ACR–SPR PRACTICE PARAMETER FOR THE SAFE AND OPTIMAL PERFORMANCE OF FETAL MAGNETIC RESONANCE IMAGING (MRI)

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question. The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

---

1 *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.*

I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR) and the Society for Pediatric Radiology (SPR).

Magnetic resonance imaging (MRI) is a proven, established imaging modality for evaluating fetal anomalies that are not adequately or completely assessed by sonography [1-8]. MRI is used for problem solving and only in select circumstances for screening. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment, delivery planning, and counseling. However, sonography is the most appropriate first-line imaging screening modality in the fetus. Fetal MRI should be performed only for a valid medical reason and only after careful consideration of sonographic findings or family history of an abnormality for which screening with MRI might be beneficial.

This practice parameter addresses the use of MRI in fetal diagnosis.

Although MRI is an effective noninvasive diagnostic test for characterizing many fetal abnormalities, its findings may be misinterpreted if not closely correlated with the clinical history and sonographic findings. Adherence to the following practice parameters will enhance the probability of appropriately diagnosing such abnormalities.

II. INDICATIONS and CONTRAINDICATIONS

When an anomaly is suspected on ultrasound (US) or limited by fetal lie, descent of the fetal head into the maternal pelvis, maternal body habitus, oligohydramnios, overlying bone/gas, and/or small field of view (FOV), MRI can provide additional information that may impact parental counseling, perinatal management, delivery planning, and postnatal care [9-11]. Primary indications for MRI include, but are not limited to, the following:

II. INDICATIONS and CONTRAINDICATIONS

A. Brain and Spine

1. Congenital anomalies of the brain or skull suspected or not adequately assessed by sonography [3, 12-33], including, but not limited to, the following:
    a. Ventriculomegaly
    b. Agenesis of the corpus callosum
    c. Abnormalities of the cavum septum pellucidum
    d. Holoprosencephaly
    e. Posterior fossa anomalies
    f. Cerebral cortical malformations or migrational anomalies
    g. Solid or cystic masses
    h. Cephalocele
    In addition, MRI can be helpful in screening fetuses with a family risk for brain abnormalities, such as tuberous sclerosis, corpus callosal dysgenesis, or lissencephaly.

2. Vascular abnormalities of the brain suspected or not adequately assessed by sonography [34, 35] including, but not limited to, the following:
    a. Vascular anomalies
    b. Hydranencephaly
    c. Infarction
    d. Hemorrhage
    e. Monochorionic twin or multiple gestation pregnancy complications

3. Congenital anomalies of the spine suspected or not adequately assessed by sonography [9, 13, 36-42] including, but not limited to, the following:
    a. Neural tube defects
    b. Sacrococcygeal teratomas
    c. Caudal regression/sacral agenesis
    d. Sirenomelia
    e. Vertebral anomalies

II. INDICATIONS and CONTRAINDICATIONS

B. Skull, Face, and Neck

1. Anomalies of the face and neck suspected or not adequately assessed by sonography [11, 12, 43-46] including, but not limited to, the following:

a. Vascular or lymphatic anomalies
b. Goiter
c. Teratomas
d. Facial clefts
e. Congenital cysts and cystic masses
f. Micrognathia

2. MRI can be helpful in assessing airway obstruction that may impact parental counseling, prenatal management, delivery planning, and postnatal therapy [11, 43-46].

II. INDICATIONS and CONTRAINDICATIONS

C. Thorax

1. Thoracic pathology suspected or not adequately assessed by sonography, [47-49] including, but not limited to, the following:
    a. Congenital airway and lung malformations (including congenital high airway obstruction, pulmonary airway malformations, bronchogenic cyst, bronchopulmonary, sequestration, and congenital lobar overinflation)
    b. Congenital diaphragmatic hernia
    c. Effusions
    d. Mediastinal masses
    e. Esophageal atresia
    f. Pulmonary Lymphangiectasia (primary or secondary from congenital heart disease)

2. MRI can be used for volumetric assessment of fetal lung parenchyma [47-49], particularly in those fetuses at risk for pulmonary hypoplasia secondary to diaphragmatic hernia, oligohydramnios, omphalocele, chest mass, or skeletal dysplasias. In the setting of congenital diaphragmatic hernia, the percentage of liver volume herniating into the chest can also be measured by MRI [50, 51].

II. INDICATIONS and CONTRAINDICATIONS

D. Abdomen, Retroperitoneum, and Pelvis

1. Abdominal and pelvic pathologies suspected or not adequately assessed by sonography include, but are not limited to, the following:
    a. Tumors, such as hemangiomas, neuroblastomas, sacrococcygeal teratomas, and suprarenal or renal masses
    b. Abdominal-pelvic cyst
    c. Complex genitourinary anomalies, such as bladder exstrophy, cloacal malformation and anorectal malformations, or complex lower urinary tract obstruction
    d. Renal anomalies in cases of severe oligohydramnios
    e. Complex bowel anomalies, such as cloaca, anorectal malformations, or complex bowel obstructions
    f. Complex abdominal wall defects

II. INDICATIONS and CONTRAINDICATIONS

E. Muscoskeletal

1. Musculoskeletal pathologies suspected or not adequately assessed by sonography include, but are not limited to, the following:
    a. Assessment of extremity masses, such as lymphatic malformations and Klippel-Trenaunay-Weber
    b. Skeletal dysplasias, for assessment of associated anomalies
    c. Confirmation of suspected limb anomalies

II. INDICATIONS and CONTRAINDICATIONS

F. Multiple Gestation Pregnancies

1. Complications of multiple gestation pregnancies suspected or not adequately assessed by sonography include, but are not limited to, the following:
   a. Monochorionic twins: delineation of vascular anatomy before laser treatment of twins, assessment of morbidity after death of a monochorionic co-twin area in which MRI may be useful because of its high spatial resolution, contrast resolution, large FOV, and multiplanar imaging capabilities.
   b. Conjoined twins: further delineation of anatomy can impact parental counseling, delivery planning, and postnatal management

II. INDICATIONS and CONTRAINDICATIONS

G. Fetal Interventions Assessment

When an abnormality is identified that may benefit from fetal interventions, MRI is a useful adjunct in confirming the diagnosis and planning potential interventional options[39, 52-56]. It can also be used in assessing the fetal brain both before and after surgical interventions [57].

The high risk to mother and fetus of potential in utero interventions requires accurate assessment of all anomalies. This includes, but is not limited to, the following:

1. Open neural tube defects
2. Sacrococcygeal teratomas
3. Processes obstructing the airway, such as a neck mass or congenital high airway obstruction
4. Complications of monochorionic twins
5. Chest masses [58]
6. Congenital diaphragmatic hernia
7. Lower urinary tract obstruction

II. INDICATIONS and CONTRAINDICATIONS

H. Placental Assessment

1. Although US remains the reference standard, MRI may be particularly useful for the assessment of placental disorders, such as gestational trophoblastic disorders and abnormalities of implantation [59].

II. INDICATIONS and CONTRAINDICATIONS

I. Safety Guidelines and Possible Contraindications

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [60], the ACR Manual on MR Safety [61], and the ACR Manual on Contrast Media [62]

A. Imaging pregnant patients, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [63].

   Present data have not conclusively documented any deleterious effects of MRI at 1.5T or 3T on the developing fetus [64-76]. Therefore, no special consideration is recommended for any trimester in pregnancy. Pregnant patients can undergo MR scans at any stage of pregnancy if, in the determination of a level 2 MR personnel-designated radiologist [77], the risk-benefit ratio to the patient warrants that the study be performed. The radiologist should review the indications and document them in the radiology report or the patient's medical record.

   There are theoretical radiofrequency power considerations that are greater at long exposure times and at a higher specific absorption rate [78, 79]. Radiologists should be cognizant of the increased power deposition typically accompanying some higher field studies and ensure that they do not exceed established guidelines.

B. MRI contrast agents should not be routinely administered in fetal MRIs.

There are no documented fetal indications for the use of MRI contrast. Please refer to the ACR Manual on Contrast Media for further discussion of contrast administration in pregnancy [62].

For the unusual circumstance in which contrast is being contemplated, the decision to administer contrast must be made on a case-by-case basis by the covering level 2 MR personnel-designated attending radiologist in conjunction with the referring health care practitioner who will assess the risk-benefit ratio for that particular patient. A well-documented and thoughtful risk-benefit analysis should accompany the decision to administer a gadolinium-based MR contrast agent to pregnant patients. This analysis can defend a decision to administer the contrast agent based on overwhelming potential benefits to the fetus, outweighing the theoretical but potentially real risks of long-term exposure of the developing fetus to free gadolinium ions.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [60].

Individuals interpreting fetal MRI should be familiar with both fetal and neonatal diagnoses because these knowledge bases overlap but can differ, both from each other and from those of the older pediatric and adult populations.

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for fetal MRI should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient’s clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

The supervising physician must understand the indications, risks, and benefits of the examination and alternative imaging procedures. The physician should be familiar with relevant ancillary studies that the patient may have undergone. The physician performing MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The supervising physician must also understand the pulse sequences to be used and their effect on the appearance of the images, including the potential generation of image artifacts. Standard imaging protocols may be established and varied case-by-case when necessary. These protocols should be reviewed and updated periodically.

Documentation that satisfies medical necessity includes 1) fetal gestational age and 2) relevant history (including sonographic findings and family history of pertinent abnormalities). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

IV. SPECIFICATIONS OF THE EXAMINATION

A. Patient Selection

The physician responsible for the examination should supervise appropriate patient selection and preparation and be available in person or by phone for consultation. Patients must be screened and interviewed before the examination to exclude individuals who may be at risk from exposure to the MR environment.

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate or "conscious" sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Minimal and/or Moderate Sedation/Analgesia [80].

Knowledge of the gestational age of the pregnancy is essential for optimal timing of the examination.

Before 18 weeks gestational age, the fetal MRI study can give limited diagnostic information due to the small size of the fetus and fetal movement. If the examination is limited by early gestational age, it may need to be repeated later. The need for early diagnosis should be balanced against the advantages of improved resolution later in pregnancy, with the choice dependent on the anomalies to be assessed.

IV. SPECIFICATIONS OF THE EXAMINATION

B. Facility Requirements

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be regularly monitored for inventory and drug expiration dates.

The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

IV. SPECIFICATIONS OF THE EXAMINATION

C. Examination Technique

Depending on the size of the uterus and fetal area of interest, a torso or cardiac phased array surface coil is placed over the gravid uterus. A body coil can be used if the patient does not fit into the magnet with a surface coil. The patient lies supine or in the left lateral decubitus position. The foot-first position helps minimize claustrophobia. Maternal sedation is not necessary in the vast majority of cases. Scout images orthogonal to the gravid uterus can be performed.

Fetal MRI single-shot acquisition sequences or other rapid acquisition sequences are employed to limit the effects of fetal motion. Sequences may need to be repeated if motion degrades the image of the region of interest. A T2-weighted spin-echo single-shot sequence reveals excellent anatomy. Fast acquisition T1-weighted images with gradient-echo sequences are less anatomically discriminating but help to define certain fetal tissue or fluid characteristics, such as fat, hemorrhage, liver, and meconium in the bowel. It is preferable to have T1-weighted fast gradient-echo sequences performed during a breath hold or using the respiratory trigger technique. Steady-state free precession (SSFP) sequences, Fast Imaging Employing Steady-state Acquisition (FIESTA), TrueFISP (fast imaging with steady-state precession), balance fast field echo, hydrography, diffusion-weighted imaging (DWI) or diffusion-tensor imaging, echo planar (EPI), and cine [81] imaging can also be helpful sequences.

FOV (and corresponding choice of matrix and any phase-encoding oversampling) should be tailored to fetal (and maternal) size. Overlap of maternal onto maternal anatomy ("wrap-around" or spatial misregistration artifact) is acceptable if fetal structures are well visualized. A spatial resolution in the range of 1.5-mm pixel size (or better) is highly desirable to accurately depict of most anatomic structures (eg, 35 FOV with 256 × 192 matrix). On DWI sequences, resolution of 2.0-mm pixel size is usually adequate.

1. Fetal brain
   Imaging sequences should include axial, coronal, and sagittal single-shot T2-weighted images of the fetal brain. Optimal slice thickness is 3–4 mm to balance spatial resolution and achieve high signal-to noise

ratios, but thinner slices of 2 –3 mm may be successful. A high echo time value (160-240) can help optimize evaluation of the brain parenchyma. The fast T1 gradient-echo sequence should be performed in the coronal or axial plane if there is suspicion of fat or hemorrhage. The use of DWI to evaluate metabolic or ischemic processes and EPI to evaluate for hemorrhage may be performed as needed [82-84].

2. Fetal spine
   Imaging sequences should include axial, coronal, and sagittal single-shot T2-weighted or fast imaging with steady-state images of the fetal spine. Optimal slice thickness is 2 to 3 mm, but, in some patients, a 4- to 5-mm slice thickness may be needed because of signal-to-noise consideration. Additional sequences are rarely indicated in the spine evaluation but may include EPI as noted above regarding brain evaluation. A fast T1 gradient-echo sequence may be performed if there is suspicion of a fat-containing lesion.

3. Fetal face and neck
   Imaging sequences should include axial, coronal, and sagittal single-shot T2-weighted images of the fetal face and neck. Axial and coronal fast imaging with steady-state images can help delineate facial bone structures. A slice thickness of up to 5 mm should be used with knowledge of signal-to-noise considerations, with earlier gestational age fetuses having thinner slices. A fast T1 gradient-echo sequence should be performed in the appropriate plane if there is suspicion of fat or hemorrhage.
   Repetitive sagittal images, including real-time cine, can be helpful to visualize fluid in the oropharynx if a lesion of the palate or proximal esophagus is suspected.

4. Fetal thorax
   Imaging sequences should include axial, coronal, and sagittal single-shot T2-weighted images of the fetal thorax. The slice thickness should be up to 5 mm. A fast T1 gradient-echo sequence can be performed in the coronal or sagittal plane to evaluate the liver and meconium in cases of congenital diaphragmatic hernia. SSFP sequences (FIESTA, TrueFISP) and cine images [85] can be used to refine assessment of the heart and vascular masses.

5. Fetal abdomen
   Imaging sequences should include axial, coronal, and sagittal single-shot T2-weighted images of the fetal abdomen. The slice thickness should be up to 5 mm. The fast T1 gradient-echo sequence can be performed in the coronal or sagittal plane to evaluate the liver, meconium, fat, or hemorrhage. DWI may be used to identify renal tissue as needed. T2*gradient recalled echo GRE imaging can be used to screen for hemochromatosis [11, 86].

6. Fetal volumetry
   Various studies have established MRI-derived volumes and equations for weight [42, 87-92]. The most commonly used are lung volumes to predict hypoplasia. Fetal weight has also been estimated. The technique for calculating volumes by MRI involves tracing the boundaries of the organ/region of interest on consecutive MRI images to determine cross-sectional areas, then multiplying by slice thickness. The slice thickness should be 3 to 4 mm with no gap. Volume assessments should be reserved for specific indications.

7. Dynamic imaging
   Studies have demonstrated the utility of multisection balanced steady-state free precession cine sequences to assess fetal limb motion, swallowing, breathing, and cardiac motion [93-96].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [97].

Specific policies and procedures related to MRI safety should be in place with documentation that is updated annually and compiled under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with the MRI examination of the patient as well as to others in the immediate area. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination.

VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MR) Imaging Equipment [98].

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of the magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

VII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

ACKNOWLEDGEMENTS

This practice parameter was developed according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Practice Parameters – Pediatric Imaging of the ACR Commission on Pediatric Radiology in collaboration with the SPR.

Writing Committee – members represent their societies in the initial and final revision of this practice parameter

ACR
Lai, Hollie A MD, Chair
Lala, Shailee V MD
Noda, Sakura MD

SPR
Chapman, Teresa MD
Cohen, Harris L MD
Desoky, Sarah M MD
Mahdi, Eman MD
Nagaraj, Usha MD
Teixeira, Sara Reis MD, PhD

Committee on Practice Parameters – Pediatric Imaging
(ACR Committee responsible for sponsoring the draft through the process)

Amodio, John B MD, Chair
Betz, Bradford W MD
Blumfield, Einat MD
Goldman-Yassen, Adam MD
Lala, Shailee V MD
Laufer, Adina MD
Li, Arleen MD
Noda, Sakura MD
Trout, Andrew T MD
Alizai, Hamza MD
Bhimaniya, Sudhir X MBBS, MD
Collard, Michael MD
Lai, Hollie A MD
Lasiecka, Zofia M MD, PhD
Levin, Terry L MD
Maloney, John A MD
Shah, Summit MD
Vatsky, Seth DO

Committee on Practice Parameters and Technical Standards
(ACR Committee responsible for sponsoring the draft through the process)

Caplin, Drew M MD, Chair

Bulas, Dorothy I MD, Chair, Commission on Pediatric Radiology
Larson, David B MBA, MD, Chair, Commission on Quality and Safety

Comments Reconciliation Committee

Edmonson, Heidi A PhD - CSC, Co-Chair	Prosper, Ashley MD - CSC, Chair
Amodio, John B MD	Bulas, Dorothy I MD
Caplin, Drew M MD	Chapman, Teresa MD
Cohen, Harris L MD	Desoky, Sarah M MD
Lai, Hollie A MD	Lala, Shailee V MD
Larson, David B MBA, MD	Mahdi, Eman MD
Nagaraj, Usha MD	Noda, Sakura MD
Teixeira, Sara Reis MD, PhD	

REFERENCES

1. Breysem L, Bosmans H, Dymarkowski S, et al. The value of fast MR imaging as an adjunct to ultrasound in prenatal diagnosis. Eur Radiol. 2003 Jul;13(7):1538-48.
2. Frates MC, Kumar AJ, Benson CB, Ward VL, Tempany CM. Fetal anomalies: comparison of MR imaging and US for diagnosis. Radiology. 2004;232(2):398-404.
3. Glenn OA, Goldstein RB, Li KC, et al. Fetal magnetic resonance imaging in the evaluation of fetuses referred for sonographically suspected abnormalities of the corpus callosum. J Ultrasound Med. 2005 Jun;24(6):791-804.
4. Levine D, Barnes PD, Edelman RR. Obstetric MR imaging. Radiology. 1999 Jun;211(3):609-17.
5. Quinn TM, Hubbard AM, Adzick NS. Prenatal magnetic resonance imaging enhances fetal diagnosis. J Pediatr Surg. 1998 Apr;33(4):553-8.
6. Twickler DM, Magee KP, Caire J, Zaretsky M, Fleckenstein JL, Ramus RM. Second-opinion magnetic resonance imaging for suspected fetal central nervous system abnormalities. Am J Obstet Gynecol. 2003 Feb;188(2):492-6.
7. Chapman T, Alazraki AL, Eklund MJ. A survey of pediatric diagnostic radiologists in North America: current practices in fetal magnetic resonance imaging. Pediatr Radiol. 2018 Dec;48(13):1924-1935.
8. Griffiths PD, Bradburn M, Campbell MJ, et al. Use of MRI in the diagnosis of fetal brain abnormalities in utero (MERIDIAN): a multicentre, prospective cohort study. Lancet. 2017 Feb 04;389(10068):S0140-6736(16)31723-8.
9. Avni FE, Guibaud L, Robert Y, et al. MR imaging of fetal sacrococcygeal teratoma: diagnosis and assessment. AJR Am J Roentgenol. 2002 Jan;178(1):179-83.
10. Cassart M, Massez A, Metens T, et al. Complementary role of MRI after sonography in assessing bilateral urinary tract anomalies in the fetus. AJR Am J Roentgenol. 2004 Mar;182(3):689-95.
11. Coakley FV, Hricak H, Filly RA, Barkovich AJ, Harrison MR. Complex fetal disorders: effect of MR imaging on management--preliminary clinical experience. Radiology. 1999 Dec;213(3):691-6.
12. 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 May;13(5):327-34.
13. Levine D, Barnes PD, Madsen JR, Abbott J, Mehta T, Edelman RR. Central nervous system abnormalities assessed with prenatal magnetic resonance imaging. Obstet Gynecol. 1999 Dec;94(6):1011-9.
14. Levine D, Barnes P, Korf B, Edelman R. Tuberous sclerosis in the fetus: second-trimester diagnosis of subependymal tubers with ultrafast MR imaging. AJR Am J Roentgenol. 2000 Oct;175(4):1067-9.
15. Hubbard AM, States LJ. Fetal magnetic resonance imaging. Top Magn Reson Imaging. 2001 Apr;12(2):93-103.
16. Whitby E, Paley MN, Davies N, Sprigg A, Griffiths PD. Ultrafast magnetic resonance imaging of central nervous system abnormalities in utero in the second and third trimester of pregnancy: comparison with ultrasound. BJOG. 2001 May;108(5):519-26.
17. Guo WY, Chang CY, Ho DM, et al. A comparative MR and pathological study on fetal CNS disorders. Childs Nerv Syst. 2001 Sep;17(9):512-8.
18. Bouchard S, Davey MG, Rintoul NE, Walsh DS, Rorke LB, Adzick NS. Correction of hindbrain herniation and anatomy of the vermis after in utero repair of myelomeningocele in sheep. J Pediatr Surg. 2003 Mar;38(3):451-8; discussion 451-8.
19. Resta M, Greco P, D'Addario V, et al. Magnetic resonance imaging in pregnancy: study of fetal cerebral malformations. Ultrasound Obstet Gynecol. 1994 Jan 01;4(1):7-20.
20. Adamsbaum C, Moutard ML, André C, et al. MRI of the fetal posterior fossa. Pediatr Radiol. 2005 Feb;35(2):124-40.

21. Glenn OA, Norton ME, Goldstein RB, Barkovich AJ. Prenatal diagnosis of polymicrogyria by fetal magnetic resonance imaging in monochorionic cotwin death. J Ultrasound Med. 2005 May;24(5):711-6.
22. Ghai S, Fong KW, Toi A, Chitayat D, Pantazi S, Blaser S. Prenatal US and MR imaging findings of lissencephaly: review of fetal cerebral sulcal development. Radiographics. 2006;26(2):389-405.
23. Limperopoulos C, Robertson RL, Estroff JA, et al. Diagnosis of inferior vermian hypoplasia by fetal magnetic resonance imaging: potential pitfalls and neurodevelopmental outcome. Am J Obstet Gynecol. 2006 Apr;194(4):1070-6.
24. Tilea B, Delezoide AL, Khung-Savatovski S, et al. Comparison between magnetic resonance imaging and fetopathology in the evaluation of fetal posterior fossa non-cystic abnormalities. Ultrasound Obstet Gynecol. 2007 Jun;29(6):651-9.
25. Benacerraf BR, Shipp TD, Bromley B, Levine D. What does magnetic resonance imaging add to the prenatal sonographic diagnosis of ventriculomegaly?. J Ultrasound Med. 2007 Nov;26(11):1513-22.
26. Dinh DH, Wright RM, Hanigan WC. The use of magnetic resonance imaging for the diagnosis of fetal intracranial anomalies. Childs Nerv Syst. 1990 Jun;6(4):212-5.
27. Revel MP, Pons JC, Lelaidier C, et al. Magnetic resonance imaging of the fetus: a study of 20 cases performed without curarization. Prenat Diagn. 1993 Sep;13(9):775-99.
28. Okamura K, Murotsuki J, Sakai T, Matsumoto K, Shirane R, Yajima A. Prenatal diagnosis of lissencephaly by magnetic resonance image. Fetal Diagn Ther. 1993;8(1):56-9.
29. Sonigo P, Elmaleh A, Fermont L, Delezoíde AL, Mirlesse V, Brunelle F. Prenatal MRI diagnosis of fetal cerebral tuberous sclerosis. Pediatr Radiol. 1996;26(1):1-4.
30. Levine D, Barnes PD, Madsen JR, Li W, Edelman RR. Fetal central nervous system anomalies: MR imaging augments sonographic diagnosis. Radiology. 1997;204(3):635-642.
31. Sonigo PC, Rypens FF, Carteret M, Delezoide AL, Brunelle FO. MR imaging of fetal cerebral anomalies. Pediatr Radiol. 1998 Apr;28(4):212-22.
32. d'Ercole C, Girard N, Cravello L, et al. Prenatal diagnosis of fetal corpus callosum agenesis by ultrasonography and magnetic resonance imaging. Prenat Diagn. 1998 Mar;18(3):247-53.
33. Greco P, Resta M, Vimercati A, et al. Antenatal diagnosis of isolated lissencephaly by ultrasound and magnetic resonance imaging. Ultrasound Obstet Gynecol. 1998 Oct;12(4):276-9.
34. de Laveaucoupet J, Audibert F, Guis F, et al. Fetal magnetic resonance imaging (MRI) of ischemic brain injury. Prenat Diagn. 2001 Sep;21(9):729-36.
35. Brunel H, Girard N, Confort-Gouny S, et al. Fetal brain injury. J Neuroradiol. 2004 Mar;31(2):123-37.
36. Okamura M, Kurauchi O, Itakura A, Naganawa S, Watanabe Y, Mizutani S. Fetal sacrococcygeal teratoma visualized by ultra-fast T2 weighted magnetic resonance imaging. Int J Gynaecol Obstet. 1999 May;65(2):191-3.
37. Mangels KJ, Tulipan N, Tsao LY, Alarcon J, Bruner JP. Fetal MRI in the evaluation of intrauterine myelomeningocele. Pediatr Neurosurg. 2000 Mar;32(3):124-31.
38. Beuls EA, Vanormelingen L, van Aalst J, et al. In vitro high-field magnetic resonance imaging-documented anatomy of a fetal myelomeningocele at 20 weeks' gestation. A contribution to the rationale of intrauterine surgical repair of spina bifida. J Neurosurg. 2003 Mar;98(2 Suppl):210-4.
39. Hedrick HL, Flake AW, Crombleholme TM, et al. Sacrococcygeal teratoma: prenatal assessment, fetal intervention, and outcome. J Pediatr Surg. 2004 Mar;39(3):430-8; discussion 430-8.
40. Glenn OA, Barkovich J. Magnetic resonance imaging of the fetal brain and spine: an increasingly important tool in prenatal diagnosis: part 2. AJNR Am J Neuroradiol. 2006 Oct;27(9):1807-14.
41. Fitzmorris-Glass R, Mattrey RF, Cantrell CJ. Magnetic resonance imaging as an adjunct to ultrasound in oligohydramnios. Detection of sirenomelia. J Ultrasound Med. 1989 Mar;8(3):159-62.
42. Kirkinen P, Partanen K, Merikanto J, Ryynänen M, Haring P, Heinonen K. Ultrasonic and magnetic resonance imaging of fetal sacrococcygeal teratoma. Acta Obstet Gynecol Scand. 1997 Nov;76(10):917-22.
43. Bekker MN, van Vugt JM. The role of magnetic resonance imaging in prenatal diagnosis of fetal anomalies. Eur J Obstet Gynecol Reprod Biol. 2001 Jun;96(2):173-8.
44. Kathary N, Bulas DI, Newman KD, Schonberg RL. MRI imaging of fetal neck masses with airway compromise: utility in delivery planning. Pediatr Radiol. 2001 Oct;31(10):727-31.
45. Ogura T, Hamada H, Obata-Yasuoka M, et al. Antepartum assessment of fetal cystic lymphangioma by magnetic resonance imaging. Gynecol Obstet Invest. 2002;53(4):237-9.
46. Tsuda H, Matsumoto M, Yamamoto K, et al. Usefulness of ultrasonography and magnetic resonance imaging for prenatal diagnosis of fetal teratoma of the neck. J Clin Ultrasound. 1996 May;24(4):217-9.
47. Hubbard AM. Magnetic resonance imaging of fetal thoracic abnormalities. Top Magn Reson Imaging. 2001 Feb;12(1):18-24.

48. Levine D, Barnewolt CE, Mehta TS, Trop I, Estroff J, Wong G. Fetal thoracic abnormalities: MR imaging. Radiology. 2003 Aug;228(2):379-88.
49. Matsuoka S, Takeuchi K, Yamanaka Y, Kaji Y, Sugimura K, Maruo T. Comparison of magnetic resonance imaging and ultrasonography in the prenatal diagnosis of congenital thoracic abnormalities. Fetal Diagn Ther. 2003;18(6):447-53.
50. Ruano R, Lazar DA, Cass DL, et al. Fetal lung volume and quantification of liver herniation by magnetic resonance imaging in isolated congenital diaphragmatic hernia. Ultrasound Obstet Gynecol. 2014 Jun;43(6):662-9.
51. Zamora IJ, Olutoye OO, Cass DL, et al. Prenatal MRI fetal lung volumes and percent liver herniation predict pulmonary morbidity in congenital diaphragmatic hernia (CDH). J Pediatr Surg. 2014 May;49(5):S0022-3468(14)00148-1.
52. Coakley FV. Role of magnetic resonance imaging in fetal surgery. Top Magn Reson Imaging. 2001 Feb;12(1):39-51.
53. Hu LS, Caire J, Twickler DM. MR findings of complicated multifetal gestations. Pediatr Radiol. 2006 Jan;36(1):76-81.
54. Mota R, Ramalho C, Monteiro J, et al. Evolving indications for the EXIT procedure: the usefulness of combining ultrasound and fetal MRI. Fetal Diagn Ther. 2007;22(2):107-11.
55. Hayakawa M, Seo T, Itakua A, et al. The MRI findings of the right-sided fetal lung can be used to predict postnatal mortality and the requirement for extracorporeal membrane oxygenation in isolated left-sided congenital diaphragmatic hernia. Pediatr Res. 2007 Jul;62(1):93-7.
56. Hubbard AM, Crombleholme TM, Adzick NS. Prenatal MRI evaluation of giant neck masses in preparation for the fetal exit procedure. Am J Perinatol. 1998 Apr;15(4):253-7.
57. Grant RA, Heuer GG, Carrión GM, et al. Morphometric analysis of posterior fossa after in utero myelomeningocele repair. J Neurosurg Pediatr. 2011 Apr;7(4):362-8.
58. Ali K, Grigoratos D, Cornelius V, Davenport M, Nicolaides K, Greenough A. Outcome of CDH infants following fetoscopic tracheal occlusion - influence of premature delivery. J Pediatr Surg. 2013 Sep;48(9):S0022-3468(13)00133-4.
59. Zaghal AA, Hussain HK, Berjawi GA. MRI evaluation of the placenta from normal variants to abnormalities of implantation and malignancies. J Magn Reson Imaging. 2019 Dec;50(6):1702-1717.
60. American College of Radiology. ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI). Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=146+&releaseId=2
61. American College of Radiology. ACR Committee on MR Safety. 2024 ACR Manual on MR Safety. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Radiology-Safety/Manual-on-MR-Safety.pdf.
62. American College of Radiology. ACR Committee on Drugs and Contrast Media. Manual on Contrast Media. Available at: https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Contrast-Manual.
63. American College of Radiology. ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation. Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=23+&releaseId=2.
64. Clements H, Duncan KR, Fielding K, Gowland PA, Johnson IR, Baker PN. Infants exposed to MRI in utero have a normal paediatric assessment at 9 months of age. Br J Radiol. 2000 Feb;73(866):190-4.
65. Chew S, Ahmadi A, Goh PS, Foong LC. The effects of 1.5T magnetic resonance imaging on early murine in-vitro embryo development. J Magn Reson Imaging. 2001 Mar;13(3):417-20.
66. Levine D, Zuo C, Faro CB, Chen Q. Potential heating effect in the gravid uterus during MR HASTE imaging. J Magn Reson Imaging. 2001 Jun;13(6):856-61.
67. Kok RD, de Vries MM, Heerschap A, van den Berg PP. Absence of harmful effects of magnetic resonance exposure at 1.5 T in utero during the third trimester of pregnancy: a follow-up study. Magn Reson Imaging. 2004 Jul;22(6):851-4.
68. Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. Radiology. 2004 Sep;232(3):635-52.
69. Merkle EM, Dale BM, Paulson EK. Abdominal MR imaging at 3T. Magn Reson Imaging Clin N Am. 2006 Feb;14(1):17-26.
70. Ray JG, Vermeulen MJ, Bharatha A, Montanera WJ, Park AL. Association Between MRI Exposure During Pregnancy and Fetal and Childhood Outcomes. JAMA. 2016;316(9):952-961.
71. Chartier AL, Bouvier MJ, McPherson DR, Stepenosky JE, Taysom DA, Marks RM. The Safety of Maternal and Fetal MRI at 3 T. AJR Am J Roentgenol. 2019 Nov;213(5):1170-1173.
72. Schwartz JL, Crooks LE. NMR imaging produces no observable mutations or cytotoxicity in mammalian cells.

AJR Am J Roentgenol. 1982 Sep;139(3):583-5.
73. Glover P, Hykin J, Gowland P, Wright J, Johnson I, Mansfield P. An assessment of the intrauterine sound intensity level during obstetric echo-planar magnetic resonance imaging. Br J Radiol. 1995 Oct;68(814):1090-4.
74. Baker PN, Johnson IR, Harvey PR, Gowland PA, Mansfield P. A three-year follow-up of children imaged in utero with echo-planar magnetic resonance. Am J Obstet Gynecol. 1994 Jan;170(1 Pt 1):32-3.
75. Kanal E, Gillen J, Evans JA, Savitz DA, Shellock FG. Survey of reproductive health among female MR workers. Radiology. 1993 May;187(2):395-9.
76. Myers C, Duncan KR, Gowland PA, Johnson IR, Baker PN. Failure to detect intrauterine growth restriction following in utero exposure to MRI. Br J Radiol. 1998 May;71(845):549-51.
77. Expert Panel on MR Safety, Kanal E, Barkovich AJ, et al. ACR guidance document on MR safe practices: 2013. J Magn Reson Imaging. 37(3):501-30, 2013 Mar.
78. Gowland PA, De Wilde J. Temperature increase in the fetus due to radio frequency exposure during magnetic resonance scanning. Phys Med Biol. 2008 Nov 07;53(21):L15-8.
79. Hand JW, Li Y, Hajnal JV. Numerical study of RF exposure and the resulting temperature rise in the foetus during a magnetic resonance procedure. Phys Med Biol. 2010 Feb 21;55(4):913-30.
80. American College of Radiology. ACR–SIR Practice Parameter For Minimal and/or Moderate Sedation/Analgesia. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=95+&releaseId=2
81. van Amerom JFP, Lloyd DFA, Price AN, et al. Fetal cardiac cine imaging using highly accelerated dynamic MRI with retrospective motion correction and outlier rejection. Magn Reson Med. 2018 Jan;79(1):327-338.
82. Baldoli C, Righini A, Parazzini C, Scotti G, Triulzi F. Demonstration of acute ischemic lesions in the fetal brain by diffusion magnetic resonance imaging. Ann Neurol. 2002 Aug;52(2):243-6.
83. Agid R, Lieberman S, Nadjari M, Gomori JM. Prenatal MR diffusion-weighted imaging in a fetus with hemimegalencephaly. Pediatr Radiol. 2006 Feb;36(2):138-40.
84. Brugger PC, Stuhr F, Lindner C, Prayer D. Methods of fetal MR: beyond T2-weighted imaging. Eur J Radiol. 2006 Feb;57(2):172-81.
85. van Amerom JFP, Lloyd DFA, Deprez M, et al. Fetal whole-heart 4D imaging using motion-corrected multi-planar real-time MRI. Magn Reson Med. 2019 Sep;82(3):1055-1072.
86. Martí-Bonmatí L, Baamonde A, Poyatos CR, Monteagudo E. Prenatal diagnosis of idiopathic neonatal hemochromatosis with MRI. Abdom Imaging. 1994;19(1):55-6.
87. Uotila J, Dastidar P, Heinonen T, Ryymin P, Punnonen R, Laasonen E. Magnetic resonance imaging compared to ultrasonography in fetal weight and volume estimation in diabetic and normal pregnancy. Acta Obstet Gynecol Scand. 2000 Apr;79(4):255-9.
88. Kok RD, van den Berg PP, van den Bergh AJ, Nijland R, Heerschap A. Maturation of the human fetal brain as observed by 1H MR spectroscopy. Magn Reson Med. 2002 Oct;48(4):611-6.
89. Zaretsky MV, Reichel TF, McIntire DD, Twickler DM. Comparison of magnetic resonance imaging to ultrasound in the estimation of birth weight at term. Am J Obstet Gynecol. 2003 Oct;189(4):1017-20.
90. Zaretsky M, Ramus R, McIntire D, Magee K, Twickler DM. MRI calculation of lung volumes to predict outcome in fetuses with genitourinary abnormalities. AJR Am J Roentgenol. 2005 Nov;185(5):1328-34.
91. Baker PN, Johnson IR, Gowland PA, et al. Fetal weight estimation by echo-planar magnetic resonance imaging. Lancet. 1994 Mar 12;343(8898):644-5.
92. Gong QY, Roberts N, Garden AS, Whitehouse GH. Fetal and fetal brain volume estimation in the third trimester of human pregnancy using gradient echo MR imaging. Magn Reson Imaging. 1998 Apr;16(3):235-40.
93. Salomon LJ, Sonigo P, Ou P, Ville Y, Brunelle F. Real-time fetal magnetic resonance imaging for the dynamic visualization of the pouch in esophageal atresia. Ultrasound Obstet Gynecol. 2009 Oct;34(4):471-4.
94. Hayat TT, Nihat A, Martinez-Biarge M, et al. Optimization and initial experience of a multisection balanced steady-state free precession cine sequence for the assessment of fetal behavior in utero. AJNR Am J Neuroradiol. 2011 Feb;32(2):331-8.
95. Houshmand G, Hosseinzadeh K, Ozolek J. Prenatal magnetic resonance imaging (MRI) findings of a foregut duplication cyst of the tongue: value of real-time MRI evaluation of the fetal swallowing mechanism. J Ultrasound Med. 2011 Jun;30(6):843-50.
96. Roy CW, Seed M, van Amerom JF, et al. Dynamic imaging of the fetal heart using metric optimized gating. Magn Reson Med. 2013 Dec;70(6):1598-607.
97. American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at https://gravitas.acr.org/PPTS/GetDocumentView?docId=74+&releaseId=2
98. American College of Radiology. ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance (MR) Imaging Equipment. Available at

*Practice parameters and technical standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

<u>Development Chronology for this Practice Parameter</u>
2010 (Resolution 13)
Amended 2014 (Resolution 39)
Revised 2015 (Resolution 11)
Revised 2020 (Resolution 45)
Amended 2023 (Resolution 2c)
Revised 2025 (Resolution 26)