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Fetal intracranial hemorrhage and infarct: Main sonographic and MRI characteristics: A review article

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ABSTRACT

Early detection of fetal intracranial hemorrhage and infarct during pregnancy is crucial for preventing lethal and debilitating complications in neonatal life. Every radiologist must be aware of the imaging features of these conditions to refer patients to specialists. Sonographic and MRI features of fetal intracranial hemorrhage and infarct have been discussed in many previous articles. The aim of this article is to organize and categorize these findings into a practical guideline for improved application in diagnosing these diseases. The use of MRI sequences, such as DWI and multiplanar EPI should be developed for suspected prenatal infarct and intracranial hemorrhage and can serve as additional tools for early detection. In this review article, we first explain possible etiologic factors contributing to the development of fetal IVH and infarct. Then we discuss the different imaging features of these disorders on sonography and MRI separately, as well as their differential diagnosis. Finally, the mortality and morbidity associated with these two concerning fetal abnormalities will be addressed.

1. Introduction

Intracranial hemorrhage (ICH) and fetal ischemic brain injury are rare imaging findings in fetuses. Accurately estimating their true prevalence is challenging due to the limitation of prenatal imaging and varying definitions in the literature such as “fetal stroke”, “prenatal cerebrovascular disease”,” perinatal stroke”, and “perinatal brain injury”. Fetal stroke typically develops between the 14th week of pregnancy and delivery [1], while fetal ICH often occurs after 20 weeks of gestational age[2–4], particularly in the late second or early third trimester(between 22 and 34 weeks), when vascular connections between the germinal matrix and subependymal veins are established [5–10].

Most of our knowledge about Germinal Matrix Hemorrhage- Intraventricular hemorrhage (GMH-IVH) is derived from studies on preterm neonates[11]. Hemorrhage and ischemia in the fetal brain are major causes of mortality and morbidity during the perinatal period and can result in irreversible brain injury [5, 9, 11]. Fetal ICH and infarct can be accurately diagnosed and classified through prenatal ultrasound and fetal MRI[2].

1.1. MRI protocol

Fetal MRI primarily relies on T2-weighted contrast, achieved using fast spin-echo (SE) or steady-state free-precession (SSFP) sequences, with long echo times (TE) preferred for brain imaging. T1-weighted contrast is typically obtained using 2D gradient echo (GRE) sequences at 1.5 T, requiring brief maternal breath-holding, while achieving it at 3 T is more challenging. GRE, fast spoiled GRE, SE, radial volumetric interpolated breath-hold examination (VIBE) and Dixon sequences have been used to achieve this. Newer sequences like 2D MP-RAGE allow for T1-weighted fetal brain imaging without maternal breath-holding. T1-weighted contrast helps identify features like subacute hemorrhages, calcifications, glands, and meconium. Single-shot high-resolution (SSH)

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GRE echoplanar imaging (EPI) is used for visualizing bones, calcifications and breakdown products of blood, such as deoxyhemoglobin, which suggests a recent bleed, or hemosiderin, as a residual of an older hemorrhage. Optional sequences include diffusion-weighted imaging (DWI), diffusion tensor imaging (DTI), dynamic SSFP sequences and SSH magnetic resonance cholangiopancreatography sequences, which offer 3D-like images [12]. Based on ISUOG guideline 2023, we recommend using T1-weighted VIBE, T2-weighted HASTE and TRUFI, and DWI sequences routinely for the evaluation of fetal brain.

2. Fetal intracranial hemorrhage (ICH)

2.1. Definition and classification of fetal ICH

Fetal ICH is defined as bleeding within the cranium that occurs during the prenatal period, commonly caused by non-traumatic factors but can also result from maternal trauma [13,14]. Based on its location, fetal ICH is categorized into two major types:

Extracerebral hemorrhage is further subdivided into:

- extradural(epidural)
- subdural
- subarachnoid

Intracerebral hemorrhage is classified into:

- intraparenchymal
- intraventricular
- periventricular
- infratentorial (posterior fossa), which includes cerebellar hemorrhage[2, 3, 5, 8–10, 15–22].

The most prevalent subtype of fetal ICH is intraventricular hemorrhage (IVH)[9, 10, 17–21, 23–25]. Additional study has shown that IVH is generally the most prevalent type of fetal ICH (62 %), followed by subpial (15 %), subdural (15 %), and parenchymal (8 %) hemorrhage. [26].

According to another classification system, ICH is categorized to germinal matrix hemorrhage (GMH) and non-GMH subtypes.

- **GMH**, or subependymal hemorrhage (SEH), accounts for approximately two-third of cases and is the most common and least sever type of ICH. It occurs in the caudothalamic groove, located beneath the frontal horns of the lateral ventricles, over the caudate nucleus. GMH can extend into the lateral ventricles and periventricular white matter[5, 9, 21, 23, 27].
- **Non-GMH** includes IVH without associated subependymal hemorrhage (normal germinal matrix), parenchymal hemorrhage in the cerebrum or cerebellum without IVH, and extracerebral hemorrhage such as subdural and subarachnoid hemorrhages, as well as hemorrhage in corpus callosum[18,23].

2.2. Prevalence of fetal intracranial hemorrhage(ICH)

Fetal ICH is relatively rare with an incidence ranging from 0.5–1 per 1000 pregnancies[1, 2, 17, 18, 22, 23, 28–30]. Other studies indicate a prevalence of 17–35 per 100000 live births[11,17]. Intraventricular hemorrhage (IVH) is the most common type of GMH-IVH, with a prevalence of 5.5 per 100000 live births[31]. The most sever forms of fetal ICH include grade III and periventricular hemorrhagic infarcts, which accounts for 10–25 % of cases[32].

2.3. which Pathophysiological mechanisms and predisposing factors are involved in fetal ICH?

The pathophysiology of fetal ICH is complex and involves three main factors: the immaturity of vessel wall, the fragility of germinal matrix microvessels, and the lack of glial support. Additionally, fluctuations in cerebral blood flow and the absence of autoregulatory mechanisms play significant roles. Hypoxic-ischemic insults and cardiovascular disorders can lead to changes in blood pressure. Increased venous pressure, in turn, results in hemorrhage through the fragile, immature microvasculature[11, 18, 19, 33].

Demonstrating the etiology of fetal ICH is crucial for managing the current pregnancy and making decisions regarding future pregnancies [1].

Risk factors of fetal ICH can be categorized into three major groups: maternal, Fetal, and placental.

Maternal factors contributing to fetal ICH include hypertensive disease such as preeclampsia, recurrent miscarriage, and the use of certain medications, including warfarin, cholestyramine, aspirin, cocaine, methamphetamine, and antiepileptic medications. Additionally, platelet and coagulation disorders, such as von Willebrand disease, severe thrombocytopenia, and thrombophilia (e.g., Factor V Leiden and SSA/SSB antibody positivity) as well as full-blown systemic lupus erythematosus, can increase the risk of ICH. Other factors include cholestasis of pregnancy, vitamin K deficiency, convulsion, trauma, smoking, and viral or bacterial infections such as cytomegalovirus, rubella, toxoplasmosis, parvovirus B19, or herpes simplex. Febrile illness and procedures like amniocentesis are also associated with increased risk [1, 2, 5, 6, 10, 11, 17, 18, 20, 28, 29, 34–46].

If cerebellar hemorrhage is diagnosed, an evaluation for infection should be performed[47].

Fetal predisposing factors for ICH include genetic factors such as congenital thrombophilia and mutations in COL4A1 and COL4A2. Other factors consist of Intracranial tumors, twin-twin transfusion syndrome, single co-twin demise, fetal anemia, Alloimmune thrombocytopenia, vascular malformations, hydrops fetalis, feto-maternal hemorrhage, intrauterine growth restriction (IUGR), umbilical cord entanglement, umbilical cord thrombosis, and sever hypoxia[2, 5, 10, 11, 16–18, 20, 26, 28, 29, 34, 41, 48–59].

The primary placental risk factor is placental abruption [5,11]. Additionally, Idiopathic causes of fetal ICH are detected more frequently than expected, accounting for a range of 20–45 % of cases [2, 9, 10, 17, 21, 25, 41, 60]..

2.4. How can we grade fetal GMH-IVH?

In 1978, Papile et al. developed a grading system for intraventricular hemorrhage (IVH) based on brain CT scan images of premature infants. Thirty years later, Volpe et al. modified this classification to better predict disease severity and mortality rates using sonography. These grading systems can now be applied across various imaging modalities [31, 61–63]..

According to Papile et al., GMH-IVH is classified into four grades:

- Grade I: Subependymal hemorrhage (SEH) limited to germinal matrix layer
- Grade II: Extension of SEH into the lateral ventricles with normal diameter of ventricle or ventriculomegaly < 15 mm at the level of atrium
- Grade III: Intraventricular hemorrhage with ventriculomegaly ≥ 15 mm at the level of atrium
- Grade IV: Extension of intraventricular hemorrhage into periventricular brain parenchyma, regardless of the grade of GMH-IVH. The term “Periventricular hemorrhagic infarction” is equivalent to grade IV of IVH in this grading system (Fig. 2)[1, 2, 5, 9, 11, 18, 21, 22, 29, 32, 61, 62, 64].

Volpe et al. introduced a similar grading system for IVH consisting of three grades:

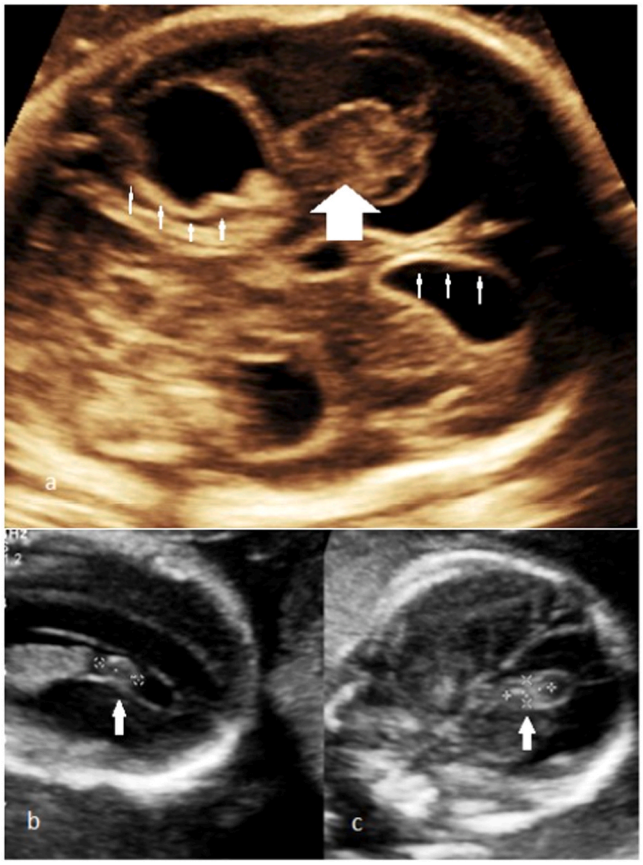

Fig. 1. Ultrasound findings in fetal IVH: a) large avascular, echogenic mass in a porencephalic cavity (large arrow) associated with ventriculomegaly and nodular echogenic ependyma (arrowhead); b) A 20 weeks fetus with unilateral IVH grade 1 (arrows) in parasagittal and coronal views.

- Grade I: Limited to the germinal matrix with no IVH or IVH occupying less than 10 % of the ventricular area on the parasagittal view (5 % mortality)
- Grade II: IVH occupying 10-50 % of the ventricular area on the parasagittal view (10 % mortality)
- Grade III: Intraventricular hemorrhage occupying $\geq$ 50 % of the ventricular area on the parasagittal view (20 % mortality).

In this classification, periventricular hemorrhagic infarction, which has a mortality rate of 50 %, is categorized as a separate term. This distribution is made because it develops due to compression of medullary veins by any grades of hemorrhage, rather than as an extension of intraventricular hemorrhage into brain parenchyma, as described in the Papile classification. Table 1 illustrates the differences between the Papile and Volpe grading systems for IVH [31, 32, 63, 65].

Some studies have reported subependymal cysts as grade zero due to their status as sequela of previous GMH[23]. Differentiating between acute ventricular dilatation resulting from grade III GMH-IVH and post-hemorrhagic ventricular dilatation due to any grade of IVH can often be challenging[11].

2.5. *What are the main imaging characteristics of fetal IVH?*

2.5.1. *Sonography*

Despite the limitations of ultrasound and fetal neurosonography-such as fetal cephalic presentation, oligohydramnios, maternal obesity, poor view due to ossified cranial bone and brain parenchyma located near the probe and in the posterior fossa- sonography remains the first-line modality for assessing fetal ICH[18, 54, 66–71]. In most cases of fetal ICH, sonographic characteristics become evident between 28 and 33 weeks of gestation. The sonographic findings of fetal ICH are summarized in Table 2, and Fig. 1 illustrates a case related to these findings [1, 2, 5, 6, 8, 20–22, 27, 29, 32, 60, 72–76].

Grade III and IV are more commonly detected due to ventricular distension[11]. Left-sided IVH is more frequent than right-sided IVH, possibly due to the increased sensitivity of vessels in the left hemisphere to hypoxia or the better supply from right carotid artery in hypoperfusion situations[5, 9, 22].

Subdural hemorrhage appears as an extracerebral hypoechoic mass with curved borders, causing compression of the ipsilateral hemisphere and displacing the Sylvian fissure away from the inner table of the skull. Brain displacement is characteristic and observed in approximately 20 % of fetuses[2, 20–22, 72, 77, 78]. Color doppler findings of subdural hematoma may show an increased pulsatility index (PI) of the middle cerebral artery, accompanied by absent or reversed diastolic flow due to intracranial compression[79].

In cerebellar hemorrhage, abnormal hyperechoic foci are observed within the posterior fossa (Fig. 3)[20]. The evolutional stages of cerebellar hemorrhage on sonography over time include asymmetric cerebellar hemispheres, regression of echogenic area to a hypoechoic or cystic lesion, complete disappearance, and, ultimately, cerebellar hypoplasia[21, 80, 81].

The sonographic appearance of ICH varies significantly over time. There are four phases in the developmental process of hemorrhage:

- **Phase I: acute hemorrhagic phase (4-6 h to 3 days):** This phase is characterized by echogenic, homogenous blood that exhibits a continuous cast-like pattern without posterior shadowing in the lateral ventricle.
- **Phase II: liquefaction phase (3-8 days):** The blood begins to show a more complex and heterogenous appearance, transitioning to a sonolucent state from the central to peripheral area. Consequently, the hemorrhage appears as echogenic external border surrounding internal anechoic core.
- **Phase III: complete liquefaction phase (7-28 days):** During this phase, the mass becomes entirely cystic.
- **Phase IV: the solubility phase (7-105 days):** The blood clot completely resolves, and ventriculomegaly may no longer be present. A porencephalic cyst often forms about two weeks after the onset of the hemorrhagic process[2, 5, 9, 20–22, 29, 30, 32, 60, 82–85].

2.5.1.1. Are there any complications for fetal GMH-IVH?. There are two main complications associated with GMH-IVH: periventricular hemorrhagic infarction (PHI) and post-hemorrhagic ventricular dilatation (PHVD).

-Periventricular Hemorrhagic infarction(PHI):

PHI occurs in approximately 15 % of GMH-IVH cases. While it can be associated with any grades of IVH, it is more commonly seen with higher grades. The high pressure from the hemorrhage obstructs the medullary subependymal veins, leading to ischemia and hemorrhagic infarction [32, 86, 87]. This complication typically occurs before 32 weeks of gestation [86,88].

PHI characteristically appears as the “iris sign” or as periventricular triangular,” fan-shaped” echogenicities on imaging, typically located ipsilateral to the GMH-IVH. These are more prominent in the deep frontal white matter and often appear asymmetrically. Thrombosed veins may also be visible on MRI. Sonographically, PHI is observed as asymmetric hyperechogenicity in the basal ganglia and thalamus, with its apex at the caudothalamic groove. In the acute phase, the lesion is distinct from the ventricular wall but may gradually enlarge, eventually touching the ventricular wall and merging with the GMH-IVH to form a large hyperechoic lesion. In some cases, it may persist as a separate small hyperechoic lesion in the periventricular white matter. In the delayed

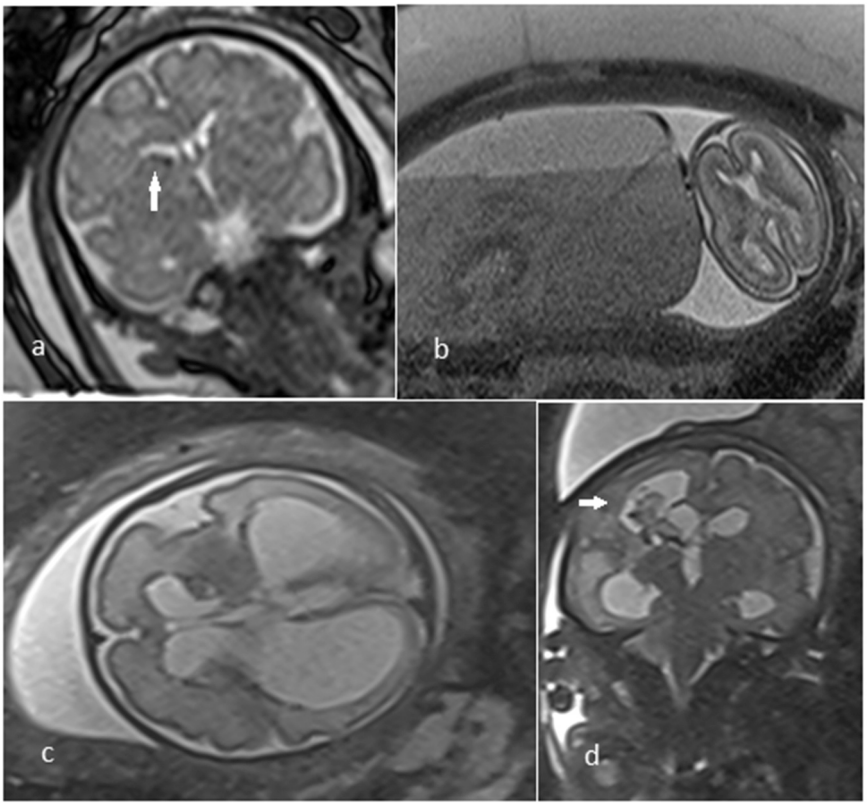

Fig. 2. 4 different fetuses with IVH grade 1–4 based on Paplie criteria in fetal MRI T2- weighted sequence. a) Unilateral IVH grade 1 in a 35 weeks fetus; b) Bilateral IVH grade 2 in a 20 weeks fetus with placental abruption; c) Bilateral IVH grade 3 with severe ventriculomegaly in a 27 weeks fetus; d) Unilateral IVH grade 4 in a 33 weeks fetus.

Table 1
Comparison between Papile and Volpe grading systems:.

Papile criteria	description	Volpe criteria	description
Grade I	Hemorrhage limited to germinal matrix	Grade I	Blood in the germinal matrix with or without IVH less than 10 % of ventricular space
Grade II	Blood noted within the ventricular system but not distending it	Grade II	IVH occupying 10–50 % of ventricular space on parasagittal view
Grade III	Blood in the ventricles with distension of the ventricles	Grade III	IVH occupying greater than 50 % of ventricle with or without ventricular echo-densities
Grade IV	Intraventricular Hemorrhage with parenchymal extension	Separate term	Periventricular Hemorrhagic infarction

Table 2
Sonographic findings in fetal ICH.

1	Ventriculomegaly (most common)
2	Hyperechogenic nodular ependyma
3	Thick, irregular shape, bulky, nodular, heterogenous echogenicity of choroid plexus
4	Hyperechogenic ventricular wall
5	Hyperechogenic intraventricular hemorrhage or clot separate from choroid plexus in real time
6	Hyperechogenic acute clot adherent to bulky nodular choroid plexus
7	Variable echogenicity avascular mass in brain parenchyma
8	Hyperechogenic clot outlining cerebral cortex
9	Increased echogenicity of periventricular white matter
10	Porencephaly
11	hydranencephaly

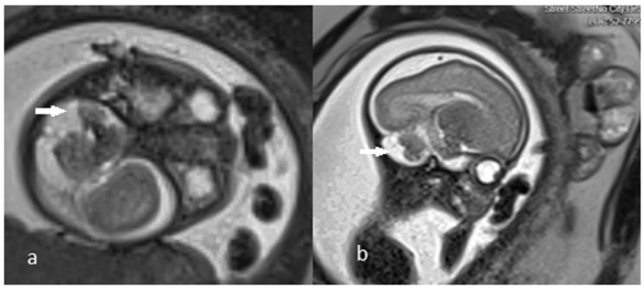

Fig. 3. A 25 weeks fetus with unilateral cerebellar atrophy with peripheral low T2 rim due to hemosiderin: Old hemorrhage.

phase, periventricular white matter volume loss occurs, sparing the cortex and basal ganglia. Other findings may include focal irregularity of the ventricular margin and hemosiderin staining. PHI progresses into cavitation (porencephalic cyst) adjacent to the ventricular wall after 1–2 months. If the gestational age is less than 26 weeks, the porencephalic cyst typically has a smooth wall without surrounding signal abnormalities. After 26 weeks, however, the cyst is covered with gliosis.

The main differential diagnosis of PHI is periventricular leukomalacia (PVL). In PHI, Cavitation is typically single, asymmetric, and persistent, whereas the cysts in PVL are smaller, bilateral, symmetrical, more posteriorly located, and tend to resolve within a few weeks. On color Doppler sonography, diminished blood flow velocity in the ipsilateral terminal veins may be observed. MRI T2- weighted FSE sequences reveal low signal intensity [8, 22, 32, 56, 63, 73, 86, 89–92].

-**Post-Hemorrhagic Ventricular Dilatation (PHVD)**:

approximately 25 % of GMH-IVH cases progress to ventricular dilatation within a few days or weeks. PHVD is more common in higher

grades of IVH, such as grade III or in association with PHI. Hemorrhagic particles can obstruct cerebrospinal fluid (CSF) circulation, leading to intraventricular and cisternal adhesions, which in turn cause ventricular dilatation, often at the level of cerebellum.

There are several types of PHVD depending on the level of CSF obstruction:

1. **Unilateral:** Caused by obstruction of the foramen of Monro on one side.

2.**Triventricular**: Due to aqueductal obstruction.

3.**Tetraventricular (complete internal hydrocephalus)**: Caused by obstruction of the outlets of the fourth ventricle.

4.**Communicating hydrocephalus:** Resulting from obstruction in the arachnoid space.

5.**Isolated fourth ventricle:** Occurs when both the aqueduct and the outlets of the fourth ventricle are obstructed.

Common sonographic parameters used to evaluate PVHD include the ventricular index (VI) and anterior horn width (AHW) in the coronal view passing through the foramen of Monro, and the thalamo-occipital distance (TOD) in the parasagittal view. Sonographic findings of PHVD include a rounded upper margin of the frontal horns on the coronal view (often referred to as ballooning) and a rounded anterior profile of the third ventricle on the midsagittal view. A dilated fourth ventricle on the midsagittal view is indicative of tetraventricular or communicating hydrocephalus[32, 84, 93–95].

2.5.1.2. What are the differential diagnoses of fetal ICH on sonography?. ◆◆ ***Cortical dysplasia:*** Hyperechoic hemorrhage outlining the cerebral cortex may resemble cortical dysplasia[1].

◆◆ ***Gray matter heterotopia:*** An irregular ventricular wall and hyperechoic nodular ependyma can have a similar sonographic appearance to heterotopia[1].

◆◆ Other causes of ventriculomegaly[1].

◆◆ Tumor vs. Clot: A clot typically has less mass effect than a tumor and changes in appearance and echogenicity over time, eventually evolving into a porencephalic cyst. Unlike tumors, clots are avascular masses. In sever forms of ICH, such as periventricular hemorrhagic infarction, the clot may replace damaged brain parenchyma. One of the most common fetal brain tumor, lipoma, is associated with agenesis of corpus callosum, which has characteristic imaging features like colpocephaly and the absence of the cavum septum pellucidum. A lipoma appears as an echogenic, midline avascular mass with fat signal visible on all MRI sequences.

The key distinguishing factor is that fetal IVH typically increases slightly in size or remains stable within the first few days, then begin to regress after about two weeks, showing varying degrees of echogenicity. In contrast, brain tumors remain stable in echogenicity and are usually more echogenic than hemorrhage. Tumors also tend to enlarge with increasing gestational age. Finally, color Doppler may help differentiate between a clot and a tumor[1, 60, 96–99].

◆◆ Porencephalic cyst vs arachnoid cyst:

A porencephalic cyst is a cavity associated with the destruction of brain parenchyma and is often accompanied by ex vacuo dilatation of the adjacent lateral ventricle. In contrast, an arachnoid cyst is a space-occupying lesion that exerts a mass effect on the adjacent cerebral hemisphere. Ventricular dilatation in the case of an arachnoid cyst is caused by compression of the foramen of Monro. A porencephalic cyst usually communicates with the lateral ventricles but does not extend to the inner table of the skull, whereas an arachnoid cyst does not communicate with the lateral ventricles. Complications such as developmental delay and seizures are more commonly associated with porencephalic cysts. Arachnoid cysts, on the other hand, generally have a good prognosis, except in cases where mass effect or obliteration of CSF flow occurs[1, 72, 100].

◆◆ Connatal cyst vs. Subependymal cyst:

A connatal cyst is a type of entrapment cyst located adjacent to the lateral border of the frontal horns, with no blood products visible on any MRI sequence. In contrast, a subependymal cyst results from a GMH grade I and is located beneath the germinal matrix layer at the floor of the frontal horns[1, 101, 102].

◆◆ ***Hydranencephaly* vs. *Giant open-lip schizencephaly vs. Sever hydrocephaly:***

Hydranencephaly, a lethal condition, and sever hydrocephaly, which is non-lethal, both involve large CSF-filled spaces. The key distinction between them is the presence of thin, compressed cortical mantle in sever hydrocephaly, which is absent in hydranencephaly. Schizencephaly, on the other hand, is characterized by a cleft in the brain parenchyma lined with gray matter. Giant bilateral open-lip schizencephaly may resemble hydranencephaly due to its communication with both the subarachnoid space and the ventricular system. Both conditions, however, are associated with poor outcomes [1, 103–106].

◆◆ Subarachnoid hemorrhage vs. Subdural hematoma:

A subarachnoid hemorrhage can expand the cerebral sulci, while a subdural hematoma does not widen the sulci and may compress them [1].

2.5.2. MRI

Due to its superior spatial and contrast resolution compared to multiplanar neurosonography (5.4 % greater capability), MRI provides more detailed information regarding the location, extent, timing, and size of bleeding, IVH grading, prognosis, the mechanisms of hypoxic brain damage and its effect, as well as the etiology of ventriculomegaly. It also helps rule out other CNS pathologies. MRI is particularly effective in detecting Small periventricular and intraventricular hemorrhage [1, 2, 9, 14, 20, 21, 29, 41, 85, 107–109]. In one recent study by Sanapo et al., it was reported that among cases with fetal ICH, the most common referral indication was cerebral anomaly (86 %), especially ventriculomegaly (55 %). However, ICH was the referral reason in only for 22 % of the cases. Additionally, ICH was diagnosed through detailed ultrasound in only 64 % of fetuses on the same day at their center. The study concluded that, particularly when ultrasound reports a non-specific intracranial abnormality, MRI serves as an important modality for the prenatal detection of ICH[30]. MRI is considered a complementary imaging tool, often used to solve problems and provide a more precise evaluation of the pathologic findings that may or may not have been detected by sonography in 30–55 % of cases[1, 17, 22, 30, 74, 86, 110–116]. MRI has a positive impact on obstetric management during pregnancy. It aids in making decisions about fetal surgery or early neonatal interventions and can lead to changes in neonatal care compared to ultrasound [17, 54, 70, 112]. However, there are certain limitations to MRI that affect its quality: motion artifacts from both the fetus and the mother, longer acquisition times, higher costs, limited availability (mostly in tertiary centers), and small size of the fetus[18, 30, 47, 117].

MRI sequences, such as T1- and T2- weighted images, are crucial for evaluating of fetal ICH and ischemia. Additional sequences like DWI, T2 * , and echo-planar imaging (EPI) also play a role. Specifically, in cases of hemorrhage, EPI shows blooming, T1-weighted sequences reveal hyperintensity, and DWI indicates diffusion restriction [1, 44, 72, 84, 118–123].

The germinal matrix becomes more prominent during the second trimester, particularly at 24–26 weeks of gestational age, and appears as a band of low signal on T2-weighted images along the lateral margin of the lateral ventricles. Germinal Matrix Hemorrhage(GMH) is typically appears as a darker linear structure in the caudothalamic groove or subependymal region on T2-weighted images[73].

MRI findings in fetal ICH are presented in Table 3, with Figs. 2 and 3 illustrating cases related to these findings. T1- and T2- weighted sequences help assess the acuteness of bleeding. Table 4 demonstrates changes in signal intensity on T1- and T2- weighted images over time [18, 20, 30, 89, 117].

The gradient echo-planar imaging (EPI) T2-Weighted sequence, the

Table 3
MRI findings in fetal ICH depending on grading:.

Grade	MRI finding	Gradient EPI T2-W	SSFSE T2-W	T1-W
I	GMH Irregular border and thick germinal matrix Subependymal cyst	Marked low signal	Low signal	High signal
II	IVH without ventriculomegaly	Marked low signal	Low signal	High signal
III	intraventricular clot ventriculomegaly Intraventricular fluid-fluid level	Marked low signal	Low signal	High signal
IV	Parenchymal hemorrhage Abnormal cortical signal Porencephalic cyst	Marked low signal	Low signal	High signal

Table 4
Evolution of signal intensity in parenchymal hemorrhage:.

Age of hemorrhage	phase	Blood content	T1-weighted imaging	T2-weighted imaging
2 days	hyperacute	intracellular oxyhemoglobin	Not seen/ high signal rim	Low signal
3 –10 days	acute	intracellular deoxyhemoglobin	Not seen/ high signal	Low signal/ high signal periphery
10 –21 days	Early subacute	intracellular methemoglobin	High signal	High signal
3 –6 weeks	Late subacute	extracellular methemoglobin	High signal	High signal/ low signal periphery
6 weeks- 10 months	chronic	ferritin and hemosiderin	Not seen/ minimal high signal	Not seen/ low signal
10 –22 months	chronic	ferritin and hemosiderin	Not seen	Minimal low signal/ not seen

most sensitive for detecting fetal ICH, along with the T2-SSFSE sequence, is valuable for grading of fetal GMH-IVH.

- **Grade I GMH:** The hemorrhage is best detected on gradient EPI T2-Weighted images as a region of marked hypointensity in the caudothalamic groove. It may also appear as low signal intensity on SSFSE T2-Weighted images and as high signal intensity on T1-Weighted images. An irregular, thickened appearance of the germinal matrix layer can help differentiate abnormal cases from normal ones. Focal subependymal cysts may result from previous germinal matrix hemorrhage, congenital infections, or metabolic disease.
- **Grade II GMH:** T2 hypointensity at the caudothalamic groove extending into the lateral ventricle.
- **Grade III GMH:** T2 hypointensity at the caudothalamic groove extending into the lateral ventricle, accompanied by ventriculomegaly and layering of signal intensity within the ventricle.
- **Grade IV GMH:** T2 hypointensity at the caudothalamic groove extending into the periventricular brain parenchyma. This appears as a markedly low-signal area in the parenchyma on gradient EPI T2-Weighted images, low signal on SSFSE T2-Weighted images, and high signal on T1-Weighted sequences. However, signal intensity may vary depending on the stage of hemorrhage. T2 hypointensity can persist for several months[23, 47, 89].

2.5.2.1. What is the differential diagnosis of fetal IVH on MRI?. ◆◆ ***Fetal motion artifact:***

When ventriculomegaly is present, CSF may move around the dilated ventricles during fetal movement. This results in low signal intensity on T2-weighted images, which can be mistakenly interpreted as low-signal blood products. However, the presence of a high signal intensity clot on T1-weighted sequence and consistent signal intensity across different planes can help differentiate this artifact from true ICH[1].

◆◆ ***Acute hydrocephalus* vs. *White matter volume loss:***

Dilatation of the temporal horn and the inferior and posterior recesses of the third ventricle is more commonly seen in cases of acute hydrocephalus, which may occur due to hemorrhage[73].

2.6. What is the neurological outcome of infants with prenatal ICH, and which factors influence the prognosis?

The neurological outcome of fetal IVH is generally poor, often leading to neurodevelopmental delays, cerebral palsy, motor impairment, ventriculoperitoneal shunt dependency, and epilepsy. Studies show a strong correlation between the grade of IVH and prognosis. Therefore, grade I and II of fetal IVH generally have a favorable prognosis, with a mortality rate of approximately 7 %. Grade III and IV, on the other hand, are associated with a significantly worse prognosis, with a mortality rate of about 44 %. The prognosis worsens when the hemorrhage extends from the germinal matrix into intraparenchymal region. Other factors leading to poorer neurological outcome include white matter loss, such as encephalomalacia and periventricular leukomalacia, porencephalic cyst formation and ventricular dilatation [1, 2, 5, 6, 9, 17, 18, 21–23, 30, 32, 74, 108].

Grade 1 and 2 hemorrhages are associated with more prevalent normal neurological outcome compared to Grade 3 and 4, with approximately 72 % in Grades 1 and 2, in contrast to 41 % in Grades 3 and 4. A recent study reported poorer outcome in two-thirds of infants with grade 3 fetal ICH[9, 21, 22, 29]. In one study, the mortality rate for fetal intraventricular hemorrhage was reported to be 16 % [21]. In rare cases, fetal IVH can completely resolve in utero, leading to a normal postnatal outcome and excellent neurological results, particularly in grade I-II [3, 9, 10, 14, 17, 21]. However, some studies report more favorable outcomes, with 75 % of cases resulting in live births and 57 % showing normal neurodevelopment[17]. Neonatal outcomes depend on several factors, including gestational age at the time of delivery, brain maturity, white matter involvement, etiology, and the severity of GMH-IVH[31].

Brain parenchymal involvement and hemosiderin deposition are key indicators of fetal outcomes. Fetal GMH-IVH without parenchymal extension does not have an unfavorable prognosis, as subependymal hemorrhages are typically absorbed without significant sequelae [6]. Punctate white matter lesions,hemorrhage, or ventricular dilatation without intraventricular hemorrhage are not necessarily associated with poor outcomes [124].

Postnatal complications of fetal ICH can include neurological deficiencies, cognitive impairments, seizure disorders, psychomotor delays, cerebral palsy, hemiparesis, and even death, particularly in cases with higher grades of hemorrhage [5].

Fetal subdural hematoma is generally associated with a good prognosis in 58 % of cases[78].

Intrauterine unilateral cerebellar hemorrhage without associated vermian or other anomalies is also associated with a good postnatal outcome[125].

Periventricular hemorrhagic infarction (PVHI) may primarily result in motor impairments (in more than 75 % of cases), cerebral palsy (50–75 %), developmental delays (50 %), shunt placement, epilepsy (28 %), and mortality [11]. In cases of progressive hydrocephalus due to IVH, early delivery via cesarean section can improve outcomes and prevent irreversible brain damage [6].

3. Fetal infarct

3.1. What is the definition of perinatal stroke?

Perinatal stroke is defined as the loss of cerebral vascular flow due to venous or arterial thrombosis or emboli occurring between 20 weeks of gestation and 28 days postnatally [126].

3.2. What is the prevalence of fetal cerebrovascular disease?

Fetal stroke can develop from 14 weeks of gestation until the end of pregnancy. The incidence is approximately 1 in 2300–5000 live births, with 80 % of cases related to arterial ischemic stroke [1, 86, 127–130]. Sinovenous thrombosis is much less common, occurring in about 0.6 to 12 per 100 000 live births [128]. Another study estimated a prevalence rate of 1 in 1600 to 1 in 2300 live births [131].

3.3. What are the risk factors of fetal stroke?

The primary cause of perinatal stroke is the passage of maternal thromboembolic agents through the planta and the foramen ovale. Inflammatory cytokines in maternal febrile states can impair cerebral vascular development, while preeclampsia reduces blood flow to the placenta leading to fetal hypoxia. By the end of the embryonic stage, the fetal cerebral arterial system is fully developed, and the arterial territories involved in fetal stroke are similar to those in adults. The middle cerebral artery (MCA) territory is the most commonly affected, with an incidence of 75 %, and it is more prevalent on the left side[73, 128, 132–134]. If the ischemic event occurs in the second trimester, it can lead to the formation of porencephalic cysts. In a more mature brain, however, a complete astrocytic reaction results in encephalomalacia. Between these two periods, in the late second and early third trimester, the astrocytic reaction is underdeveloped, and cystic lesions with intervening glial septation may form[127,135].

Fetal disorders:

a) Cardiac causes

- Congenital heart disease
- Patent ductus arteriosus

b) Blood disorders

- Polycythemia
- Disseminated intravascular coagulopathy
- Factor-V Leiden mutation
- Protein-S deficiency
- Protein-C deficiency
- Prothrombin mutation
- Elevated homocysteine levels
- Lipoprotein (a)
- Factor VIII abnormalities

c) Vascular abnormalities

- Vascular maldevelopment
- Vasculopathy (e.g., collagen 4A1 and 4A2 mutation)

d) Infectious disorders

- Central nervous system infections
- Systemic infections

e) Other causes

- Trauma and catheterization
- Twin-to-twin transfusion syndrome
- Fetal asphyxia
- Dehydration
- Extracorporeal membrane oxygenation
- Hydrops fetalis
- Fetal tachycardia
- Meconium-stained amniotic fluid
- Tight nuchal cord

f) Genetic factors

- Collagen IVA mutations
- *JAM3* mutations

Maternal disorders:

- Causes:

- Prolonged rupture of membranes
- Preeclampsia
- Autoimmune disorders

– Thrombocytopenia
– Antiphospholipid syndrome

- Coagulation disorders

– Factor V Leiden deficiency
– Anticardiolipin antibodies

- In utero cocaine exposure
- Infection

– Chorioamnionitis

- Trauma
- Diabetes
- Seizures
- Pre-eclampsia

– Interventions

- Amniocentesis
- Amnioreduction
- Laser coagulation for twin-twin transfusion
- Blood transfusions
- Management of prolonged labor
- Instrumented delivery
- Emergency cesarean section

Placental disorders:

- Placental thrombosis
- Placental abruption
- Placental infection
- Fetal-maternal hemorrhage[8, 56, 73, 128, 132].

3.4. What are the main imaging characteristics of fetal infarct?

3.4.1. Sonography

The key point in diagnosing fetal stroke is the identification of an ischemic lesion that follows a specific vascular territory on imaging. Fetal infarcts typically exhibit two major appearances:

1. Perforator territory infarct appears as punctate, wedge-shaped, or ill-defined lesions. 2.superficial brain infarct represents wedge-shaped lesions in both gray and white matter[127].

In the acute phase of fetal stroke, ill-defined, wedge-shaped hyperechogenic foci may be observed in the cortex and white matter within a specific vascular territory. These foci become gradually apparent over several days [73, 86, 132, 136].

In the early stages of fetal infarction, the differential diagnosis primarily includes hemorrhage, as both conditions present with hyperechogenicity on imaging. However, more focal regions of hyperechogenicity within an echogenic area are more suggestive of hemorrhage[86,137].

Acute Phase (6 h to 6 days post-infarction).

During this phase, vasogenic edema develops due to endothelial injury and the disruption of the blood-brain barrier resulting from coagulation necrosis. This is characterized by brain swelling, sulcal effacement, subfalcine and uncal herniation and midline shift[73].

Subacute Phase (2 to 4 weeks post-infarction).

After 2–4 weeks, cystic degeneration accompanied by ex vacuo dilatation of the ipsilateral ventricle becomes evident [86,137].

Chronic Phase.

In the chronic phase, the most prevalent manifestations include ventriculomegaly, cystic encephalomalacia, and volume loss, with or without hemorrhage [84, 86, 132].

It is important to note that the acute phase of fetal stroke is rarely diagnosed by sonography and is often detected in the chronic phase[84, 132].

Color and power Doppler imaging of fetal infarction.

In the hyperacute phase of infarction (0–6 h), color and power Doppler imaging reveal asymmetric reduced blood flow and a loss of pulsatility in the middle cerebral artery (MCA) of the infarcted area. However, these findings typically disappear in the acute phase (24 h to 1 week), where luxury perfusion is observed, characterized by high arterial diastolic flow and low resistive indices. This pattern can persist for approximately one week[73, 86, 127, 138–140].

Over time, the echogenicity of the Infarcted brain parenchyma varies similarly to that of hemorrhage, gradually becoming less echogenic before eventually disappearing (see Fig. 4)[1].

3.4.2. MRI

Diffusion weighted images (DWI) should be included in the routine fetal MRI to effectively detect acute ischemic injury [86]. The MRI findings of cerebral infarcts vary depending on the timing of the insult, as outlined below (see Table 5):

1. Early hyperacute phase (0-6 h)

- Decreased diffusivity occurs in the infarcted area after approximately 30 min
- This phase shows a high signal on DWI and a low signal on Apparent Diffusion Coefficient (ADC) before changes are evident on T2-weighted images [73, 86, 127, 141, 142].

2. Late hyperacute phase (6-24 h)

- Vasogenic edema is present due to damage to the blood-brain barrier, appearing as hyperechogenicity on sonography.
- DWI remains indicative of diffusion restriction.
- T1 and T2 sequences typically show normal or slightly abnormal signals, with regional sulcal effacement and loss of the cortical ribbon[127,140].

3. Acute phase (24 h to 1 week)

- increased T2 signal intensity in the cortex and adjacent white matter is observed due to cytotoxic and vasogenic edema occurring 24-48 h post-infarction (missing cortex sign or loss of cortical ribbon).
- Associated findings include low signal intensity of the cortex on T1-weighted images.

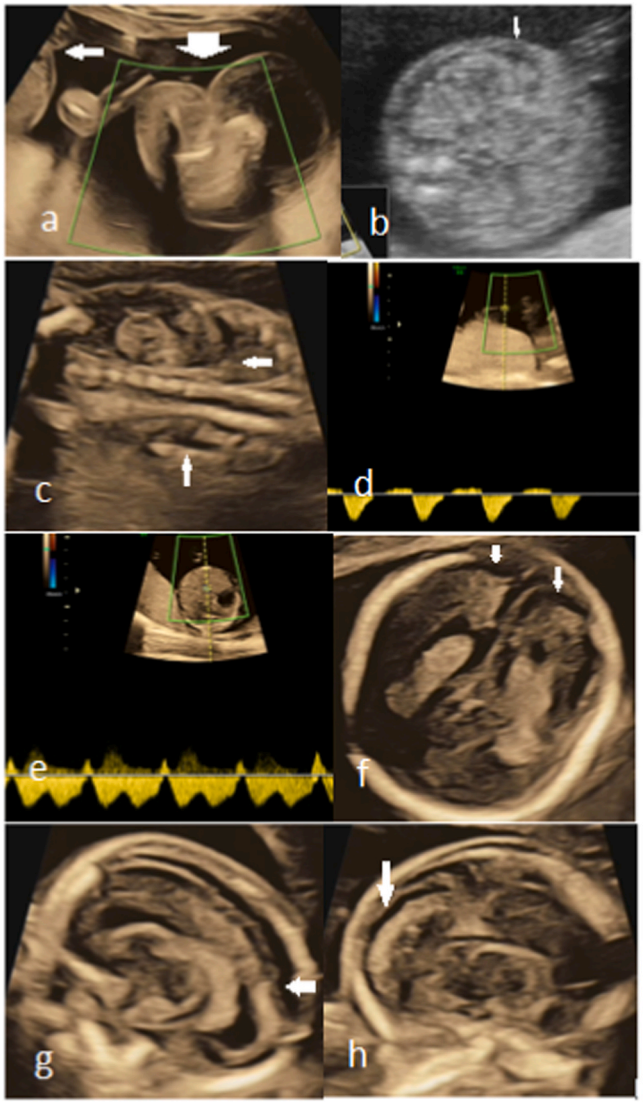

Fig. 4. a monochorionic twin pregnancy, who underwent cord occlusion for one of the fetuses due to a twin reversed arterial perfusion (TRAP) sequence, was referred to our department at 24 h following the procedure for an ultrasound exam. The surviving twin developed bradycardia and hydrops after reduction. No anemia was found on Doppler imaging of MCA. However, increased echogenicity was detected in the watershed areas of bilateral frontoparietal and parieto-occipital lobes, which suggested an acute cerebral ischemic injury. The fetus expired almost six hours later;a) An edematous dead fetus with TRAP (wide arrow), an alive fetus (narrow arrow); b) mild ascites; c) bilateral mild pleural effusion; d) bradycardia and reversed diastolic flow in umbilical cord; e) reversed ductus venosus flow; f) increased echogenicity in frontoparietal and parietooccipital areas (arrows) due to acute brain infarction in watershed regions.

- Reduced diffusivity (low ADC) persists for about 6 days, peaking around 3 days, before beginning to increase during the second week (4-10 days), a phenomenon known as pseudonormalization (T2 shine through)[73, 86, 127, 143–151]. However, in our previous published study, we found that diffusion restriction in cases of intrauterine fetal death can persist for approximately 6-7 weeks[152,153]. DWI also demonstrates reduced diffusivity in the white matter pathways, including the corpus callosum, thalamus, and descending corticospinal tract, within a few days of infarction. This phenomenon is referred to as pre-wallerian degeneration or acute network injury (Fig. 5)[86,154].

Table 5
imaging findings of fetal stroke:.

phase	sonography	Color doppler	T1	T2	T1 + C	FLAIR	DWI	ADC
Early hyperacute (0 −6 h)	normal	asymmetric blood flow and loss of pulsatility in the MCA	normal	normal	Enhancement-		high	low
Late hyperacute (6 −24 h)	hyperechoic		Normal or subtle abnormal	Normal or subtle abnormal	Enhancement-		high	low
Acute (24h−1 w)	ill-defined hyperechoic foci in a vascular territory	Findings in early hyperacute resolve. luxury perfusion with high diastolic and low resistive indices	low	High- Sulcal effacement and loss of cortical ribbon (missing cortex sign)	Enhancement-		high	High (T2 shine through)
Subacute (1 −3 w)			High (cortical highlighting)	low	Enhancement+			
Intermediate phase[3d–6w]		Peripheral neovascularization	Water signal	Water signal		Gliosis without cavitation		
Chronic (3 w and later)	Ventriculomagaly Volume loss ± hemorrhage		Volume loss, Cystic cavitation	Volume loss, Cystic cavitation		gliosis		

4. Subacute phase (1-3 weeks)

- T1-weighted images exhibit high signal intensity in the infarcted gray matter and cortex, a finding known as cortical highlighting. This is attributed to petechial hemorrhage, lipid laden microglia, high protein content, and manganese accumulation.
- T2-weighted images show low signal intensity due to the presence of petechial hemorrhages, lipids, and calcifications.
- Contrast enhancement may be observed due to the formation of leaky immature vessels during the process of neovascularization. However, in earlier phases, contrast enhancement is typically not seen unless reperfusion occurs early[73, 86, 127, 141, 142, 148, 155–162].

5. Intermediate phase (3 days – 6 weeks)

- The organization of the parenchymal infarct includes the development of central liquefaction with gliosis formation without cavitation
- Changes in myelin, the presence of microcysts, calcification, and peripheral neovascularization are observed.
- Signal changes correspond to increased water content and the formation of bridging strands of tissue through the infarct area[73].

6. Chronic Phase (3-4 weeks and beyond)

- Brain parenchyma exhibits volume loss and atrophy, with the development of cystic cavitation or encephalomalacia accompanied by varying degrees of gliosis starting from approximately 3 weeks after injury. As a result, the complete ipsilateral hemisphere appears smaller, with compensatory expansion of the diploic space as well as the paranasal and mastoid sinuses. Hemosiderin deposits may also be observed[73, 86, 127].

Brain Ischemia manifests as a loss of the normal laminated pattern on T2-weighted images and presents with focal or diffuse T2 hyperintensity lesions in various brain regions, including the germinal matrix, white matter, and cortex. Ischemic complications, such as cortical malformations, polymicrogyria, encephalomalacia, germinolytic cysts, hemorrhage, ventriculomegaly, and delayed sulcation, are more effectively visualized through MRI[47, 84, 163, 164].

Placental infarction: During the acute stage of placental infarction, color Doppler sonography may show no obvious reduction in decidual blood flow; however, it appears as a signal abnormality on MRI. Therefore, when abnormal signal intensity is detected in the placenta on MRI, it is crucial to conduct a comprehensive assessment of fetal CNS for ischemia[131].

In a study regarding co-twin demise, MRI identified findings that were not detected by sonography in one-third of the patients. Consequently, MRI should be performed as soon as possible for acute injury in these twins and repeated after two weeks to assess for subacute or chronic complications in the surviving co-twin[47,164].

3.5. *Other types of fetal stroke*

3.5.1. *Hemorrhagic stroke*

The prevalence of perinatal hemorrhagic stroke is approximately 1 in 6000–9000 live births[35, 86, 165–167]. The etiology of hemorrhagic stroke includes coagulopathies, sinus venosus thrombosis, vascular malformations, hemorrhagic transformation of ischemic infarcts (both arterial or venous), and genetic factors (mutation in collagen IVA and *JAM3*)[59, 86, 165, 168–174].

MRI is the imaging modality of choice for distinguishing hemorrhagic transformation of an ischemic infarct from primary hemorrhage, underlying tumors, or vascular malformations. Susceptibility-weighted imaging (SWI) can help differentiate between hemorrhage and calcification[86,175]. MRI findings can range from large subcortical hematoma to small petechial hemorrhage, often associated with edematous brain parenchyma[86].

3.5.2. *Venous infarct/ Cerebral Sinovenous Thrombosis(CSVT)*

The prevalence of venous infarction is approximately 2.6 per 100,000 individuals [86]. The causes of venous thrombosis include maternal gestational diabetes, preeclampsia, chorioamnionitis, dehydration, instrumental delivery and prothrombotic state, which fall under the broader concept of Virchow's triad [86, 176–178]. The torcula herophili is commonly involved [8, 179, 180].

Venous thrombosis is suspected when unexplained hemorrhage or parenchymal injury is detected without trauma or infection, and when the pattern does not align with an arterial territory[86,181]. Venous sinus thrombosis leads to vasogenic edema and, if left unresolve without collateral formation, can result in venous infarction[86,182].

Dural venous thrombosis often presents as a dilated venous sinus with triangular or round hyperechoic mass between the occipital lobes, surrounded by slow-flow fluid on sonography. This finding compresses normal infratentorial structures and is characteristic of the condition. On MRI, dural venous thrombosis typically shows abnormal signals including T1 shortening, marked T2 hypointensity, susceptibility

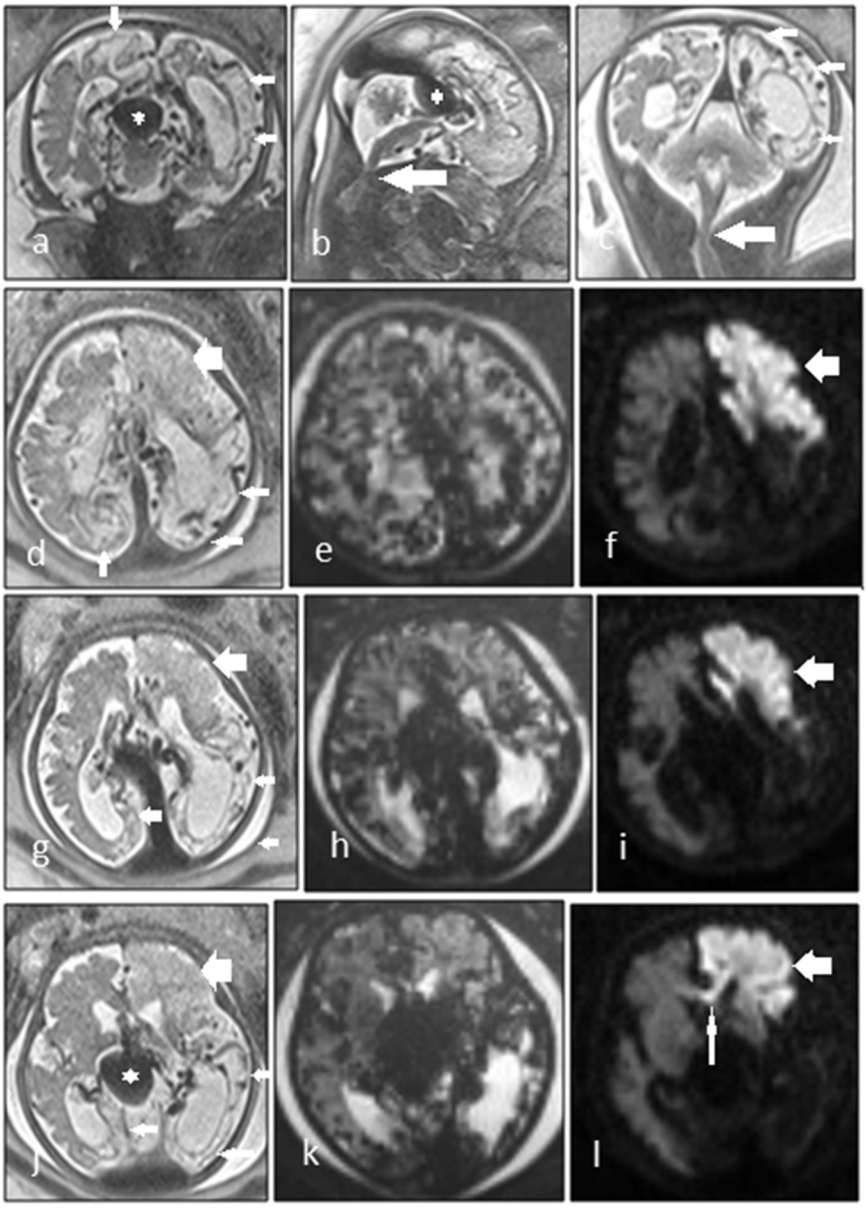

Fig. 5. A case of Vein of Galen Malformation (VGAM) with concurrent acute and chronic brain infarct. a,b,c) dilated prosencephalic vein or VGAM (asterisk), straight sinus and dilated tuft of vessels. Extensive encephalomalacia was found bilaterally more prominent in left side (small arrows). d-l) In 3 different axial levels, including T2-weighted images (d,f,g), T2 * -weighted (Hemo) sequence (e,h,k) and DWI sequence (f,I,l) you can see simultaneous acute (large arrows) and chronic (small arrows) fetal brain infarcts and cortical and intraparenchymal hemorrhage. Extension of acute infarct to genu of corpus callosum was present (narrow arrow in l). Foramen magnum stenosis as an accompanying abnormality (large arrows in b,c).

artifact and diffusion restriction depending on the age of thrombosis [47, 84, 183, 184].

Periventricular venous infarction is discussed earlier in the chapter of GMH-IVH.

MRI findings of venous thrombosis include the following:

- **acute phase (<7 days):** marked hypointensity on SWI or GRE sequences, along with dilatation of the affected sinus and brain parenchymal vasogenic edema.
- **Subacute phase (6-15 days):** hyperintensity on T1-weighted images. Non-contrast enhanced flow-related MRI sequences, such as phase contrast and time of flight, can also be used for better evaluation of fetal CSVT[86, 185–187].

Other findings include diffuse brain swelling due to venous hypertension, ventriculomegaly secondary to IVH in deep venous infarctions, and focal edema in the cortex and subcortical white matter, often associated with intralesional hemorrhagic components. A mixed pattern of signal intensity is commonly observed in this phase on DWI/ADC. some specific pattern of involvement include:

- parasagittal subcortical hemorrhage with superior sagittal sinus thrombosis (the most common)
- Thalamic and intraventricular hemorrhage with occlusion of the internal cerebral vein
- Striatohippocampal hemorrhage with basal vein thrombosis
- Temporal lobe or cerebellar hemorrhage with transverse sinus thrombosis[73].

3.6. Are there any complications for fetal stroke?

The complications of fetal stroke depend on the timing of infarction,

the maturity of the brain, and the astrocytic response. If the stroke occurs at an earlier gestational age, the complications tend to be more sever.

••***Schizencephaly***:

A cleft covered by dysplastic gray matter often develops when the insult occurs before 20 weeks of gestation.

••***Porencephaly***:

A CSF-filled cavity with a smooth wall covered by white matter, which may or may not communicate with the lateral ventricle, is formed if the injury occurs between 20–24 weeks of gestation.

••***Encephalomalacia and gliosis***:

This complication develops in the late second trimester and afterward. It appears as an irregular, fluid-filled lesion with thin septation and surrounding parenchymal signal abnormalities, best seen on FLAIR images (gliosis)[86,127].

••***Hydranencephaly***:

Defined as the destruction of the cerebral hemispheres, which are replaced by anechoic fluid, and the absence or incomplete formation of the falx [188,189].

3.7. What are the differential diagnosis of fetal stroke?

- ***Cystic brain lesions (especially arachnoid cysts)***:These lesions do not communicate with the lateral ventricle, unlike porencephalic cysts.
- ***Unilateral schizencephaly:*** Characterized by clefts in the brain lined by gray matter, which communicate with the subarachnoid space.
- ***Cystic neoplasm***: Unlike infarctions with volume loss, cystic neoplasms typically present with a mass effect.
- ***Metabolic disorders*****:** includes both congenital and acquired metabolic conditions that may contribute to brain abnormalities.
- ***Intracranial infections and inflammation:*** These can lead to various forms of brain injury, including stroke-like presentations.
- ***Drug toxicity:*** Certain drugs can cause fetal brain damage, mimicking stroke or other focal lesions.
- ***Focal lesions (such as tumors):*** These should be considered in cases of focal brain abnormalities.
- ***Primary hemorrhage:*** This is in differential diagnosis of hemorrhagic transformation of ischemia. More focal regions of hyperechogenicity within an echogenic area are often indicative of primary hemorrhage, whereas hemorrhagic transformation of infarction is more likely associated with a specific arterial vascular territory[86, 190, 191].

3.8. What is the neurological outcome of infants with prenatal infarct,and which factors influence the prognosis?

The incidence of long-term neurological disabilities in perinatal stroke is estimated to affect more than half of the cases[86,192]. The most common outcome is motor deficits, particularly hemiplegic cerebral palsy, which occurs in up to 60 % of cases. In arterial lesions, the upper extremity is often more affected than the lower extremity, whereas in periventricular venous infarction, this pattern tends to be reversed. Involvement of the basal ganglia and periventricular venous infarction are associated with a poorer outcome[86, 127, 193]. Other complications of perinatal stroke include recurrent seizures, cerebral palsy, visual deficits, cognitive and behavioral disorders, and developmental delay, all of which result from brain cortical involvement[73, 86, 128, 193–195]. Although hemiplegia can occur as a result of periventricular venous infarction, these patients are less likely to present with seizures or cognitive delays due to the lack of cortical involvement [76, 86, 196].

The most important imaging characteristic associated with poor neurodevelopmental outcome is decreased diffusion in descending white matter tract without notable changes in T1- and T2-weighted images, prior to the development of Wallerian degeneration[86].

4. Conclusion

Fetal ICH is a rare but significant condition that requires prenatal diagnosis due to its impact on both the current pregnancy and future pregnancies. Diagnosing ICH in utero can be achieved through ultrasound, particularly in the later stages of gestation when the condition is most likely to occur. In this review, we discuss the risk factors and etiology of fetal GMH-IVH and perinatal stroke. With advancements in sonographic technology, targeted and detailed fetal brain ultrasonography can now facilitate the early detection of even lower-grade intrauterine GMH-IVH and brain ischemic insults. MRI serves as a complementary tool to further clarify mild or uncertain ultrasound findings. While DWI and EPI can offer significant advantages in assessing fetal intracranial abnormalities, the decision to use them routinely should be based on the clinical context, the specific abnormalities detected, and the available resources. In centers where fetal MRI is routinely performed, DWI and EPI may be integrated into the management plan for fetuses with significant ultrasound findings. We recommend DWI routinely for the evaluation of fetal ICH and infarction. Early prenatal evaluation of these brain abnormalities can help reduce postnatal complications, neonatal disabilities, and ultimately improving patient's outcome and survival rates. As research and new techniques continue to evolve, it may become possible to identify areas at risk earlier, allowing for interventions to prevent brain damage.

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CRediT authorship contribution statement

Mohammad Ali Kazemi: Supervision, Data curation. **Laleh Eslamian:** Data curation. **Mahboobeh Shirazi:** Data curation. **Reihaneh Mortazavi Ardestani:** Writing – original draft, Resources, Methodology. **Behnaz Moradi:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of Competing Interest

All of the authors declare no conflict of interest.

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Contribution to authorship

Dr. Behnaz Moradi has made the first conception of this topic, planned the research and edit the final manuscript. Dr. Reihaneh Mortazavi contributed in planning, searching previous articles and writing this article. Dr. Mahboobeh Shirazi helped in finding related cases. Dr. Laleh Eslamian contributed in data gathering. Dr. Mohammad Ali Kazemi had the role of analysis the data.

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