

Diagnostic Performance of Fetal Brain Ultrasound for Prenatal Detection of Fetal Meningitis: A Systematic Review

Asad Khan

Department of MS Diagnostic Ultrasound, Ibadat International University, Islamabad, Pakistan.

Muhammad Shoaib

Department of MS Diagnostic Ultrasound, Ibadat International University, Islamabad, Pakistan.

Hilal Ahmad Malik (Corresponding Author)

Department of Management Sciences, Ibadat International University, Islamabad, Pakistan.

hilal.ahmed@dms.iiui.edu.pk

Author Details

Keywords: Fetal meningitis, Prenatal ultrasound, Neurosonography, Congenital CNS infection, Ventriculomegaly, Fetal MRI, Prenatal diagnosis, Systematic review.

Received on 7 May 2026

Accepted on 10 Jun 2026

Published on 18 Jun 2026

Corresponding E-mail & Author*:

Hilal Ahmad Malik

Department of Management Sciences, Ibadat International University, Islamabad, Pakistan.

hilal.ahmed@dms.iiui.edu.pk

Abstract

Background: Fetal meningitis and congenital central nervous system (CNS) infections are associated with significant neurological morbidity, including ventriculomegaly, hydrocephalus, developmental delay, hearing impairment, and long-term neurodevelopmental deficits. Early prenatal diagnosis is challenging because clinical manifestations are often absent and laboratory confirmation may be difficult. Fetal brain ultrasound, particularly dedicated neurosonography, plays a central role in the prenatal assessment of suspected CNS infections. **Objective:** To evaluate the diagnostic performance of fetal brain ultrasound in the prenatal detection of fetal meningitis and related congenital CNS infections.

Methods: A systematic literature search was conducted in PubMed and Google Scholar. Studies reporting prenatal ultrasound findings in fetuses with suspected or confirmed CNS infection were included. After screening and eligibility assessment, 12 studies met the inclusion criteria and were included in the qualitative synthesis. Due to heterogeneity in study design, imaging protocols, and

outcome measures, a meta-analysis was not performed. Study quality was assessed using the QUADAS-2 tool.

Results: The included studies consisted of prospective cohorts, retrospective analyses, case series, and observational studies, with sample sizes ranging from 5 to 250 participants. The most frequently reported sonographic findings were ventriculomegaly, periventricular echogenicity, intracranial calcifications, ventricular debris, and hydrocephalus. Ultrasound demonstrated high sensitivity for detecting major structural abnormalities associated with fetal CNS infection, particularly ventricular abnormalities and intracranial inflammatory changes. However, its sensitivity was lower for subtle cortical abnormalities, white matter lesions, and migrational disorders. Fetal MRI provided complementary diagnostic information and improved detection of

parenchymal, cortical, cerebellar, and posterior fossa abnormalities. Quality assessment revealed an overall moderate risk of bias, primarily due to small sample sizes, retrospective study designs, and variability in imaging protocols.

Conclusion: Fetal brain ultrasound remains an effective and indispensable first-line imaging modality for the prenatal detection of abnormalities associated with fetal meningitis and congenital CNS infections. Dedicated neurosonography enhances diagnostic accuracy, while fetal MRI serves as a valuable complementary tool for identifying subtle brain abnormalities and improving prognostic evaluation. Further prospective studies are needed to establish standardized imaging criteria and determine the true diagnostic accuracy of prenatal ultrasound for fetal meningitis.

Introduction

Fetal meningitis represents a severe inflammatory condition involving the meninges and central nervous system during intrauterine life (1). Although relatively uncommon, fetal meningitis may lead to devastating neurological consequences including ventriculomegaly, hydrocephalus, developmental delay, epilepsy, hearing impairment, and long-term neurodevelopmental disability (2). Early prenatal diagnosis remains challenging because clinical manifestations are frequently absent and laboratory confirmation is often difficult (3).

Ultrasonography is the primary imaging modality used for routine fetal assessment because of its safety, accessibility, non-invasive nature, and real-time imaging capabilities (4). Advances in fetal neurosonography have significantly improved visualization of intracranial structures and increased the detection rate of subtle abnormalities associated with fetal infections. Common sonographic manifestations of CNS infection include ventriculomegaly, ventricular debris, periventricular echogenicity, hydrocephalus, intracranial calcifications, cerebral atrophy, and white matter abnormalities (5). These findings reflect inflammatory involvement of the meninges, ventricular system, and brain parenchyma (6). Congenital cytomegalovirus (CMV) infection is one of the most extensively studied causes of fetal CNS infection. Ultrasonographic findings associated with congenital CMV include abnormal periventricular echogenicity, ventriculomegaly, intracranial calcifications, and cortical abnormalities (7). Studies have demonstrated good correlation between dedicated fetal neurosonography and MRI findings, highlighting the role of ultrasound as a reliable screening tool (8). Recent evidence further emphasizes the complementary role of fetal MRI. Dedicated neurosonography remains the primary modality for detecting fetal brain abnormalities, while MRI provides improved visualization of white matter lesions, migrational disorders, cortical abnormalities, and posterior fossa involvement (9). Therefore, this systematic review aims to evaluate the diagnostic performance of fetal brain ultrasound in the prenatal detection of fetal meningitis and related CNS infections.

METHODOLOGY

This systematic review was conducted to evaluate the diagnostic performance of fetal brain ultrasound in the prenatal detection of fetal meningitis and related congenital central nervous system (CNS) infections. The review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A comprehensive literature search was conducted using PubMed and Google Scholar databases to identify relevant studies published up to December 2025. The search strategy utilized combinations of keywords and Medical Subject Headings (MeSH) terms including “fetal meningitis,” “prenatal ultrasound,” “fetal neurosonography,” “congenital CNS infection,” “fetal ventriculitis,” “congenital cytomegalovirus,” “fetal brain infection,” “prenatal diagnosis,” and “fetal MRI.” Boolean operators (AND and OR) were applied to optimize the search process, and reference lists of selected articles were manually screened to identify additional relevant studies. Studies were considered eligible if they reported prenatal ultrasound findings in fetuses with suspected or confirmed fetal meningitis or congenital CNS infection and

provided information regarding diagnostic imaging findings, neurosonographic features, or prenatal outcomes. Prospective studies, retrospective studies, cohort studies, observational studies, and case series published in English were included. Studies focusing solely on postnatal imaging, maternal infection without fetal imaging assessment, review articles, editorials, conference abstracts, non-English publications, and articles with unavailable full texts were excluded. All identified records were screened by title and abstract after removal of duplicate studies. Full-text articles of potentially relevant studies were subsequently assessed for eligibility according to the predefined inclusion and exclusion criteria.

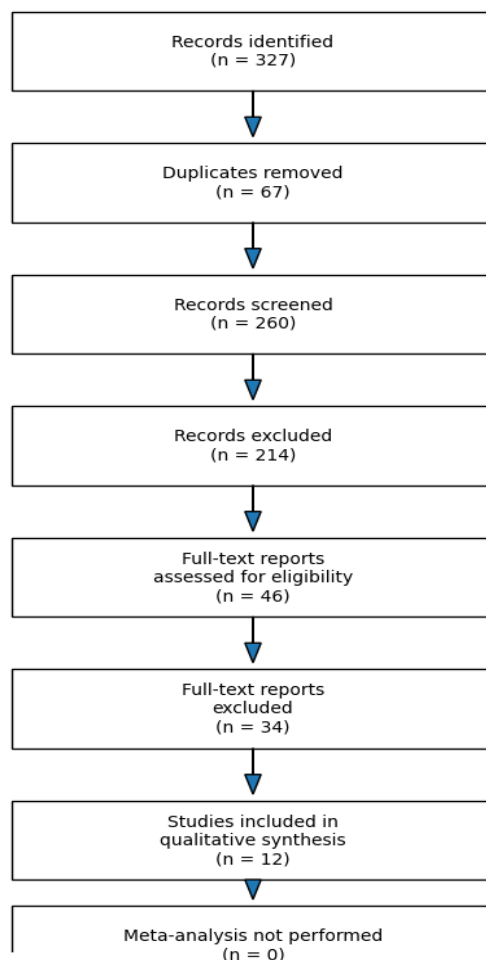
Data extraction was performed using a standardized form that included information regarding the first author, year of publication, study design, sample size, gestational age at diagnosis, type of infection, ultrasound findings, use of fetal MRI, and reported diagnostic outcomes. The methodological quality of the included studies was assessed using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool, which evaluates risk of bias in patient selection, index test, reference standard, and flow and timing domains. Due to substantial heterogeneity among the included studies in terms of study design, patient populations, imaging protocols, reference standards, and reported outcomes, a quantitative meta-analysis was not feasible. Therefore, findings were synthesized qualitatively, with emphasis placed on the diagnostic performance of fetal ultrasound and its comparison with fetal MRI where available.

RESULTS

Study Selection

The systematic search was conducted in PubMed and Google Scholar databases. A total of 327 records were identified through database searching, including 112 records from PubMed and 215 records from Google Scholar. After removing 67 duplicate records, 260 unique studies remained for title and abstract screening. Following title and abstract screening, 214 articles were excluded because they were unrelated to fetal meningitis, did not involve prenatal ultrasound, focused on postnatal imaging, or were review articles. The full texts of 46 potentially eligible studies were assessed for eligibility. Of these, 34 studies were excluded due to insufficient imaging data ($n = 12$), absence of prenatal ultrasound findings ($n = 10$), focus on maternal infection only ($n = 7$), and unavailable full text or non-English publication ($n = 5$). Consequently, 12 studies met the eligibility criteria and were included in the qualitative synthesis. Due to substantial heterogeneity in study design, imaging protocols, and outcome measures, quantitative meta-analysis was not performed.

PRISMA FLOW DIAGRAM



Characteristics of Included Studies

The included studies comprised prospective cohorts, retrospective analyses, case series, and observational studies evaluating prenatal imaging findings in fetuses with suspected congenital central nervous system infection. Most studies focused on congenital cytomegalovirus infection, ventriculitis, or fetal inflammatory brain lesions. Sample sizes ranged from 5 to 250 participants. Gestational age at diagnosis varied between 18 and 36 weeks. The majority of studies used dedicated fetal neurosonography as the primary imaging modality, while fetal MRI was employed as a complementary examination.

Sonographic Findings

The most frequently reported ultrasound findings included:

Sonographic Finding	Frequency Reported
Ventriculomegaly	Very Common
Periventricular echogenicity	Very Common
Intracranial calcifications	Common
Ventricular debris	Common
Hydrocephalus	Common
White matter abnormalities	Moderate
Cerebral atrophy	Moderate
Microcephaly	Moderate
Cortical malformations	Less Common
Posterior fossa abnormalities	Less Common

Ventriculomegaly and abnormal periventricular echogenicity were the most consistently reported prenatal indicators of fetal CNS infection. Dedicated neurosonography improved visualization of ventricular abnormalities and inflammatory changes.

Diagnostic Performance of Ultrasound

Across the included studies, fetal ultrasound demonstrated high sensitivity for detecting major structural abnormalities associated with fetal CNS infection. Ultrasound was particularly effective in identifying ventriculomegaly, hydrocephalus, intracranial calcifications, and ventricular debris.

However, several studies reported reduced sensitivity for detecting subtle cortical abnormalities, migrational disorders, and white matter injury. In such cases, fetal MRI provided additional diagnostic information.

Comparison Between Ultrasound and Fetal MRI

Most studies reported that fetal MRI complemented ultrasound findings rather than replacing them. MRI improved the detection of:

- White matter lesions
- Cortical developmental abnormalities
- Migrational disorders
- Cerebellar abnormalities
- Posterior fossa lesions

Ultrasound remained the preferred first-line screening modality because of its accessibility, lower cost, and real-time imaging capabilities, whereas MRI was primarily utilized for confirmation and prognostic evaluation.

Quality Assessment

Assessment using the QUADAS-2 tool demonstrated an overall moderate risk of bias. The most common limitations included:

- Small sample sizes
- Retrospective study designs
- Lack of standardized reference standards
- Heterogeneity in ultrasound protocols

Nevertheless, most studies demonstrated acceptable methodological quality and supported the use of fetal neurosonography in the prenatal evaluation of suspected fetal CNS infection.

DISCUSSION

The findings of this review indicate that fetal ultrasound remains the most important first-line imaging modality for prenatal evaluation of suspected fetal CNS infection. Neurosonography provides detailed assessment of ventricular size, intracranial anatomy, and inflammatory changes that may suggest meningitis or ventriculitis.

Studies examining ultrasound manifestations of meningitis have consistently reported findings such as echogenic sulci, ventriculitis, ventricular debris, hydrocephalus, ventriculomegaly, cerebritis, brain abscesses, and subdural collections. These sonographic abnormalities reflect inflammatory changes occurring within the meninges, ventricular system, and cerebral parenchyma.

Evidence from congenital CMV studies demonstrates that ventriculomegaly and abnormal periventricular echogenicity are among the most frequent prenatal imaging findings. These abnormalities are readily detectable by ultrasound and often serve as the first indication of fetal CNS infection.

However, ultrasound has several limitations. Detection of subtle cortical abnormalities, white matter injury, and posterior fossa lesions may be challenging, particularly during early gestation. Fetal MRI overcomes many of these limitations and provides additional information regarding brain parenchymal injury. Several studies have demonstrated that MRI can identify abnormalities not visible on ultrasound, thereby improving prognostic assessment and parental counseling.

The reviewed literature supports the concept that ultrasound and MRI should be considered complementary rather than competing imaging modalities. Ultrasound remains the preferred screening tool because it is widely available, inexpensive, and safe. MRI should be reserved for cases with abnormal or equivocal ultrasound findings, suspected complex CNS abnormalities, or when additional prognostic information is required.

CONCLUSION

Fetal brain ultrasound is an effective and indispensable modality for the prenatal detection of abnormalities associated with fetal meningitis and congenital CNS infections. Sonographic findings such as ventriculomegaly, ventricular debris, hydrocephalus, echogenic ventricular lining, and periventricular abnormalities may suggest intrauterine CNS infection. Dedicated fetal neurosonography improves diagnostic accuracy and should be performed whenever infection is suspected. Fetal MRI provides important complementary information, particularly for the evaluation of subtle parenchymal and cortical abnormalities. Future prospective studies are required to establish standardized imaging criteria and determine the true diagnostic accuracy of prenatal ultrasound for fetal meningitis.

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