 25% (6/24) and 16.7% (4/24), respectively (Table 2). The PPV or NPV of placental histologic features associated with acute inflammation was fair (PPV: 60%–73.9%; NPV: 47.1%–66.7%) (Table 2). Overall, the accuracy of placental histologic features of acute inflammation for the identification of microbial-associated intra-amniotic inflammation only ranged from 50% to 70% (Table 2).

The diagnostic performance of placental histologic lesions for the identification of FIRS is displayed in Table 3. The sensitivity and specificity ranged from 44.4% to 66.7% and 51.4% to 94.3%, respectively. Acute funisitis ≥ stage 2 had the highest specificity (94.3%) followed by acute histologic chorioamnionitis ≥ stage 2 (82.9%) when compared to other placental histologic lesions (Table 3). All placental histologic features had an NPV above 80%; however, the PPV ranged from 22.7% to 66.7% (Table 3). Acute funisitis ≥ stage 2 had a positive likelihood ratio of 7.8 for the identification of FIRS.

The diagnostic indices of acute inflammatory histologic features of the placenta for the identification of intra-amniotic inflammation are shown in Table 4. The sensitivity and NPV for such placental histologic features ranged from 14.7% to 61.7%, and 23.7%–38.1%, respectively. The overall accuracy was <70% in the identification of intra-amniotic inflammation (Table 4).

**Discussion**

**Principal findings of the study**

1) The presence of acute histologic chorioamnionitis and funisitis was associated with the presence of proven intra-amniotic infection assessed by amniotic fluid analysis; 2) funisitis was also associated with the presence of FIRS; 3) the NPV of funisitis ≥ stage 2 for the identification of neonates born to mothers with intra-amniotic infection was <50%, and therefore suboptimal to exclude fetal exposure to bacteria in the amniotic cavity; and 4) funisitis ≥ stage 2 had an NPV of 86.8% for the identification of FIRS in a population with a prevalence of 20%. Further studies are required to determine whether molecular markers can enhance the performance of placental pathology in the identification of neonates at risk for neonatal sepsis.

**Acute histologic chorioamnionitis and funisitis: two different types of inflammatory responses and their relationship with microbial invasion of the amniotic cavity**

Acute histologic chorioamnionitis or chorionitis consists of the infiltration of the chorion or chorioamniotic membranes by maternal neutrophils and, therefore, is a maternal host response to chemotactic products [156, 158, 163, 170–173]. The mechanism underlying neutrophil infiltration is the presence of high concentrations of neutrophil chemokines in the amniotic fluid, which would generate a gradient promoting the migration of the neutrophils from the decidua to the chorion, and subsequently, the amnion. The following chemotactic factors have been identified in the amniotic cavity of patients in preterm labor: IL-8 [43,
Table 1: Clinical characteristics, amniotic fluid interleukin-6 concentrations, microorganisms identified in the amniotic cavity, and placental histologic features consistent with acute inflammation in mothers whose neonates have fetal inflammatory response syndrome (FIRS) (n=10/45; 22.2%).

<table>
<thead>
<tr>
<th>No.</th>
<th>Organisms identified by cultivation</th>
<th>Organisms identified by PCR/ESI-MS</th>
<th>Microbial-associated intra-amniotic inflammation (intra-amniotic infection)</th>
<th>GA at delivery (weeks)</th>
<th>Amniotic fluid IL-6 concentration (ng/mL)</th>
<th>Umbilical cord plasma IL-6 concentration (pg/mL)</th>
<th>Maternal response to acute inflammation</th>
<th>Fetal response to acute inflammation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Peptostreptococcus spp.</td>
<td>Gardnerella vaginalis</td>
<td>Yes</td>
<td>41³</td>
<td>97.1</td>
<td>170.85</td>
<td>No</td>
<td>Umbilical arteritis</td>
</tr>
<tr>
<td>2.</td>
<td>Fusobacterium spp.</td>
<td>Fusobacterium nucleatum/periodonticum</td>
<td>Yes</td>
<td>37⁴</td>
<td>118.35</td>
<td>103.01</td>
<td>Acute chorioamnionitis</td>
<td>Umbilical arteritis</td>
</tr>
<tr>
<td>3.</td>
<td>Ureaplasma urealyticum</td>
<td>Ureaplasma urealyticum</td>
<td>Yes</td>
<td>40⁴</td>
<td>83.19</td>
<td>14.3</td>
<td>Acute chorioamnionitis</td>
<td>Umbilical arteritis</td>
</tr>
<tr>
<td>4.</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>40⁴</td>
<td>109.19</td>
<td>12.14</td>
<td>Acute chorioamnionitis</td>
<td>Umbilical arteritis</td>
</tr>
<tr>
<td>5.</td>
<td>Ureaplasma urealyticum</td>
<td>Firmicute (Lactobacillus)</td>
<td>Yes</td>
<td>41⁴</td>
<td>14.12</td>
<td>101.09</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>6.</td>
<td>Ureaplasma urealyticum</td>
<td>Peptostreptococcus anaerobius</td>
<td>Yes</td>
<td>41³</td>
<td>19.94</td>
<td>52.84</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>7.</td>
<td>Staphylococcus agalactiae</td>
<td>Staphylococcus agalactiae</td>
<td>Yes</td>
<td>40⁴</td>
<td>32.82</td>
<td>31.67</td>
<td>Acute chorioamnionitis</td>
<td>Umbilical phlebitis/chorionic vasculitis</td>
</tr>
<tr>
<td>8.</td>
<td>Staphylococcus aureus</td>
<td>Staphylococcus aureus</td>
<td>Yes</td>
<td>39⁴</td>
<td>10.45</td>
<td>14.78</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>9.</td>
<td>No</td>
<td>Acinetobacter spp.</td>
<td>Yes</td>
<td>40⁴</td>
<td>18.41</td>
<td>12.38</td>
<td>Acute subchorionitis/chorionitis</td>
<td>No</td>
</tr>
<tr>
<td>10.</td>
<td>Mycoplasma hominis</td>
<td>Propionibacterium acnes</td>
<td>Yes</td>
<td>38⁴</td>
<td>74.08</td>
<td>32.99</td>
<td>N/A⁴</td>
<td>N/A⁴</td>
</tr>
</tbody>
</table>

*No A placental pathology report was not available for 1 patient, PCR ESI/MS=broad-range PCR coupled with electrospray ionization mass spectrometry, GA=gestational age, IL=interleukin. Microbial-associated intra-amniotic inflammation defined by the presence of bacteria in the amniotic cavity and intra-amniotic inflammation (IL-6 ≥ 2.6 ng/mL); fetal inflammatory response is defined by a concentration of umbilical cord plasma IL-6 > 11 pg/mL.

Acute subchorionitis/chorionitis=maternal response to acute inflammation stage 1, Acute chorioamnionitis=maternal response to acute inflammation stage 2, Necrotizing chorioamnionitis and subacute chorioamnionitis=maternal response to acute inflammation stage 3, Umbilical phlebitis/chorionic vasculitis=acute funisitis stage 1, Umbilical arteritis=acute funisitis stage 2, Necrotizing funisitis=acute funisitis stage 3.
Table 2: The diagnostic performance of placental histologic features consistent with acute inflammation for the identification of intra-amniotic infection (microbial-associated intra-amniotic inflammation) in patients with clinical chorioamnionitis at term (n=25/45; 55.56%).

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive likelihood ratio (95% CI)</th>
<th>Negative likelihood ratio (95% CI)</th>
<th>Positive predictive value (%)</th>
<th>Negative predictive value (%)</th>
<th>Accuracy % (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute subchorionitis, chorioamnionitis (n=22/44)</td>
<td>66.7% (16/24)</td>
<td>70.0% (14/20)</td>
<td>2.2 (1.0–4.6)</td>
<td>0.5 (0.3–0.9)</td>
<td>72.7% (16/22)</td>
<td>63.6% (14/22)</td>
<td>68.2% (30/44)</td>
</tr>
<tr>
<td>Acute funisitis (n=13/44)</td>
<td>33.3% (8/24)</td>
<td>70.0% (14/20)</td>
<td>1.3 (0.5–3.4)</td>
<td>0.9 (0.6–1.3)</td>
<td>61.5% (8/13)</td>
<td>48.4% (15/31)</td>
<td>52.3% (23/44)</td>
</tr>
<tr>
<td>Acute inflammatory histologic features of the placenta (n=23/44)</td>
<td>70.8% (17/24)</td>
<td>71.4% (15/21)</td>
<td>2.4 (1.2–4.8)</td>
<td>0.4 (0.2–0.8)</td>
<td>73.9% (17/23)</td>
<td>66.7% (15/23)</td>
<td>70.5% (31/44)</td>
</tr>
<tr>
<td>Acute histologic chorioamnionitis ≥ stage 2 (n=10/44)</td>
<td>25.0% (6/24)</td>
<td>80.0% (16/20)</td>
<td>1.3 (0.4–3.8)</td>
<td>0.9 (0.7–1.3)</td>
<td>60.0% (6/10)</td>
<td>47.1% (16/34)</td>
<td>50% (22/44)</td>
</tr>
<tr>
<td>Acute funisitis ≥ stage 2 (n=6/44)</td>
<td>16.7% (4/24)</td>
<td>90.0% (18/20)</td>
<td>1.7 (0.3–8.2)</td>
<td>0.9 (0.7–1.2)</td>
<td>66.7% (4/6)</td>
<td>47.4% (18/38)</td>
<td>50% (22/44)</td>
</tr>
</tbody>
</table>

*A placental pathology report was not available for 1 patient.

CI = confidence interval, intra-amniotic infection (microbial-associated intra-amniotic inflammation) is defined by the presence of bacteria in the amniotic cavity and intra-amniotic inflammation (IL-6 ≥ 2.6 ng/mL).

Acute subchorionitis/chorionitis = maternal response to acute inflammation stage 1, Acute chorioamnionitis = maternal response to acute inflammation stage 2, Necrotizing chorioamnionitis and subacute chorioamnionitis = maternal response to acute inflammation stage 3, Umbilical phlebitis/chorionic vasculitis = acute funisitis stage 1, Umbilical arteritis = acute funisitis stage 2, Necrotizing funisitis = acute funisitis stage 3.

Acute inflammatory histologic features of the placenta: acute subchorionitis, chorioamnionitis and/or acute funisitis.
Table 3: The diagnostic performance of placental histologic features consistent with acute inflammation for the identification of fetal inflammatory response syndrome (FIRS) in patients with clinical chorioamnionitis at term (n=9/45; 20%).

| Diagnosis | Sensitivity (%) | Specificity (%) | Positive likelihood ratio (95% CI) | Negative likelihood ratio (95% CI) | Positive predictive value (%) | Negative predictive value (%) | Accuracy
|-----------|----------------|----------------|-----------------------------------|-----------------------------------|------------------------------|-----------------------------|-----------
|           | % (n)          | % (n)          |                                   |                                   | % (n)                        | % (n)                       | % (n)     |
| Acute subchorionitis, chorioamnionitis (n=22/44) | 55.6% (5/9) | 51.4% (18/35) | 1.1 (0.6–2.3) | 0.9 (0.4–1.9) | 22.7% (5/22) | 81.8% (18/22) | 95% CI |
| Acute funisitis (n=13/44) | 55.6% (5/9) | 77.1% (27/35) | 2.4 (1.1–5.7) | 0.6 (0.3–1.2) | 38.5% (5/13) | 87.1% (27/31) | 95% CI |
| Acute inflammatory histologic features of the placenta (n=23/44) | 66.7% (6/9) | 51.4% (18/35) | 1.4 (0.8–2.4) | 0.7 (0.2–1.7) | 26.1% (6/23) | 85.7% (18/21) | 95% CI |
| Acute histologic chorioamnionitis ≥ stage 2 (n=10/44) | 44.4% (4/9) | 82.9% (29/35) | 2.6 (0.9–7.3) | 0.7 (0.4–1.2) | 40.0% (4/10) | 85.3% (29/34) | 95% CI |
| Acute funisitis ≥ stage 2 (n=6/44) | 44.4% (4/9) | 94.3% (33/35) | 7.8 (1.7–35.9) | 0.6 (0.3–1.1) | 66.7% (4/6) | 86.8% (33/38) | 95% CI |

*A placental pathology report was not available for 1 patient.
CI=confidence interval, FIRS=fetal inflammatory response syndrome is defined by umbilical cord interleukin-6 concentration >11 pg/mL.
Acute subchorionitis/choriitis = maternal response to acute inflammation stage 1, Acute chorioamnionitis = maternal response to acute inflammation stage 2, Necrotizing chorioamnionitis and subacute chorioamnionitis = maternal response to acute inflammation stage 3, Umbilical phlebitis/chorionic vasculitis = acute funisitis stage 1, Umbilical arteritis = acute funisitis stage 2, Necrotizing funisitis = acute funisitis stage 3.
Acute inflammatory histologic features of the placenta: acute subchorionitis, chorioamnionitis and/or acute funisitis.
### Table 4: The diagnostic performance of placental histologic features consistent with acute inflammation for the identification of intra-amniotic inflammation in patients with clinical chorioamnionitis at term (n=35/45; 77.8%).

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive likelihood ratio (95% CI)</th>
<th>Negative likelihood ratio (95% CI)</th>
<th>Positive predictive value (%)</th>
<th>Negative predictive value (%)</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% (n)</td>
<td>95% CI</td>
<td>% (n)</td>
<td>95% CI</td>
<td>% (n)</td>
<td>95% CI</td>
<td>% (n)</td>
</tr>
<tr>
<td>Acute subchorionitis, chorioamnionitis (n=22/44)</td>
<td>58.8% (20/34)</td>
<td>(40.7–75.3)</td>
<td>80% (8/10)</td>
<td>(44.4–98.9)</td>
<td>2.9 (0.8–10.5)</td>
<td>0.5 (0.3–0.9)</td>
<td>90.9% (20/22)</td>
</tr>
<tr>
<td>Acute funisitis (n=13/44)</td>
<td>32.4% (11/34)</td>
<td>(17.4–50.5)</td>
<td>80% (8/10)</td>
<td>(44.4–96.9)</td>
<td>1.6 (0.4–6.1)</td>
<td>0.9 (0.6–1.3)</td>
<td>84.6% (11/13)</td>
</tr>
<tr>
<td>Acute inflammatory histologic features of the placenta (n=23/44)</td>
<td>61.8% (21/34)</td>
<td>(43.6–77.8)</td>
<td>80% (8/10)</td>
<td>(44.4–96.8)</td>
<td>3.1 (0.9–10.9)</td>
<td>0.5 (0.3–0.8)</td>
<td>91.3% (21/23)</td>
</tr>
<tr>
<td>Acute chorioamnionitis ≥ stage 2 (n=10/44)</td>
<td>23.5% (8/34)</td>
<td>(10.8–41.2)</td>
<td>80% (8/10)</td>
<td>(44.4–96.9)</td>
<td>1.2 (0.3–4.7)</td>
<td>0.9 (0.7–1.4)</td>
<td>80.0% (8/10)</td>
</tr>
<tr>
<td>Acute funisitis ≥ stage 2 (n=6/44)</td>
<td>14.7% (5/34)</td>
<td>(5.0–31.1)</td>
<td>90% (9/10)</td>
<td>(55.5–98.3)</td>
<td>1.5 (0.2–11.2)</td>
<td>0.95 (0.7–1.2)</td>
<td>88.3% (5/6)</td>
</tr>
</tbody>
</table>

A placental pathology report was not available for 1 patient.

CI = confidence interval, IL = interleukin, intra-amniotic inflammation is defined by amniotic fluid IL-6 concentration ≥ 2.6 ng/mL.

Acute subchorionitis/chorionitis = maternal response to acute inflammation stage 1, Acute chorioamnionitis = maternal response to acute inflammation stage 2, Necrotizing chorioamnionitis and subacute chorioamnionitis = maternal response to acute inflammation stage 3, Umbilical phlebitis/chorionic vasculitis = acute funisitis stage 1, Umbilical arteritis = acute funisitis stage 2, Necrotizing funisitis = acute funisitis stage 3.

Acute inflammatory histologic features of the placenta: acute subchorionitis, chorioamnionitis and/or acute funisitis.
Placental histologic features associated with amniotic fluid infection for the identification of neonates at risk for infection/sepsis

Acute inflammatory histologic features of the placenta are associated with microbial invasion of the amniotic cavity, intra-amniotic inflammation/infection [46, 53, 98, 147–155, 157, 159–162, 165–169, 237, 238, 242–246], and neonatal infection [147–149, 155, 245, 247–256]. A previous study reported that adding placental inflammation (amnionitis) to clinical factors (gestational age, clinical chorioamnionitis, duration of labor, maternal age, race, and parity), which are used in the identification of neonatal infection, decreased the administration of antibiotics from 35% to 10% [257]. Hoang et al. also proposed to use the presence or absence of acute histologic chorioamnionitis to guide the duration of antimicrobial treatment in neonates at risk for sepsis [258].

We report herein that the acute inflammatory histologic features of the placenta could not accurately identify neonates born to mothers with intra-amniotic infection/inflammation, or neonates with FIRS/suspected sepsis. These findings are consistent with previous reports [164, 259]. Cuna et al. reported that the presence of acute histologic chorioamnionitis did not improve the predictive performance of other biomarkers for the identification of early-onset neonatal sepsis [259]. Moreover, in that study, none of the clinically stable term infants with acute histologic chorioamnionitis had early-onset neonatal sepsis, suggesting that isolated acute subchorionitis/histologic chorioamnionitis is not associated with adverse neonatal outcomes or the requirement of antimicrobial treatment [259]. Other investigators have also reported that 38% (53/139) of patients with “clinical chorioamnionitis” did not have histologic evidence of chorioamnionitis [153], and that only 4% of women at term gestation with acute histologic chorioamnionitis were found to have microorganisms in the placenta, despite using both cultivation and molecular microbiologic techniques [164]. These observations, as well as our findings reported herein, indicate that the conventional methods to examine the human placenta with hematoxylin and eosin have limitations in determining whether intra-amniotic infection was present or whether the inflammatory response in the umbilical cord can be attributed to microorganisms.

Acute funisitis is more specific but less sensitive than acute histologic chorioamnionitis for the identification of intra-amniotic infection [154]. This is easy to understand because acute chorioamnionitis merely reflects the presence of inflammatory stimuli in the amniotic cavity, such as microorganisms or danger signals [156, 158, 163].
However, if the microorganisms in the amniotic cavity do not invade the human fetus, funisitis should not be present.

Funisitis was reported in 70% of preterm neonates with sepsis [260]. In contrast, in our previous study, which included 832 consecutive patients who delivered within 72 h of amniocentesis, funisitis was present in 17% of patients at term with positive amniotic fluid culture for bacteria [157], and none of these neonates had neonatal sepsis. Therefore, the clinical significance of funisitis in term and preterm gestations is substantially different [157, 239]. We have proposed that microbial invasion of the amniotic cavity during the course of spontaneous labor at term is short-lived, resulting in a more modest intra-amniotic inflammatory response, as well as a lower risk of FIRS, than in preterm gestation [41]. Intra-amniotic infection in patients presenting with an episode of preterm labor is likely to have occurred days or weeks before the initiation of labor and to have eventually led to the initiation of parturition with intact or ruptured membranes [261, 262]. Evidence in support of this is that patients with positive amniotic cultures for microorganisms at the time of genetic amniocentesis in the midtrimester eventually have preterm labor or preterm prelabor rupture of the membranes, which occurs frequently after a period of weeks [261–263]. Prolonged exposure to microorganisms in preterm gestations with subclinical microbial invasion of the amniotic cavity is more likely to result in fetal invasion. This would explain why congenital neonatal sepsis is more frequent in preterm than in term neonates [264, 265]. This view is consistent with our report about the differences in fetal IL-6 umbilical cord concentrations in response to microbial invasion of the amniotic cavity between term and preterm gestations [41].

The most likely explanation for the limitations of placental pathology to identify intra-amniotic infection is that the inflammation of the chorioamnionic membranes is a non-specific mechanism of host defense against danger signals of both microbial and non-microbial origin. We have recently reported that sterile intra-amniotic inflammation is common in patients with clinical chorioamnionitis at term [1], preterm labor with intact membranes [36, 39], preterm prelabor rupture of the membranes [35], and a short cervix [37]. These patients often exhibit evidence of acute chorioamnionitis in the absence of microorganisms in the amniotic fluid. The mechanisms responsible for the acute inflammatory response in the absence of microorganisms remain to be discovered, although we have previously proposed that alarmins could also play a role [39, 54]. The possibility that patients with sterile inflammation may have had an intra-amniotic infection controlled by the host, which leads to eradication of the microorganisms but an unresolved intra-amniotic inflammatory response, cannot be excluded.

In the current study, we focused on examining the relationship between placental histology and FIRS, because it is now evident that many of the complications of infection are mediated by the effects of systemic inflammation rather than the presence of organisms [177–209]. Indeed, patients could have asymptomatic bacteremia, which is transient and does not have adverse outcomes; yet, the combination of bacteria and systemic inflammation can lead to sepsis or septic shock [26–28, 32, 133]. In addition, the presence of FIRS or neonatal systemic inflammation is associated with adverse outcomes, even in the absence of detectable bacteria by cultivation and molecular microbiologic techniques, suggesting that an exaggerated inflammatory response plays a major role in neonatal outcomes [82, 98, 177–209, 266]. Previous studies have also shown a correlation between the concentrations of TNF-α in neonatal blood and the progression of neonatal sepsis to septic shock [267, 268].

Strengths and limitations

The major strength of this study is that both cultivation and molecular microbiologic techniques were used to identify microorganisms in the amniotic cavity; therefore, the diagnosis of microbial invasion was based on state-of-the-art methodologies. However, a larger sample size and replication are desirable. The use of molecular markers to identify the presence of microorganisms in the extrachorionic membranes, chorionic plate, and umbilical cord could be an important approach in providing morphologic evidence of the location of microorganisms in different sites. This could be accomplished using fluorescent in situ hybridization with probes aimed at identifying the conserved regions of the prokaryote genome, or alternatively, using stains for bacteria in tissues [161, 269]. Similarly, markers for neutrophil activation can improve the performance of conventional examination of the placenta [270].

Conclusion

Acute histologic chorioamnionitis and funisitis are associated with intra-amniotic infection and the presence of FIRS. Current pathologic methods have limitations in
the identification of the fetus exposed to microorganisms present in the amniotic cavity. The use of molecular methods to identify bacteria in tissues and neutrophil activation may improve the performance of histologic examination of the placenta in the prediction of neonates at risk for sepsis.

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