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The Value of a Prenatal MRI In Adjunct to Prenatal USG For Cases with Suspected or Diagnosed Fetal Anomalies

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ABSTRACT

An accurate diagnosis of the anomalies plays a crucial role in the guidance and management of pregnancy, prenatal counselling, and postnatal therapies. This study aimed to evaluate the value of fetal magnetic resonance imaging (MRI) in adjunct to ultrasonography (USG) for cases with suspected or diagnosed fetal anomalies.

This retrospective study included 86 fetuses that were evaluated using a fetal MRI and USG within 14 days for a diagnostic query. To evaluate the diagnostic performance and value of the fetal MRI, patients were grouped according to the final diagnosis, which was revealed in the post-natal or post-terminated period. The patients were grouped according to weather, or not correct or additional findings revealed on these diagnostic modalities.

According to the final diagnosis, the most common anomaly was the central nervous system (CNS) (n=62, 72%), followed by genitourinary (n=11, 13%). Both modalities were correct, and MR did not reveal additional findings in most cases (65 of 86 cases, 76%). İn eight cases (9%) MR was correct, but USG was incorrect. USG was correct and MRI was incorrect in 2 cases (2%). USG was correct but MRI revealed additional findings in 9 cases (10%) were in group 4. Both modalities were incorrect in 2 cases (2%).

İn adjunct to USG, a fetal MRI increases the diagnostic accuracy and provides additional information. The MRI is more useful for certain indications, such as agenesis of corpus callosum, neural migration defects, posterior fossa anomalies, intracranial cysts, and urogenital system anomalies.

Keywords: Fetal diagnoses, fetal imaging, fetal anomalies, magnetic resonance imaging, ultrasonography

Introduction

Fetal structural anomalies cause complications in up to 3% of pregnancies. An accurate diagnosis of the anomalies plays a crucial role in the guidance and management of pregnancy, prenatal counselling, and postnatal therapies. Ultrasonography (USG) is the primary screening tool in pregnancy as it is widely available, non-invasive, uses real-time imaging, has a high-resolution capacity and is safe both for the fetus and mother (1). However, a complete evaluation of the fetus via USG is not always possible due to technical problems. These problems could be due to maternal obesity, oligohydramnios, fetal positions, acoustic shadowing from the calvaria or the gestational week at which the USG is performed. Choosing another imaging modality in the case of inconclusive, uncertain, or additional findings from the USG may be helpful for diagnosis (2,3). The most common imaging modality used in obstetrics for fetal structural anomalies in adjunct to prenatal USG is fetal magnetic resonance imaging (MRI) (3). An MRI has a non-invasive procedure, does not involve ionising radiation, has a high contrast resolution, a large field of view and can visualise both sides of the fetal organs. İn the mid-80s, MRIs began to be used in the obstetrics field. At the beginning, MRIs had several major disadvantages, such as long acquisition times of the standard spin-echo images (one to ten minutes) and fetal movements.

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This degraded the images, and diazepam or pancuronium had to be used to reduce the fetal motion. However, these pharmacological interventions posed a risk for the mother and fetus. Nowadays, fast, and ultrafast MRIs, which take less than one second, are available in many centres, which means that maternal sedation is no longer required (4,5).

For pregnancies that are screened using prenatal USG, the detection rate of fetal anomalies varies between 15% to 80% (1,2). Previous studies showed that using a fetal MRI increases the diagnostic accuracy. For the assessment of the fetal brain, in congenital diaphragmatic hernia or pre-surgical planning of spina bifida repair, a fetal MR can be useful (2,6-8).

This study aims to evaluate the usefulness of the fetal MRI in adjunct to fetal USG in cases with suspected or diagnosed fetal congenital abnormalities, except for fetal cardiac abnormalities.

Material and Methods

This study was conducted in a tertiary referral center, which is 16,000 deliveries per year. The ethics committee has approved this study (Health Science University ethical council, ethical approval number: 2020-15/20). Pregnancies with diagnosed or suspected fetal anomalies on the prenatal USG that were screened with a fetal MRI in adjunct to USG, between January 2015 and January 2020, were included in the study.

According to our diagnostic protocol, all cases with diagnosed or suspected fetal anomalies were evaluated by senior perinatologists with at least eight years' experience in fetal anomaly screening. They used a Voluson E6 equipped with 5–9-MHz volumetric transvaginal transducers and a 4–8-MHz volumetric convex transducer, (GE Medical Systems, Horten, Norway). The fetal anatomic survey was conducted according to ISOUG guidelines (9). For pregnancies under 14 gestational weeks, suspected fetal brain abnormalities with cephalic presentation or patients who were thought to provide additional information, a vaginal probe was used in adjunction to the abdominal probe for diagnosis. İf the USG examination revealed inconclusive, uncertain and possibility additional findings or requiring to confirmation the fetal MRI was proposed to patients.

The expert radiologist who performed fetal MR imaging had the results of the fetal USG at the time of acquisition and when the MR images were interpreted.

The fetal MRI studies were performed using a Philips Achieva 1.5 T system (amplitude on axis, 30 mT/m; slew rate on axis, 120 T/m/s gradients, equipped with a four-channel phased-array body coil; Philips Healthcare, Andover, MA, USA), using Single Shot Fast Spin Echo sequences to produce high-resolution T2-weighted images (echo time (TE), 120 ms; echo train length (ETL), 96; slice thickness, 3–4 mm), fast-gradient-echo (GrE) sequences to obtain axial T1-weighted images (repetition time (TR)/TE, 154/4.6ms; flip angle (FA), 80∘; slice thickness ranged from 3 mm to 5 mm) and echo planar imaging (EPI) for diffusion-weighted imaging (DWI) (TR/TE, 2000/90 ms; Max B factor, 600; slice thickness, 3 to 5 mm; with calculation of trace and apparent diffusion coefficient [ADC] maps). Breath holding techniques were used when necessary. When a haemorrhagic or destructive lesion was suspected, or to visualise meconium-filled bowel loops or the position of the liver, T1-weighted sequences were obtained using a fast, multiplanar, gradient-echo technique. Maternal sedation and fetal curarsiation were not used. All MRIs were performed within 14 days of prenatal USG.

To compare the diagnostic accuracy of USG with the MRI, only findings that were detected prior to the MRI were considered. With respect to the final diagnosis, which was reported after the fetal autopsy, the MRI, computerised tomography (CT), USG, surgery or physical examination in the post-natal or after pregnancy termination period, the patients were grouped as follows: group 1 had a correct USG and MRI; group 2 had an incorrect USG and correct MRI; group 3 had a correct USG and incorrect MRI; group 4 had a correct USG in concordance with the MR, but the MRI added value; and group 5 had an incorrect USG and MRI.

The first group included the patients whose findings on the USG were in concordance with the MRI, and the MRI did not add any value. The second group included the patients whose USG diagnosis was discordant with the MRI, and the MRI contributed significantly and was correct according to the final diagnosis. The third group included the patients whose USG diagnosis was correct, but the MRI added no value according to final diagnosis. The fourth group included the patients whose USG findings were correct and in concordance with the MRI but inconclusive, and the MRI contributed significantly and was correct according to the final diagnosis. The fifth group

Table 1. Characteristic Features of Study Group

Variables	
Age (Year) Median (Min–Max)	28 (19–44)
Gravidity Median (Min–Max)	2 (1–7)
Parity Median (Min–Max)	1 (0–3)
BMI (kg/m2), Mean (±SD)	26.73 ± 5.43
USG (Week) Median (Min–Max)	25 (20–34)
MRI (Week) Median (Min–Max)	26 (20–36)
Time from USG to MRI (day) Median (Min–Max)	7 (0–14)

included the patients whose MRI and USG diagnosis were incorrect according to the final diagnosis, irrespective of the concordance.

Results

During the study period, 147 patients were requested to perform a fetal MRI. Among them, 52 patients were unable to perform a fetal MRI because the patients either declined the exam (n=30), opted for a direct termination of pregnancy (TOP) (n=16) or were claustrophobic (n=6). Six cases were excluded because information after the TOP or birth was unavailable. A total of 86 patients who were evaluated using both prenatal USG and MRI were included. The mean gestational weeks at USG was 25 (range 20–34), MRI was 26 (range 20–36) and the mean time between the USG and MRI was seven days (range 0–14) (Table 1). The distribution and percentage of anomalies according to the final diagnosis methods are shown in Table 2. The most common anomaly that was revealed in the postpartum or post-termination period was the central nervous system (CNS) (n=62, 72%) followed by genitourinary (n=11, 13%), gastrointestinal (n=4, %5), respiratory (n=3, 3%) and the musculoskeletal system (n=1, 1%). Ventriculomegaly was the most common anomaly in the CNS and constituted 42% of all CNS anomalies (Table 3).

Regarding the final diagnosis, the prenatal USGs and MRIs were correct and concordant, and the MRI did not add more value in 65/86 (76%) patients (group 1). Ventriculomegaly was the most common anomaly in this group 26/86 (30%). Only one case was misdiagnosed as ventriculomegaly on USG and was corrected after the MRI to normal. İn eight cases (9%) (group 2), the USG was incorrect and discordant with the MRI, and the MRI was correct. All of these had CNS anomalies, except for one, which was misdiagnosed as a uretero-pelvic junction obstruction on USG. İn two patients (2%) (group 3), the MRI was incorrect, and the USG was correct. One of them was diagnosed with microcephaly on USG and postnatally, but the MRI was normal. Another one was diagnosed with agenesis of corpus callosum and ventriculomegaly on USG and confirmed in the postnatal period, but the MRI was reported as only ventriculomegaly (Table 4). İn nine patients (10%) (group 4), although the USG and MRI were both concordant according to the final diagnosis, the MRI revealed more information than the USG. Although they all had CNS anomalies, two were diagnosed with an ovarian cyst on the USG, and the MRI specified the cyst type as a cystic teratoma. Another was detected by USG as a cyst, but the origin could not be determined, and the MRI determined it to be an ovarian cyst. The MRI aimed to detect midbrain and posterior fossa anomalies. Both modalities were concordant but incorrect according to the final diagnosis in two cases (2%) (group 5), of which one was misdiagnosed as microcephaly and another as a large bowel obstruction. These were normal according to the postnatal diagnosis (Table 5).

Discussion

İn this study, we revealed that although the USG is the primary screening tool and has high diagnostic accuracy in the obstetrics field, the MRI in certain cases who with fetal brain abnormalities includes midbrain, migration and posterior fossa and some genitourinary abnormalities, were useful. Also, in case of inconclusive USG due to technical problems such as maternal fat, the MRI had a value. The fetal MRI changed the USG misdiagnosis to correct in 8/86 cases (9%) and added more information that the USG missed in 9/86 cases (10%). This is confirmative for USG findings in 65/86 cases (76%) and incorrect for 4/86 cases (5%). Recently, using a fetal MRI in the field of

Table 2. Postnatal Evaluation Methods

Method	No. of Neonates
USG	39 (45%)
Physical examination	15 (18%)
MRI	11 (13%)
Surgery	9 (10%)
Autopsy	9 (10%)
CT	3 (4%)

Table 3. Distribution of Anomalies According To The Affected Area

Affected System	Type of Anomaly	No. of fetuses
Central nervous system (all (n=66), anomaly (n=62), normal (n=4))	Ventriculomegaly	26
	Dandy-Walker variant	6
	Mega cisterna magna	6
	Agenesis of corpus callosum	5
	Microcephaly	2
	Dolichocephaly	1
	Brachycephaly	1
	Macrocephaly	2
	Cavum Verge	5
	Arachnoid cyst	1
	Rhombencephalon synapsis	1
	Lissencephaly	2
	Cerebellar hypoplasia	1
	Blake-pouch cyst	1
	İntracranial cyst	1
	Arachnoid cyst	1
	Normal (suspected ventriculomegaly (1), Blake's pouch cyst (1), tethered cord (1), microcephaly (1))	4
Thorax (n=3)	Congenital Diaphragmatic hernia	1
	Hypoplastic Thorax	1
	Bronchogenic cyst	1
Gastrointestinal system (all (n=5), anomaly (n=4), normal (n=1))	Enlarged large bowel (Hirschspurng's disease)	2
	Mesenteric cyst	1
	Meconium pseudo cyst	1
	Normal (suspected large bowel obstruction)	1
Genitourinary system (n=11)	Ovarian cyst	4
	Renal cortical cyst	1
	Unilateral renal agenesis	2
	Reflux in duplicated system	2
	Multicystic dysplastic kidney	1
	Pelvic kidney	1
Musculoskeletal (n=1)	Clubfoot	1

obstetrics, especially for screening fetal anomalies, is becoming more common. This is partly because MRIs are more widely available than before and have evolved to have fast and ultrafast MRIs,

Table 4. Comparison of US and MR Imaging Findings; Diagnosis Was Incorrect With At Least One Modality When Findings Were Compared With Postnatal Final Diagnosis

USG incorrect, MR imaging correct (Group 2) (n=8)	USG correct, MR imaging incorrect (Group 3) (n=2)
USG; normal	MRI; normal,
MRI; Dandy-Walker variant	USG; microcephaly
USG; Blake-pouch cyst suspected	MRI; ventriculomegaly
MRI; normal	USG; agenesis of corpus callosum and ventriculomegaly
USG; ventriculomegaly suspected	
MRI; normal	
USG; İntracranial mass suspected	
MRI; neuroepithelial cyst	
USG; tethered cord suspected at	
MRI; normal	
USG; mega cisterna magna suspected MRI; arachnoid cyst	
USG; microcephaly suspected	
MRI; normal	
USG; U-P junction obstruction suspected MRI; ureteral duplication	

which can scan in under one second. Therefore, the amount of motion artifacts decreased significantly, and sedation or curarisation were not required (4,5). However, similar to previous studies (2,7), the exact diagnostic performance of fetal MRIs cannot be determined because the radiologist received information from the USG at the time of the MRI scan or interpretation. Using a fetal MRI to screen the fetal cardiovascular system is limited (10). Except for this, the MRI has been shown to detect all organ anomalies with a high rate (2,4,5,7,11). The fetal MRI is mostly used to evaluate fetal CNS (2,7,11). Similarly, in this study, most indications for MRI are formed by suspected, inconclusive and possible additional anomalies in the fetal brain on the USG examination. This is because first, CNS abnormalities are the second most common anomalies, followed by cardiovascular anomalies. Second, due to the acoustic shadow created by fetal cranial bones, the visualisation of the fetal brain via USG can be difficult. Third, creating acoustic shadow, maternal pelvic bones decrease brain imaging quality on US, which is sometimes can be overcome by using vaginal USG's probe. A study showed that in addition to the ultrasonographer's experience, using a vaginal probe for cephalic presentations to evaluate the fetal brain is helpful, can decrease recruitment for fetal MRIs and can increase the diagnostic accuracy of the USG (2,12). Accordingly, we used the vaginal probe in adjunct to the abdominal probe for cases of fetal cephalic presentations for the fetal brain evaluation, which was suggested by İSOUG and previous studies (2,6,13). Paladini D. et al. reported that the clinical usefulness of MRIs in adjunct to the USG in evaluating fetal CNS was 5%–10% of all cases (2,12). However, most studies reported a higher percentage (range 15%–48%) (7,8,14,15). İn this study, the usefulness of a fetal MRI was 16/66 (24%) in the fetal CNS group and 17/86 (20%) for the whole group. We believe that, as proposed in previous studies (2,6), this wide range may result from different experiences in the field of fetal neurosonography, neuroradiography and indications for the MRI.

The most indication in the MRI in both previous studies and our study was ventriculomegaly. However, the contribution of the MRI in this anomaly, as revealed by the current trial, was as low as 1/26 (4%). The performance of the fetal MRI in adjunct to the USG for cases diagnosed with isolated ventriculomegaly varied (range 0%–17%) (2,15,16). However, for other brain anomalies, such as corpus callosal, space occupying or posterior fossa anomalies, the MRI is more efficient (2,6,15). Accordingly, in this study, five cases that had carpus callosum agenesia confirmed in the postnatal period would have been missed if the MRI had been not performed

Table 5. Comparison of USG and MRI imaging findings for cases in which MR imaging added information and for those in which the MRI and USG were both incorrect for the final diagnosis. Findings were confirmed at the postnatal final diagnosis

USG correct MR imaging added information (group 4) (n=9)	Both USG and MR imaging incorrect (group 5) (n=2)
USG; ventriculomegaly and mega cisterna magna MRI; ventriculomegaly with septation, mega cisterna magna and hepatosplenomegaly	(The new-born was normal on postnatal physical examination) USG; microcephaly MR; microcephaly
USG; porencephalic cyst and dolichocephaly MRI; encephalomalacia, porencephalic cyst, lissencephaly, agenesis of corpus callosum	(The new-born was normal on postnatal physical examination and USG) USG: large bowel obstruction MRI: large bowel obstruction
USG; suspected Dandy-Walker variant MRI; confirmed Dandy-Walker variant	
USG; encephalocele, agenesis of corpus callosum MRI: encephalocele, lissencephaly, agenesis of corpus callosum, bullet shaped 4. Ventricle	
USG; agenesis of corpus callosum and hypotelorism MRI; agenesis of corpus callosum, microphthalmia and hypotelorism	
USG; Ovarian cyst MRI; Ovarian cystic teratoma	
USG: intraabdominal cyst, origin could not be determined. MRI; ovarian cyst	
USG: Ventriculomegaly and mega cisterna magna MRI: Ventriculomegaly, mega cisterna magna and rhombencephalon synapsis	
USG: cerebellar hypoplasia, mega cisterna magna and club foot MRI: cerebellar hypoplasia, mega cisterna magna, club foot and agenesis of corpus callosum	

in two cases, as they had multiple brain anomalies in addition to agenesia of corpus callosum. This would be similar for 1/6 cases with the Dandy-Walker variant, 1/1 cases with a neuroepithelial cyst, 1/1 cases with an arachnoid cyst, 1/1 cases with septate ventriculomegaly, 2/2 cases with lissencephaly and 1/1 cases with rhombencephalon synapsis. İn addition, one case that was misdiagnosed by USG with Blake's pouch cyst was correctly diagnosed as normal using the MRI.

Agenesis of corpus callosum is one of most common missed anomalies by the USG. Using 3D USG with multiplanar imaging sometimes facilitates the evaluation of corpus callosum. A direct visualisation of corpus callosum with the MRI is possible, and the usefulness of the MRI was shown in many studies (17,18).

After 24 weeks of gestation, the evaluation of posterior fossa is compromised, and the image quality of the MRI is not impaired due to the ossification of the fetal skull. Therefore, the Dandy-Walker variant, enlarged cisterna magna, Arnold Chiari malformation, cerebellar hypoplasia and supratentorial anomalies can be effectively assessed using the MRI (19). When evaluating the arachnoid cyst and other cerebral cysts, the MRI is a good option because it can define the extent and relationship of the cyst with other structures (20).

Neural migration anomalies are generally not seen on the USG. Similarly, two cases with lissencephaly in this study could not be detected on the USG. An MRI is more successful in diagnosing such anomalies and can detect lissencephaly, lissencephaly and heterotopia from a normal brain (21).

Urogenital anomalies comprise 30%–50% of fetal anomalies at birth. Although the primary modality is USG for the evaluation of urogenital system anomalies, when evaluating complicated cases or when the USG is limited because of technical factors, such as poor acoustic due to oligohydramnios or anhydramnios, the MRI adds value (22). İn our study, urogenital system anomalies comprised 13% of cases, which required an MRI in adjunct to a USG. An MRI was useful in 3/11 cases. The first case was misdiagnosed as a ureteropelvic obstruction, and although the second case was diagnosed as an ovarian cyst, the type of cyst could not be determined on the USG. For the third case, an intraabdominal cyst was detected on the USG, but the origin of the cyst could not be determined. The MRI clearly depicted ureter duplication, the type of cyst, which was an ovarian cystic teratoma, and the origin of the cyst, which was an ovarian cyst.

A fetal MRI is an imaging modality that complements USG for the evaluation of the gastrointestinal system and can be used to confirm, exclude and provide additional information to USG findings (23). Bowel obstruction, bowel perforation resulting in meconium pseudocyst or meconium perforation and large bowel dilatation constitutes the most common indications of gastrointestinal system anomalies for fetal MRIs (24). A prospective study evaluated 38 fetuses due to gastrointestinal anomalies and found that a fetal MRI adds value in 28/38 cases (23). İn our study, a fetal MRI was confirmative in 4/5 cases and failed to diagnose with USG in one case, which was misdiagnosed from both modalities as a large bowel obstruction and was normal in the postpartum USG. However, due to the small number of cases with gastrointestinal anomalies included in this study, we cannot compare our results with previous studies.

Previous studies have not demonstrated that a fetal MRI is superior to USG in congenital lang malformations. In addition, USG is better at detecting the presence of a systemic vessel. However, in the presence of an intrathoracic cyst, a fetal MRI is more reliable (25). There were three cases in the current study with fetal respiratory system anomalies and indications of a bronchogenic cyst, congenital diaphragmatic hernia and hypoplastic thorax. For all cases, fetal MRIs were confirmative and did not add any value.

Articles concerning the fetal musculoskeletal system are rare. İn detecting arthrogryposis, USG is superior to an MRI because it can demonstrate real-time fetal movement (26). One of our cases, which was diagnosed with club foot, was concordant with the fetal MRI.

There are several limitations of the study. First, at the beginning, 16 patients with multiple fetal anomalies did not want any more examinations, including an MRI, and opted directly for a termination of pregnancy. Therefore, the diagnostic performance of the MRI could not be evaluated. Second, although all radiologists were experienced in evaluating fetal anomalies, the MRI acquisition and interpretation were not performed by some radiologists, which might have affected the results. Third, the findings revealed by the USG were known by radiologists who interpreted fetal MRIs, which shows a bias in favour of the MRI.

İn adjunct to USG, fetal MRIs increase the diagnostic accuracy and provide additional information. Especially for certain indications, such as agenesis of corpus callosum, neural migration defects, posterior fossa anomalies, intracranial cysts and urogenital system anomalies, the MRI is more useful.

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References

1. Best KE, Rankin J, Dolk H, Loane M, Haeusler M, Nelen V, et al. Multilevel analyses of related public health indicators: The European Surveillance of Congenital Anomalies (EUROCAT) Public Health Indicators. Paediatr Perinat Epidemiol 2020; 34: 122-129.
2. Paladini D, Quarantelli M, Sglavo G, Pastore G, Cavallaro A, D'Armiento MR, et al. Accuracy of neurosonography and MRI in clinical management of fetuses referred with

central nervous system abnormalities. Ultrasound Obstet Gynecol 2014; 44: 188-196.

3. Manganaro L, Bernardo S, Antonelli A, Vinci V, Saldari M, Catalano C. Fetal MRI of the central nervous system: State-of-the-art. Eur J Radiol 2017; 93: 273-283.
4. Tee LM, Kan EY, Cheung JC, Leung WC. Magnetic resonance imaging of the fetal brain. Hong Kong Med J. 2016; 22: 270-278.
5. Hubbard AM, Harty MP, States LJ. A new tool for prenatal diagnosis: ultrafast fetal MRI. Semin Perinatol 1999; 23: 437-447.
6. Malinger G, Ben-Sira L, Lev D, Ben-Aroya Z, Kidron D, Lerman-Sagie T. Fetal brain imaging: a comparison between magnetic resonance imaging and dedicated neurosonography. Ultrasound Obstet Gynecol 2004; 23: 333-340.
7. Frates MC, Kumar AJ, Benson CB, Ward VL, Tempany CM. Fetal anomalies: comparison of MR imaging and US for diagnosis. Radiology 2004; 232: 398-404.
8. Jarvis D, Mooney C, Cohen J, Papaioannou D, Bradburn M, Sutton A, et al. A systematic review and meta-analysis to determine the contribution of mr imaging to the diagnosis of foetal brain abnormalities In Utero. Eur Radiol 2017; 27: 2367-2380.
9. Salomon LJ, Alfirevic Z, Berghella V, Bilardo C, Hernandez-Andrade E, Johnsen SL, et al. ISUOG Clinical Standards Committee. Practice guidelines for performance of the routine mid-trimester fetal ultrasound scan. Ultrasound Obstet Gynecol 2011; 37: 116-126.
10. Schoennagel BP, Yamamura J, Kording F, Fischer R, Bannas P, Adam G,et al. Fetal dynamic phase-contrast MR angiography using ultrasound gating and comparison with Doppler ultrasound measurements. Eur Radiol 2019; 29: 4169-4176.
11. Gat I, Hoffmann C, Shashar D, Yosef OB, Konen E, Achiron R, et al. Fetal Brain MRI: Novel Classification and Contribution to Sonography. Ultraschall Med 2016; 37: 176-184.
12. Paladini D, Malinger G, Pilu G, Timor-Trisch I, Volpe P. The MERIDIAN trial: caution is needed. Lancet 2017; 389: 2103.
13. Prayer D, Malinger G, Brugger PC, Cassady C, De Catte L, De Keersmaecker B, et al. ISUOG Practice Guidelines: performance of fetal magnetic resonance imaging. Ultrasound Obstet Gynecol 2017; 49: 671-680.
14. . Levine D, Barnes PD, Robertson RR, Wong G, Mehta TS. Fast MR imaging of fetal central nervous system abnormalities. Radiology 2003; 229: 51-61.
15. Griffiths PD, Bradburn M, Campbell MJ, Cooper CL, Graham R, Jarvis D, et al. MERIDIAN collaborative group. Use of MRI in the diagnosis of fetal brain abnormalities in utero (MERIDIAN): a multicentre, prospective cohort study. Lancet 2017; 389: 538-546.
16. Kandula T, Fahey M, Chalmers R, Edwards A, Shekleton P, Teoh M,et al. Isolated ventriculomegaly on prenatal ultrasound: what does fetal MRI add? J Med Imaging Radiat Oncol 2015; 59: 154-162.
17. d'Ercole C, Girard N, Cravello L, Boubli L, Potier A, Raybaud C, et al. Prenatal diagnosis of fetal corpus callosum agenesis by ultrasonography and magnetic resonance imaging. Prenat Diagn 1998; 18: 247-253.
18. Vimercati A, Greco P, Vera L, Resta M, Selvaggi L. The diagnostic role of "in utero" magnetic resonance imaging. J Perinat Med 1999; 27: 303-308.
19. Poutamo J, Vanninen R, Partanen K, Ryynänen, Kirkinen P. Magnetic resonance imaging supplements ultrasonographic imaging of the posterior fossa, pharynx and neck in malformed fetuses. Ultrasound Obstet Gynecol 1999; 13: 327-334.
20. . Levine D, Barnes PD, Madsen JR, Abbott J, Wong GP, Hulka C, et al. Fetal CNS anomalies revealed on ultrafast MR imaging. AJR Am J Roentgenol 1999; 172: 813-818.
21. Levine D, Barnes PD. Cortical maturation in normal and abnormal fetuses as assessed with prenatal MR imaging. Radiology 1999; 210: 751-758.
22. Faghihimehr A, Gharavi M, Mancuso M, Sreedher G. Fetal MR imaging in urogenital system anomalies. J Matern Fetal Neonatal Med 2019; 32: 3487-3494.
23. Manganaro L, Saldari M, Bernardo S, Vinci V, Aliberti C, Sollazzo P,et al. Role of magnetic resonance imaging in the prenatal diagnosis of gastrointestinal fetal anomalies. Radiol Med 2015; 120: 393-403.
24. Furey EA, Bailey AA, Twickler DM. Fetal MR Imaging of Gastrointestinal Abnormalities. Radiographics 2016; 36: 904-917.
25. Beydon N, Larroquet M, Coulomb A, Jouannic JM, Ducou le Pointe H, Clément A, Garel C. Comparison between US and MRI in the prenatal assessment of lung malformations. Pediatr Radiol 2013; 43: 685-696.
26. Nemec SF, Nemec U, Brugger PC, Bettelheim D, Rotmensch S, Graham JM Jr, Rimoin DL, Prayer D. MR imaging of the fetal musculoskeletal system. Prenat Diagn 2012; 32: 205-213.