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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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also 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 sole 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, ___ N.W.2d ___ (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 well or completely assessed by sonography [1-6]. 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 screening modality of choice 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 misleading 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

When an anomaly is visualized by ultrasound but the etiology remains uncertain due to the nature of the abnormality, or due to sonographic limitations from fetal lie, maternal body habitus, oligohydramnios, or small field of view, MRI can add additional information that may impact parental counseling, management, and delivery planning [7-15]. Primary indications for MRI include, but are not limited to, the following:

A. Brain and Spine

1. Congenital anomalies of the brain or skull suspected or not adequately assessed by sonography [3,16-39] include, but are not limited to, the following:
    a. Ventriculomegaly
    b. Agenesis of the corpus callosum
    c. Abnormalities of the cavum of the 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 [40,41] include, but are not limited to, the following:
    a. Vascular anomalies
    b. Hydranencephaly
    c. Infarctions
    d. Hemorrhage
    e. Monochorionic twin pregnancy complications

3. Congenital anomalies of the spine suspected or not adequately assessed by sonography [7,11,12,27,42-46] include, but are not limited to, the following:
    a. Neural tube defects
    b. Sacrococcygeal teratomas
    c. Caudal regression/sacral agenesis
    d. Sirenomelia
    e. Vertebral anomalies

B. Skull, Face, and Neck

1. Masses of the face and neck suspected or not adequately assessed by sonography [9,31,47-50] include, but are not limited to, the following:
    a. Vascular or lymphatic anomalies
    b. Goiter
    c. Teratomas
    d. Facial clefts

2. MRI can be helpful in assessing airway obstruction that may impact parental counseling, prenatal management, delivery planning, and postnatal therapy [9,47-50].

C. Thorax

1. Thoracic pathology suspected or not adequately assessed by sonography [51-53] include, but is not limited to, the following:
    a. Congenital lung malformations (including pulmonary airway malformations, bronchogenic cyst, sequestration, and congenital lobar overinflation).
    b. Congenital diaphragmatic hernia
    c. Effusions
    d. Mediastinal masses
    e. Assessment for esophageal atresia

2. MRI can be used for volumetric assessment of fetal lung parenchyma [54-58], particularly in those fetuses at risk for pulmonary hypoplasia secondary to diaphragmatic hernia, oligohydramnios, chest mass, or skeletal dysplasias.

D. Abdominal, Retroperitoneal, and Pelvic

1. Determining the etiology of an abdominal-pelvic cyst
2. Assessing the size and location of tumors such as hemangiomas, neuroblastomas, sacrococcygeal teratomas, and suprarenal or renal masses
3. Assessing complex genitourinary anomalies, such as bladder exstrophy, cloacal malformation or exstrophy, or complex lower urinary tract obstruction such as prune belly syndrome
4. Assessing renal anomalies in cases of severe oligohydramnios
5. Diagnosing bowel anomalies such as anorectal malformations, or complex bowel obstructions such as with megacystis microcolon hypoperistalsis syndrome [59]

E. Complications of Monochorionic Twins

Delineation of vascular anatomy prior to laser treatment of twins, assessment of morbidity after death of a monochorionic co-twin, and improved delineation of anatomy in conjoined twins are areas where MRI may be useful [60-62] due to its high spatial resolution, contrast resolution, large field of view, and multiplanar imaging

capabilities. This additional information may impact parental counseling, delivery planning, and postnatal management.

F. Fetal Surgery Assessment

When an abnormality is identified that may benefit from fetal surgery, MRI is a useful adjunct in confirming the diagnosis and planning potential surgical options [11,63-67]. It can also be utilized in assessing the fetal brain both before and after surgical interventions [68].

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

1. Meningomyelocele
2. Sacrococcygeal teratomas
3. Processes obstructing the airway, such as a neck mass or congenital high airway obstruction
4. Complications of monochorionic twins needing surgery
5. Chest masses [69]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [70].

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

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [70], the ACR Guidance Document on MR Safe Practices [71], and the ACR Manual on Contrast Media [72].

A. Pregnant patients. For additional information please see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [73].

Present data have not conclusively documented any deleterious effects of MR imaging at 1.5T on the developing fetus [74-84]. Therefore, no special consideration is recommended for any trimester in pregnancy. Pregnant patients can be accepted to undergo MR scans at any stage of pregnancy if, in the determination of a level 2 MR personnel-designated attending radiologist [71], 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 RF power considerations that are greater at long exposure times and at a higher specific absorption rate (SAR) [85,86]. Radiologists should be cognizant of the increased power deposition typically accompanying some higher field studies and ensure that they do not exceed established guidelines [87,88].

B. MRI contrast agents should not be routinely administered to pregnant patients. Gadolinium is a pregnancy class C drug, meaning that the safety in humans has not been proven. This document describes fetal MRI, but for completeness we will discuss use of gadolinium contrast agents in pregnancy.

There are no documented fetal indications for the use of MRI contrast, but there may be rare instances where contrast is considered potentially helpful in assessing maternal anatomy or pathology.

The decision to administer contrast must be made on a case-by-case basis by the covering level 2 MR personnel-designated attending radiologist who will assess the risk-benefit ratio for that particular patient. The decision to administer a gadolinium-based MR contrast agent to pregnant patients should be accompanied by a well-documented and thoughtful risk-benefit analysis. This analysis should be able to defend a decision to administer the contrast agent based on overwhelming potential benefit to the patient or fetus, outweighing the theoretic but potentially real risks of long-term exposure of the developing fetus to free gadolinium ions.

Studies have demonstrated that gadolinium-based MR contrast agents pass through the placental barrier and enter the fetal circulation [89]. From there, they are filtered in the fetal kidneys and then excreted into the amniotic fluid. In this location the gadolinium-chelate molecules are in a relatively protected space and may remain in this amniotic fluid for an indeterminate amount of time before finally being reabsorbed and eliminated. As with any equilibrium situation involving any dissociation constant, the longer the chelate molecule remains in this space, the greater the potential for dissociation of the potentially toxic gadolinium ion from its chelate molecule. It is unclear what impact such free gadolinium ions might have if they were to be released in any quantity in the amniotic fluid. Certainly, deposition into the developing fetus would raise concerns of possible secondary adverse effects. The risk to the fetus with administration of gadolinium-based MR contrast agents remains unknown and may be harmful.

C. It is suggested that pregnant patients undergoing an MRI examination have a discussion with the referring or supervising physician concerning potential risks versus benefits of performing a fetal MRI. At this stage, the preponderance of research studies have failed to discover any reproducible harmful effects of exposure of the mother or developing fetus to the 3T or weaker magnetic fields used in the routine clinical MR imaging process. However, far less is known about the potential effects, if any, of the time varying gradient and/or radiofrequency magnetic fields used during actual scanning to potentiate image generation. Furthermore, the considerable majority of our data to date comes from research involving magnetic fields of 1.5T or less. Thus, we have less information regarding the potential safety issues that may exist at higher field strength systems. These theoretical risks should be carefully balanced against the potential benefits to the patient undergoing a MR examination. A decision as to whether or not to proceed with the requested MRI study will need to be based on a thorough and thoughtful evaluation of the potential and at times unknown risks of the MR examination versus the potential benefits to the patient, as well as the risks associated with declining to do so.

V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have an understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI. 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 written or electronic request for fetal MRI examinations should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). 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)

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 on a case-by-case basis 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.

A. Patient Selection

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

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance.

Knowledge of the gestational age of the pregnancy is important for planning the examination and positioning of the surface coil.

Prior to 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 then 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. Fetal motion typically occurs constantly during the examination. However, using single-shot or other rapid acquisition techniques, slices are obtained in less than 1 second, therefore images are only degraded if motion occurs during image acquisition. Sequences may need to be repeated if motion degrades the image of the region of interest.

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 monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

C. Examination Technique

Depending on the size of the uterus and fetal area of interest, either a torso or cardiac phased array surface coil is placed over the gravid uterus. If the patient will not fit into the magnet with a surface coil, then a body coil can be used. The mother lies supine or in the left lateral decubitus position. The maternal 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. 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 bowel. It is preferable to have T1-weighted fast gradient-echo sequences performed during a breath-hold or using respiratory trigger technique. Short tau inversion recovery (STIR) images may provide improved resolution of tissue characteristics when the water contents of structures are similar. Additional sequences such as fluid attenuated inversion recovery

(FLAIR), steady-state free precession (SSFP) sequences (FIESTA, TrueFISP, bFFE), hydrography, BOLD imaging, diffusion-weighted imaging (DWI), and echo planar imaging may be performed as needed.

Field of view 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.

1. Fetal brain
   Imaging sequences should include axial, coronal, and sagittal single-shot T2-weighted images of the fetal brain. 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. The fast T1 gradient echo should be performed in the coronal or axial plane if there is suspicion of fat or hemorrhage. Additional FLAIR sequences may be done to suppress the bright signal of the cerebral spinal fluid in certain cases. The use of DWI to evaluate metabolic or ischemic processes may be performed as needed [90-92].

2. Fetal spine
   Imaging sequences should include axial, coronal, and sagittal single shot T2-weighted 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 a FLAIR or spoiled fast gradient-echo sequence 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. 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. The fast T1 gradient-echo sequence should be performed in the appropriate plane if there is suspicion of fat or hemorrhage. STIR images may provide improved resolution of tissue characteristics in masses such as teratoma or in lymphatic anomalies.

   Repetitive sagittal images, including real-time cine, may be needed 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. The 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. STIR images may provide improved resolution of tissue characteristics in lesions such congenital pulmonary airway malformations in some instances [52]. SSFP sequences (FIESTA, TrueFISP) 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 [93]. STIR images may provide improved resolution of tissue characteristics in lesions of the solid organs, such as kidneys, liver, or adrenal glands. The use of DWI to identify renal tissue may be used as needed. BOLD imaging can be used to screen for hemochromatosis [9,94].

6. Fetal volumetry
   Various studies have established MRI-derived volumes and equations for weight [12,95-100]. The most commonly used are lung volumes to predict hypoplasia. Fetal weight has also been estimated. The technique involves adding together measured areas obtained by drawing free-form regions of interest on sequences that allow complete imaging of the volume without motion-induced artifact, and multiplying by slice thickness. 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, and cardiac motion [101-104].

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [105].

VII. EQUIPMENT SPECIFICATIONS

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.

VIII. 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 *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (http://www.acr.org/guidelines).

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.

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [106].

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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;13(7):1538-1548.
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;24(6):791-804.
4. Levine D, Barnes PD, Edelman RR. Obstetric MR imaging. *Radiology.* 1999;211(3):609-617.
5. Quinn TM, Hubbard AM, Adzick NS. Prenatal magnetic resonance imaging enhances fetal diagnosis. *J Pediatr Surg.* 1998;33(4):553-558.
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;188(2):492-496.
7. Avni FE, Guibaud L, Robert Y, et al. MR imaging of fetal sacrococcygeal teratoma: diagnosis and assessment. *AJR Am J Roentgenol.* 2002;178(1):179-183.
8. 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;182(3):689-695.
9. Coakley FV, Hricak H, Filly RA, Barkovich AJ, Harrison MR. Complex fetal disorders: effect of MR imaging on management--preliminary clinical experience. *Radiology.* 1999;213(3):691-696.
10. Hata K, Hata T, Kitao M. Antenatal diagnosis of sacrococcygeal teratoma facilitated by combined use of Doppler sonography and MR imaging. *AJR Am J Roentgenol.* 1991;156(5):1115-1116.
11. Hedrick HL, Flake AW, Crombleholme TM, et al. Sacrococcygeal teratoma: prenatal assessment, fetal intervention, and outcome. *J Pediatr Surg.* 2004;39(3):430-438; discussion 430-438.
12. Kirkinen P, Partanen K, Merikanto J, Ryynanen M, Haring P, Heinonen K. Ultrasonic and magnetic resonance imaging of fetal sacrococcygeal teratoma. *Acta Obstet Gynecol Scand.* 1997;76(10):917-922.
13. Poutamo J, Vanninen R, Partanen K, Kirkinen P. Diagnosing fetal urinary tract abnormalities: benefits of MRI compared to ultrasonography. *Acta Obstet Gynecol Scand.* 2000;79(1):65-71.
14. Saguintaah M, Couture A, Veyrac C, Baud C, Quere MP. MRI of the fetal gastrointestinal tract. *Pediatr Radiol.* 2002;32(6):395-404.
15. Toma P, Lucigrai G, Marzoli A, Lituania M. Prenatal diagnosis of metastatic adrenal neuroblastoma with sonography and MR imaging. *AJR Am J Roentgenol.* 1994;162(5):1183-1184.
16. Adamsbaum C, Moutard ML, Andre C, et al. MRI of the fetal posterior fossa. *Pediatr Radiol* [Review]. 2005; 2004/11/27:124-140. Available at: http://www.ncbi.nlm.nih.gov/pubmed/15565345. Accessed 2, 35.
17. 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;26(11):1513-1522.
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;38(3):451-458; discussion 451-458.
19. 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;18(3):247-253.
20. Dinh DH, Wright RM, Hanigan WC. The use of magnetic resonance imaging for the diagnosis of fetal intracranial anomalies. *Childs Nerv Syst.* 1990;6(4):212-215.
21. 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.
22. 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;24(5):711-716.
23. Greco P, Resta M, Vimercati A, et al. Antenatal diagnosis of isolated lissencephaly by ultrasound and magnetic resonance imaging. *Ultrasound Obstet Gynecol.* 1998;12(4):276-279.
24. Guo WY, Chang CY, Ho DM, et al. A comparative MR and pathological study on fetal CNS disorders. *Childs Nerv Syst.* 2001;17(9):512-518.

25. Hubbard AM, States LJ. Fetal magnetic resonance imaging. *Top Magn Reson Imaging.* 2001;12(2):93-103.
26. 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;175(4):1067-1069.
27. 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;94(6):1011-1019.
28. 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.
29. 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;194(4):1070-1076.
30. 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):56-59.
31. Poutamo J, Vanninen R, Partanen K, Ryynanen, Kirkinen P. Magnetic resonance imaging supplements ultrasonographic imaging of the posterior fossa, pharynx and neck in malformed fetuses. *Ultrasound Obstet Gynecol.* 1999;13(5):327-334.
32. Resta M, Greco P, D'Addario V, et al. Magnetic resonance imaging in pregnancy: study of fetal cerebral malformations. *Ultrasound Obstet Gynecol.* 1994;4(1):7-20.
33. 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;13(9):775-799.
34. Simon EM, Goldstein RB, Coakley FV, et al. Fast MR imaging of fetal CNS anomalies in utero. *AJNR Am J Neuroradiol.* 2000;21(9):1688-1698.
35. Sonigo P, Elmaleh A, Fermont L, Delezoide AL, Mirlesse V, Brunelle F. Prenatal MRI diagnosis of fetal cerebral tuberous sclerosis. *Pediatr Radiol.* 1996;26(1):1-4.
36. Sonigo PC, Rypens FF, Carteret M, Delezoide AL, Brunelle FO. MR imaging of fetal cerebral anomalies. *Pediatr Radiol.* 1998;28(4):212-222.
37. Stazzone MM, Hubbard AM, Bilaniuk LT, et al. Ultrafast MR imaging of the normal posterior fossa in fetuses. *AJR Am J Roentgenol.* 2000;175(3):835-839.
38. 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;29(6):651-659.
39. 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;108(5):519-526.
40. Brunel H, Girard N, Confort-Gouny S, et al. Fetal brain injury. *J Neuroradiol.* 2004;31(2):123-137.
41. de Laveaucoupet J, Audibert F, Guis F, et al. Fetal magnetic resonance imaging (MRI) of ischemic brain injury. *Prenat Diagn.* 2001;21(9):729-736.
42. 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;98(2 Suppl):210-214.
43. Fitzmorris-Glass R, Mattrey RF, Cantrell CJ. Magnetic resonance imaging as an adjunct to ultrasound in oligohydramnios. Detection of sirenomelia. *J Ultrasound Med.* 1989;8(3):159-162.
44. 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;27(9):1807-1814.
45. Mangels KJ, Tulipan N, Tsao LY, Alarcon J, Bruner JP. Fetal MRI in the evaluation of intrauterine myelomeningocele. *Pediatr Neurosurg.* 2000;32(3):124-131.
46. 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;65(2):191-193.
47. Bekker MN, van Vugt JM. The role of magnetic resonance imaging in prenatal diagnosis of fetal anomalies. *Eur J Obstet Gynecol Reprod Biol.* 2001;96(2):173-178.

48. Kathary N, Bulas DI, Newman KD, Schonberg RL. MRI imaging of fetal neck masses with airway compromise: utility in delivery planning. *Pediatr Radiol.* 2001;31(10):727-731.
49. 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):237-239.
50. 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;24(4):217-219.
51. Hubbard AM. Magnetic resonance imaging of fetal thoracic abnormalities. *Top Magn Reson Imaging.* 2001;12(1):18-24.
52. Levine D, Barnewolt CE, Mehta TS, Trop I, Estroff J, Wong G. Fetal thoracic abnormalities: MR imaging. *Radiology.* 2003;228(2):379-388.
53. 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):447-453.
54. Barnewolt CE, Kunisaki SM, Fauza DO, Nemes LP, Estroff JA, Jennings RW. Percent predicted lung volumes as measured on fetal magnetic resonance imaging: a useful biometric parameter for risk stratification in congenital diaphragmatic hernia. *J Pediatr Surg.* 2007;42(1):193-197.
55. Gorincour G, Bouvenot J, Mourot MG, et al. Prenatal prognosis of congenital diaphragmatic hernia using magnetic resonance imaging measurement of fetal lung volume. *Ultrasound Obstet Gynecol.* 2005;26(7):738-744.
56. Ward VL, Nishino M, Hatabu H, et al. Fetal lung volume measurements: determination with MR imaging--effect of various factors. *Radiology.* 2006;240(1):187-193.
57. Williams G, Coakley FV, Qayyum A, Farmer DL, Joe BN, Filly RA. Fetal relative lung volume: quantification by using prenatal MR imaging lung volumetry. *Radiology.* 2004;233(2):457-462.
58. Lee TC, Lim FY, Keswani SG, et al. Late gestation fetal magnetic resonance imaging-derived total lung volume predicts postnatal survival and need for extracorporeal membrane oxygenation support in isolated congenital diaphragmatic hernia. *J Pediatr Surg.* 2011;46(6):1165-1171.
59. Veyrac C, Couture A, Saguintaah M, Baud C. MRI of fetal GI tract abnormalities. *Abdom Imaging.* 2004;29(4):411-420.
60. Kline-Fath BM, Calvo-Garcia MA, O'Hara SM, Crombleholme TM, Racadio JM. Twin-twin transfusion syndrome: cerebral ischemia is not the only fetal MR imaging finding. *Pediatr Radiol.* 2007;37(1):47-56.
61. Zoppini C, Vanzulli A, Kustermann A, Rizzuti T, Selicorni A, Nicolini U. Prenatal diagnosis of anatomical connections in conjoined twins by use of contrast magnetic resonance imaging. *Prenat Diagn.* 1993;13(10):995-999.
62. Jelin AC, Norton ME, Bartha AI, Fick AL, Glenn OA. Intracranial magnetic resonance imaging findings in the surviving fetus after spontaneous monochorionic cotwin demise. *Am J Obstet Gynecol.* 2008;199(4):398 e391-395.
63. Coakley FV. Role of magnetic resonance imaging in fetal surgery. *Top Magn Reson Imaging.* 2001;12(1):39-51.
64. 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;62(1):93-97.
65. Hu LS, Caire J, Twickler DM. MR findings of complicated multifetal gestations. *Pediatr Radiol.* 2006;36(1):76-81.
66. Hubbard AM, Crombleholme TM, Adzick NS. Prenatal MRI evaluation of giant neck masses in preparation for the fetal exit procedure. *Am J Perinatol.* 1998;15(4):253-257.
67. 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):107-111.
68. Grant RA, Heuer GG, Carrion GM, et al. Morphometric analysis of posterior fossa after in utero myelomeningocele repair. *J Neurosurg Pediatr.* 2011;7(4):362-368.
69. 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;48(9):1831-1836.

70. American College of Radiology. ACR practice parameter for performing and interpreting magnetic resonance imaging (MRI). Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/MRI.pdf. Accessed February 19, 2014.
71. Kanal E, Barkovich AJ, Bell C, et al. ACR guidance document on MR safe practices: 2013. *J Magn Reson Imaging.* 2013;37(3):501-530.
72. American College of Radiology. Manual on contrast media v9. Available at: http://www.acr.org/Quality-Safety/Resources/Contrast-Manual. Accessed February 14, 2014.
73. American College of Radiology. ACR-SPR practice parameter for imaging pregnant or potentially pregnant adolescents and women with ionizing radiation. 2013; Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Pregnant_Patients.pdf. Accessed October 17, 2014.
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;170(1 Pt 1):32-33.
75. 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;13(3):417-420.
76. 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;73(866):190-194.
77. 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;68(814):1090-1094.
78. Kanal E, Gillen J, Evans JA, Savitz DA, Shellock FG. Survey of reproductive health among female MR workers. *Radiology.* 1993;187(2):395-399.
79. 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;22(6):851-854.
80. Levine D, Zuo C, Faro CB, Chen Q. Potential heating effect in the gravid uterus during MR HASTE imaging. *J Magn Reson Imaging.* 2001;13(6):856-861.
81. Merkle EM, Dale BM, Paulson EK. Abdominal MR imaging at 3T. *Magn Reson Imaging Clin N Am.* 2006;14(1):17-26.
82. 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;71(845):549-551.
83. Schwartz JL, Crooks LE. NMR imaging produces no observable mutations or cytotoxicity in mammalian cells. *AJR Am J Roentgenol.* 1982;139(3):583-585.
84. Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. *Radiology.* 2004;232(3):635-652.
85. Gowland PA, De Wilde J. Temperature increase in the fetus due to radio frequency exposure during magnetic resonance scanning. *Phys Med Biol.* 2008;53(21):L15-18.
86. 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;55(4):913-930.
87. Murbach M, Cabot E, Neufeld E, et al. Local SAR enhancements in anatomically correct children and adult models as a function of position within 1.5 T MR body coil. *Prog Biophys Mol Biol.* 2011;107(3):428-433.
88. Pediaditis M, Leitgeb N, Cech R. RF-EMF exposure of fetus and mother during magnetic resonance imaging. *Phys Med Biol.* 2008;53(24):7187-7195.
89. Runge VM. Safety of approved MR contrast media for intravenous injection. *J Magn Reson Imaging.* 2000;12(2):205-213.
90. Agid R, Lieberman S, Nadjari M, Gomori JM. Prenatal MR diffusion-weighted imaging in a fetus with hemimegalencephaly. *Pediatr Radiol.* 2006;36(2):138-140.
91. 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;52(2):243-246.
92. Brugger PC, Stuhr F, Lindner C, Prayer D. Methods of fetal MR: beyond T2-weighted imaging. *Eur J Radiol.* 2006;57(2):172-181.

93. Farhataziz N, Engels JE, Ramus RM, Zaretsky M, Twickler DM. Fetal MRI of urine and meconium by gestational age for the diagnosis of genitourinary and gastrointestinal abnormalities. *AJR Am J Roentgenol.* 2005;184(6):1891-1897.
94. Marti-Bonmati L, Baamonde A, Poyatos CR, Monteagudo E. Prenatal diagnosis of idiopathic neonatal hemochromatosis with MRI. *Abdom Imaging.* 1994;19(1):55-56.
95. Baker PN, Johnson IR, Gowland PA, et al. Fetal weight estimation by echo-planar magnetic resonance imaging. *Lancet.* 1994;343(8898):644-645.
96. 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;16(3):235-240.
97. 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;48(4):611-616.
98. 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;79(4):255-259.
99. 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;185(5):1328-1334.
100. 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;189(4):1017-1020.
101. 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;32(2):331-338.
102. 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;30(6):843-850.
103. Roy CW, Seed M, van Amerom JF, et al. Dynamic imaging of the fetal heart using metric optimized gating. *Magn Reson Med.* 2013;70(6):1598-1607.
104. 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;34(4):471-474.
105. American College of Radiology. ACR practice parameter for communication of diagnostic imaging findings. 2014; Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Comm_Diag_Imaging.pdf. Accessed October 17, 2014.
106. American College of Radiology. ACR-AAPM technical standard for diagnostic medical physics performance monitoring of magnetic resonance imaging (MRI) equipment. 2014; Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/standards/MonitorMRIEquipment.pdf. Accessed October 17, 2014.

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