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GUIDELINES

ISUOG Practice Guidelines: performance of fetal magnetic resonance imaging

Clinical Standards Committee

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These guidelines are based on consensus reached between participants following a survey of current practices, conducted by ISUOG in 2014 (Appendix S1).

INTRODUCTION

Fetal magnetic resonance imaging (MRI) is an important diagnostic imaging adjunct to ultrasonography[1], particularly for the assessment of fetal brain development[2]. A survey conducted by ISUOG in 2014 (Appendix S1), in which 60 international perinatal centers participated, showed that fetal MRI is being performed in one or more centers in at least 27 countries worldwide. However, the quality of imaging, sequences used and operator experience appear to differ widely between centers[3].

The impact of such differences should be reduced by development of guidelines to define better the role of fetal MRI in relation to prenatal diagnostic ultrasound. The aim of this document is to provide information on state-of-the-art fetal MRI for those performing the examination, as well as for clinicians interpreting the results.

What is the purpose of fetal MRI?

The purpose of fetal MRI is to complement an expert ultrasound examination[4,5], either by confirmation of the ultrasound findings or through the acquisition of additional information[6]. MRI is not currently used as a primary screening tool in prenatal care, although standardized and complete assessment of the fetal anatomy is probably feasible. Figure 1 presents the survey participants' opinions regarding indications for which MRI can provide useful information.

Is fetal MRI a safe procedure?

MRI is not associated with known adverse fetal effects at any point in pregnancy, when performed without administration of contrast media[7]. There are no reported adverse effects of MRI performed at 1.5 Tesla (1.5 T)[8]. However, there have been no human studies of possible adverse effects at higher field strength, such as 3.0 T[7,9,10], although recent data show that it may be safe in a porcine model[11].

Under which circumstances should fetal MRI be performed?

There is general consensus that fetal MRI is indicated following an expert ultrasound examination in which the diagnostic information about an abnormality is incomplete. Under these circumstances, MRI may provide important information that may confirm or complement the ultrasound findings and alter or modify patient management.

Presently, factors influencing the decision to perform fetal MRI include, but are not limited to: experience/equipment of the ultrasound and MRI facilities, accessibility to MRI, maternal conditions, gestational age, safety concerns, legal consideration regarding termination of pregnancy (TOP) and parental wishes after appropriate counseling[3,10,12,13].

The ISUOG survey addressed the necessity of MRI for selected indications and used a 7-point rating scale to weight the responses from 0 (not at all indicated) to 7 (definitely indicated) (Figure 1). The variety of responses is likely to reflect the divergence seen between various specialties and the spectrum of pathologies seen at each

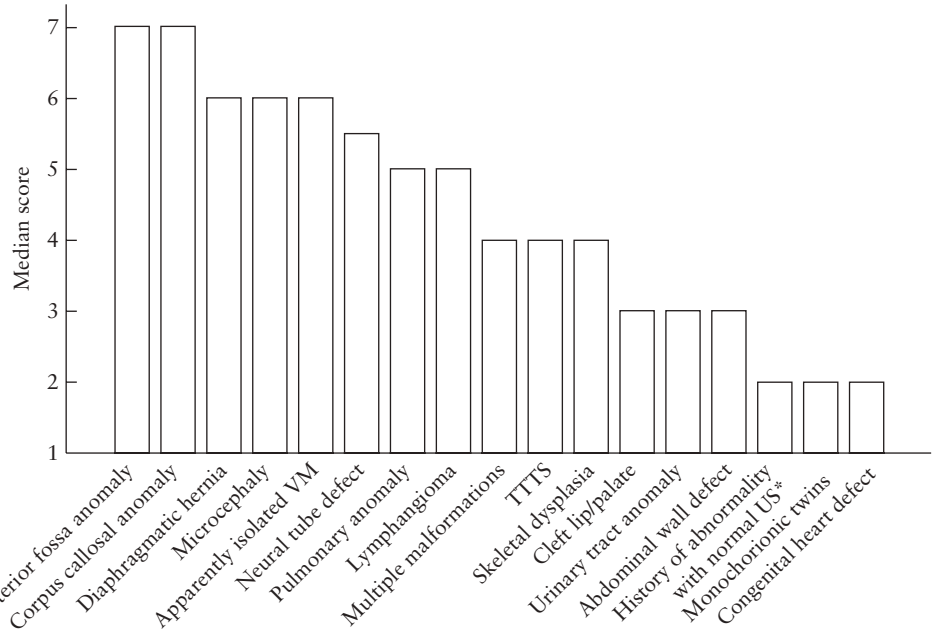

Figure 1 Results of ISUOG survey on indications for fetal magnetic resonance imaging (MRI), rated on a scale from 0 (fetal MRI not at all indicated) to 7 (definitely an indication for fetal MRI). *History of abnormality in previous pregnancy or in family member, with normal ultrasound (US) findings in current pregnancy. TTTS, twin–twin transfusion syndrome; VM, ventriculomegaly.

Table 1 The multidisciplinary team: proposed participants and their role in performing fetal magnetic resonance imaging (MRI)

Participant	*Role*
Obstetrician, radiologist	Performs sonographic/neurosonographic examination; provides information to parent(s) regarding findings and possible diagnoses; provides counseling; indicates need for fetal MRI
Radiologist, obstetrician	Available during MRI examination for acquisition of appropriate planes and changes of protocol as needed; interpretation and reporting of findings; provides counseling
Multidisciplinary team when available/necessary: obstetrician, pediatric radiologist or neuroradiologist, pediatric neurologist, geneticist, other pediatric subspecialist, social worker, psychologist	Provides counseling and recommendations based on neurosonography, MRI, genetic findings, laboratory findings and/or family history

center. The opinions may also reflect different levels of experience when performing fetal ultrasound and MRI.

In general, performance of an ultrasound examination following only the minimum recommendations for second-trimester ultrasound/basic brain examination, as proposed by ISUOG[5], is insufficient prior to requesting MRI. Additional views, such as orthogonal views, higher frequency probes and/or transvaginal imaging are required to detail the specific abnormality[14,15].

The practice of TOP and associated medicolegal implications may influence the use of fetal MRI at local institutions. In countries in which the decision about TOP has to be made before 24 weeks, the performance of MRI prior to this time may help an individual couple decide on the future of their pregnancy; however, in general, MRI is better reserved for later in the second or third trimester[13]. Although available data are still inconclusive, MRI for parental reassurance regarding the absence of associated pathologies in fetuses with apparently isolated conditions may be recommended in fetuses with isolated ventriculomegaly[16], agenesis of the corpus callosum[17], absent septum pellucidum and cerebellar or vermian anomalies[18]. In addition, fetal MRI has been found to be helpful in monochorionic twin pregnancies after iatrogenic or natural demise of a cotwin to find pathological changes in the surviving twin[19,20].

At what gestational age should fetal MRI be performed?

Fetal MRI performed before 18 weeks does not usually provide information additional to that obtained on ultrasound examination. In some cases, additional information can be obtained before 22 weeks[13] but MRI becomes increasingly helpful thereafter. Specific examples of pathologies that can be evaluated in the third trimester include, but are not limited to, those of cortical development and neck masses that may cause airway compromise[21]. Most organs can be visualized in detail between 26 and 32 weeks of pregnancy, when pathologies related to abnormal development are more

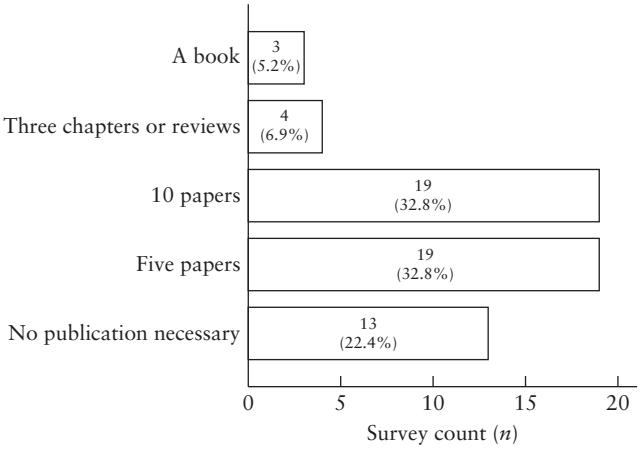

Figure 2 Results of ISUOG survey regarding how much an institution should have published in the field of fetal magnetic resonance imaging in order to qualify as a teaching center.

fully evolved, but each pregnancy and each fetus will differ. It may become more difficult for the woman to stay comfortable in the scanner with advancing gestation and consideration of left-lateral offset is recommended.

Who should perform fetal MRI?

When indicated, performed properly and interpreted correctly, MRI not only contributes to diagnosis but may be an important component of treatment choice, delivery planning and counseling. Practitioners who interpret fetal MRI should be familiar with fetal diagnosis, as it differs from diagnosis in other patient populations. Choice of appropriate protocols and techniques requires extensive training; thus, the performance of fetal MRI should be limited to individuals with specific training and expertise. The same applies to interpretation of the examination. In many centers this will require a multispecialty collaborative approach, including experts in the field of prenatal diagnosis, perinatology, neonatology, pediatric neurology and neuroradiology, genetics and other related specialties (Table 1), in order to integrate the clinical and family histories and the ultrasound and MRI findings, to optimize patient care. Consultation with a geneticist and other pediatric subspecialists may be required in order to provide the patient with the best counseling and management options.

Where should a practitioner train for fetal MRI?

Although at present we are unaware of the existence of a recognized fetal MRI specialization, individuals who perform fetal MRI should have undergone specialized training in collaboration with a teaching center, enabling them to perform a state-of-the-art fetal MRI examination after a sufficient amount of cases (GOOD PRACTICE POINT; i.e. recommended best practice based on the clinical experience of the guideline development group).

A teaching center is defined as an institution that is able to teach students, physicians and radiographers/technologists skillful performance of fetal MRI. In order to qualify as a teaching center certain requirements should be fulfilled, which include:

1. multidisciplinary specialists working in the field, including, but not limited to, fetomaternal specialists, radiologists and obstetricians;
2. institutional experience, with at least 500 fetal MRIs and at least two examinations performed per week;
3. publication of scientific papers or reference material in this field (Figure 2).

RECOMMENDATIONS

Performance of fetal MRI according to standardized criteria (Table 2) will improve the management of pregnancies complicated by a fetal malformation or acquired condition (GOOD PRACTICE POINT).

How should fetal MRI be performed?

Field strength

At present, 1.5 T is the most commonly used field strength, providing acceptable resolution even as early as 18 weeks[22]. 3 T has the potential to provide images with higher resolution and better signal-to-noise ratio than does 1.5 T, while maintaining a comparable or lower energy deposition[22]. Nonetheless, higher field strength is currently not recommended for *in-vivo* fetal imaging[10].

Course of examination

1. Exclude contraindications for MRI[22].

Table 2 Steps in performance of fetal magnetic resonance imaging (MRI)

Indication	Dependent on quality of previous ultrasound examinations, clinical question and gestational age
Counseling of pregnant woman	Explanation of indication, performance, expected outcome and consequences of the procedure, information about the possibility of an accompanying person, discussion with respect to contraindications and claustrophobia and sedative drug prescription if necessary
Prerequisites for MRI unit	Written referral with clear indication of clinical question(s), ultrasound report and images (if possible), gestational age confirmed/determined by first-trimester ultrasound
At the MRI unit	Clarification of possible contraindications, comfortable positioning of woman (either supine or lateral decubitus position), adequate coil positioning, performance of examination according to pertinent protocol
After examination	Inform patient about when the report will be ready; in the case of immediate consequences resulting from MRI examination, information regarding results should be provided promptly to the referring physician
Storage of images, report	Electronic storage of images, analysis of images, structured reporting (Table 3)

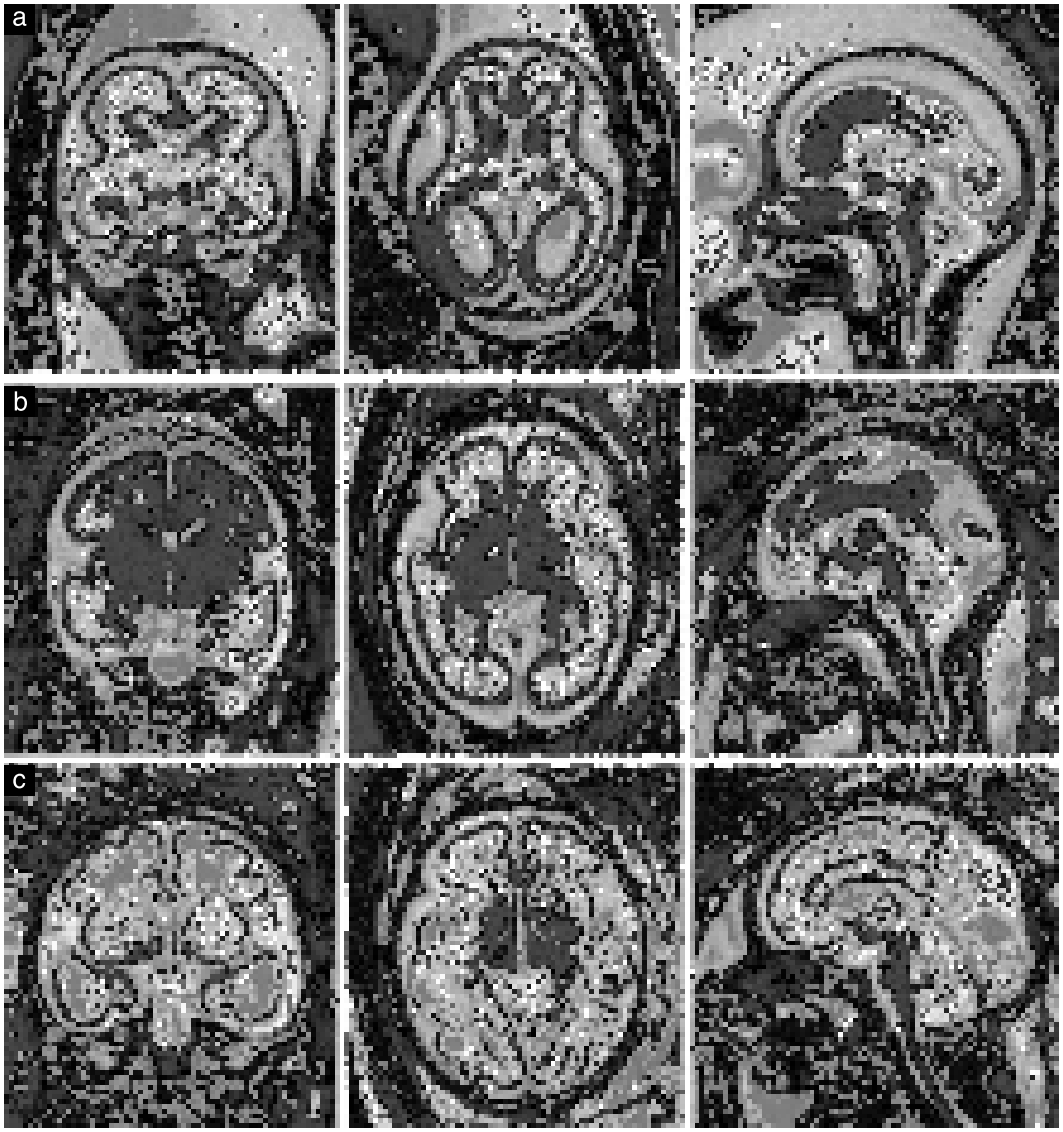

Figure 3 Coronal, axial and sagittal (left to right) T2-weighted fast (turbo) spin-echo sequences (with long echo time) of normal fetal brain at 21 + 0 (a), 28 + 1 (b) and 31 + 1 (c) weeks.

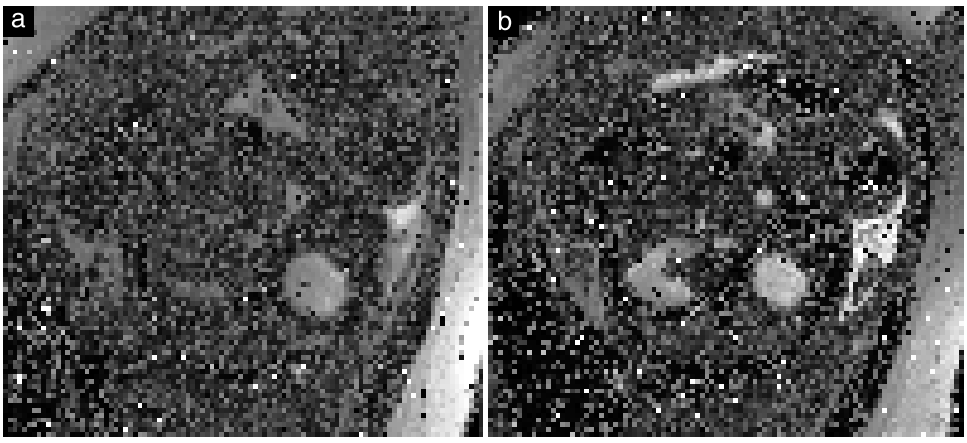

Figure 4 Axial T2-weighted fast (turbo) spin-echo sequences in a normal 39 + 4-week fetus showing how a shorter echo time (TE) gives greater detail of the fetal body: (a) TE = 80 ms; (b) TE = 140 ms.

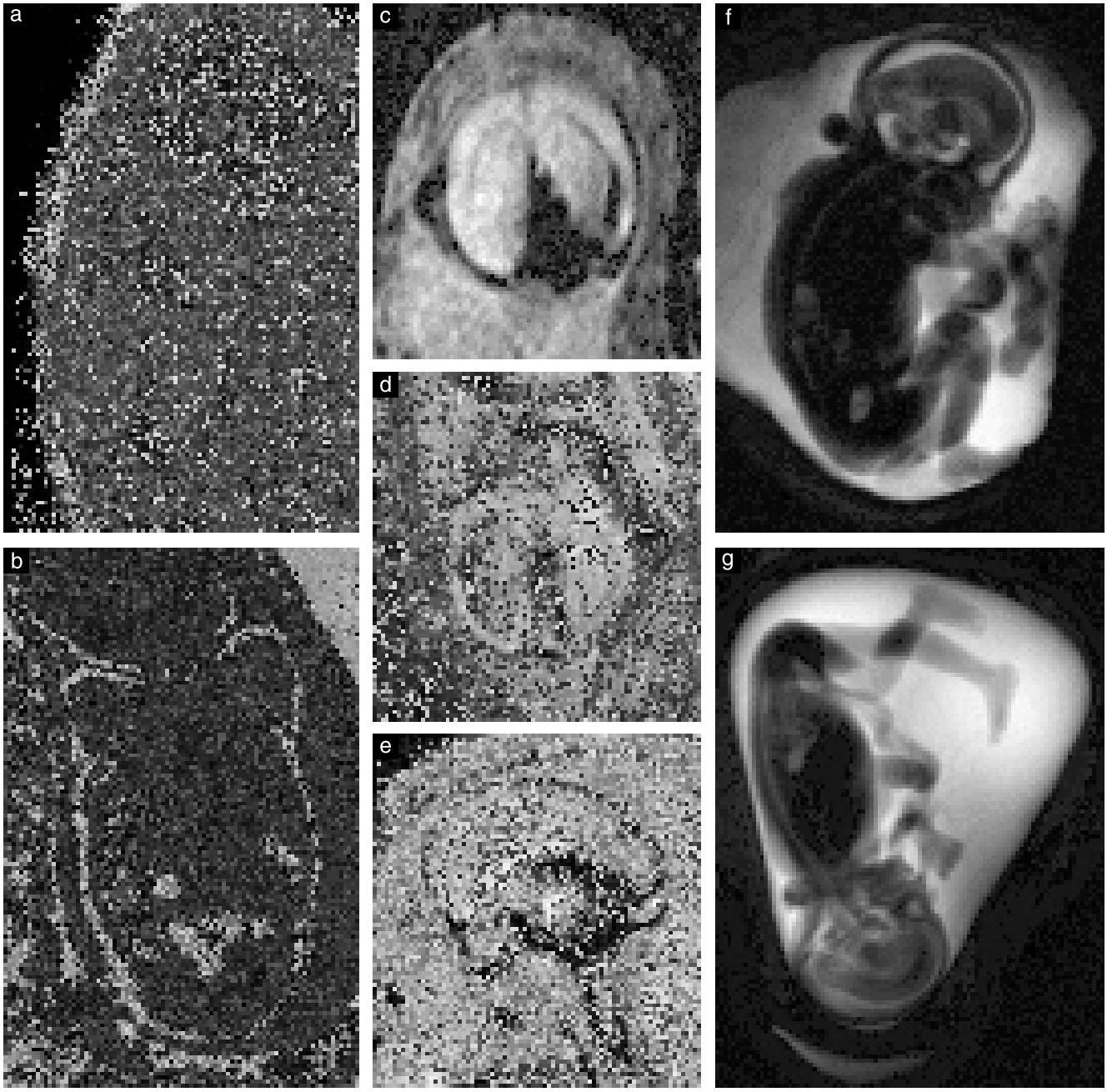

Figure 5 T2-weighted contrast is the mainstay of fetal magnetic resonance imaging (MRI). Other sequences include: T1-weighted MRI (a,b), used here in normal fetuses at 27 + 1 (a) and 38 + 3 (b) weeks of gestation, showing hyperintensity of the thyroid gland and meconium-filled bowel loops; single-shot high-resolution gradient echo echoplanar sequences, seen here in coronal (c), axial (d) and sagittal (e) planes in a 22 + 6-week fetus with an intracranial hemorrhage, showing hypointense blood-breakdown products; and magnetic resonance cholangiopancreatography sequence (40 mm thick), used here in a 24 + 4-week fetus with a cardiac malformation (not shown) (f) and a 20 + 1-week fetus with genu recurvatum (g), which allows detection of proportions and positions of hands and feet.

2. Obtain informed consent from the pregnant woman.
3. Note gestational age, ideally as assessed by first-trimester ultrasound[23], and pertinent prior clinical assessment and ultrasound findings.
4. Consider using sedation to reduce fetal movements and/or artifacts, and in anxious or claustrophobic patients.
5. Place the patient on the table in a comfortable position[24].
6. In some cases, and according to the safety regulations at the particular institution, consider accommodation of an accompanying person in the examination room[25].
7. Acquire localizer sequences.
8. Ensure correct coil placement, with first organ of interest in the center of the coil; plan for next sequences.
9. Assess the primary organ of interest.
10. When indicated, proceed to perform a complete examination of the whole fetus and the extrafetal structures (including umbilical cord, placenta and maternal cervix).

Figure 6 Sagittal T2-weighted magnetic resonance image of a normal 21 + 5-week fetus, showing the profile with intact palate.

11. Inform referring physician expeditiously if a condition becomes apparent that needs rapid intervention, such as suspected placental abruption or hypoxic ischemic fetal brain injury.

Choice of sequences

1. T2-weighted contrast is the mainstay of fetal MRI and is usually achieved using T2-weighted fast (turbo) spin-echo (SE) or steady-state free-precession (SSFP) sequences. Fast (turbo) SE sequences with long echo time (TE) should be used in imaging of the fetal brain (Figure 3). A shorter TE gives more contrast in the fetal body (Figure 4). SSFP sequences provide T2 information in moving fetuses and allow, for instance, the differentiation of vessels from solid tissue[26].
2. T1-weighted contrast is acquired by the use of two-dimensional gradient echo (GRE) sequences at 1.5 T. An average duration of 15 s permits performance during a maternal breath-hold, which facilitates the acquisition of images that are free from movement artifacts[27]. T1-weighted contrast identifies methemoglobin in subacute hemorrhage, calcification, glands and meconium[27] (Figure 5a,b).
3. Single-shot high-resolution (SSH) GRE echoplanar (EP) sequences are used to visualize bony structures, calcification and the breakdown products of blood, such as deoxyhemoglobin, which suggests a recent bleed, or hemosiderin, which represents an older hemorrhage[28] (Figure 5c–e).
4. Optional sequences include: diffusion-weighted imaging, diffusion tensor imaging, dynamic SSFP sequences and SSH magnetic resonance cholangiopancreatography sequences, which supply three-dimensional-like images (Figure 5f,g).

In all cases, the field-of-view should be adjusted to the region of interest. A slice thickness of 3–5 mm with a 10–15% intersection gap will be appropriate in most cases. The examination should include at least T2 information in three orthogonal planes of the fetal brain and body, and T1- and GRE-EP sequences in one or two planes, preferably frontal and sagittal.

This 'minimum' protocol should be executable in less than 30 min, even allowing for fetal movement and sequence repetition. Only examinations that are performed following this protocol should be regarded as 'state of the art' (GOOD PRACTICE POINT).

Standardized planes for fetal brain examination

1. Sagittal sections through the head, including a mid-sagittal plane depicting the corpus callosum, aqueduct and pituitary.
2. Coronal sections parallel to the brainstem with symmetrical visualization of the inner ear structures.
3. Axial sections, perpendicular to the sagittal sections, parallel to the course of the corpus callosum (or skull base in the case of absence of the corpus callosum), with lateral symmetry adjusted according to the coronal sections.

Table 3 Structured report for detailed fetal magnetic resonance imaging examination

Method	Imaging conditions (e.g. degradation by fetal movement, maternal obesity, premature termination of examination), field strength, coil, sequences, planes
Head	Profile, hard and soft palate (Figure 6), skull, ocular measurements
Brain	Age-related sulcation and gyration, lamination of brain parenchyma (after 30 weeks: myelination and premyelination), ventricular system, cerebellum, midline structures and width of cerebrospinal fluid spaces (Figure 3)
Chest	Configuration of thorax, lung signals, gross regularity of heart (not examined in detail) (Figure 7a,b)
Abdomen	Fetal situs, stomach and gallbladder (fluid filling), fluid and meconium signals of bowels (Figure 7c,d), kidneys, urinary bladder (fluid filling); on request: female/male external genitals (in case of latter: descent of testes) (Figure 8)
Extrafetal structures	Umbilical cord (number of vessels), amount of amniotic fluid, position and characteristics of placenta, cervical length (Figure 9) only if substantially shortened
Skeleton (when examined)	Course and completeness of spine, shape, length and position of bones, fingers and toes (not always possible to assess, especially in presence of minimal amniotic fluid, i.e. after 32–35 weeks)

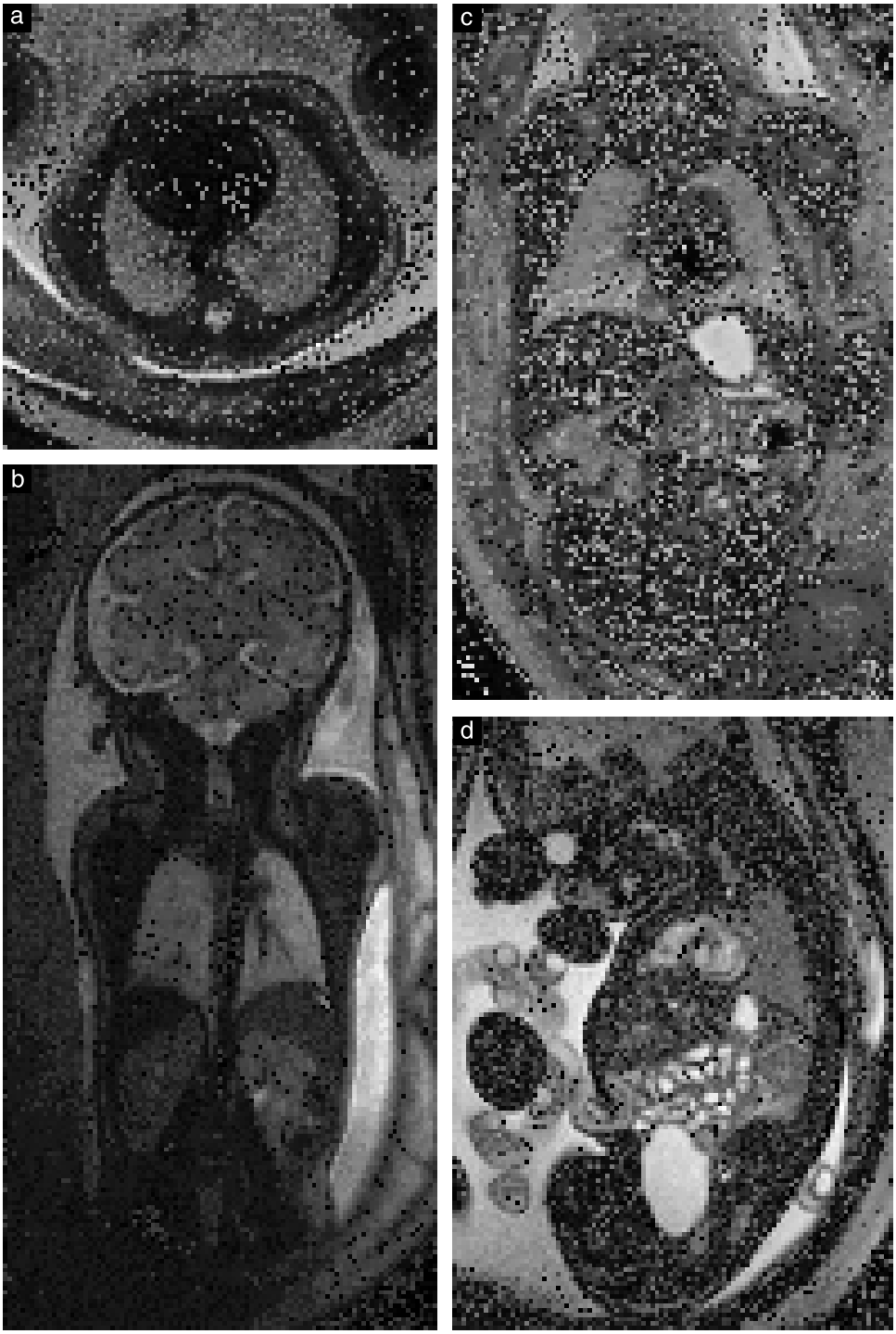

Figure 7 Magnetic resonance imaging (MRI) of normal fetal chest (a,b) and abdomen (c,d). (a) Axial T2-weighted MRI in a 34 + 2-week fetus, showing normally shaped thorax and lungs with age-matched regular signals; (b) coronal image at 35 + 3 weeks, showing additionally parts of liver, kidneys and adrenal gland on right side. (c) Coronal T2-weighted MRI in a 32 + 2-week fetus, displaying fluid-filled stomach and bowel loops; (d) sagittal steady-state free-precession image in a 35 + 6-week fetus, showing in addition the fluid-filled urinary bladder. Note hyperintensity of the heart in (d), in contrast to T2-weighted image (c).

Standardized planes for fetal body examination

These are more difficult to achieve, as the fetus is usually in a position that will not allow strictly orthogonal placement of slices.

1. Sagittal sections can be achieved by placing the middle slice through the thoracic spine and the umbilical cord insertion.
2. Coronal sections have to be adjusted to the course of the spine (parallel to the thoracic spine and the frontal body wall at the level of the abdomen).
3. Axial slices should be perpendicular to the long axis of the spine at the level of the region of interest. To perform lung volumetry, for instance, the axial sections should be perpendicular to the thoracic spine.

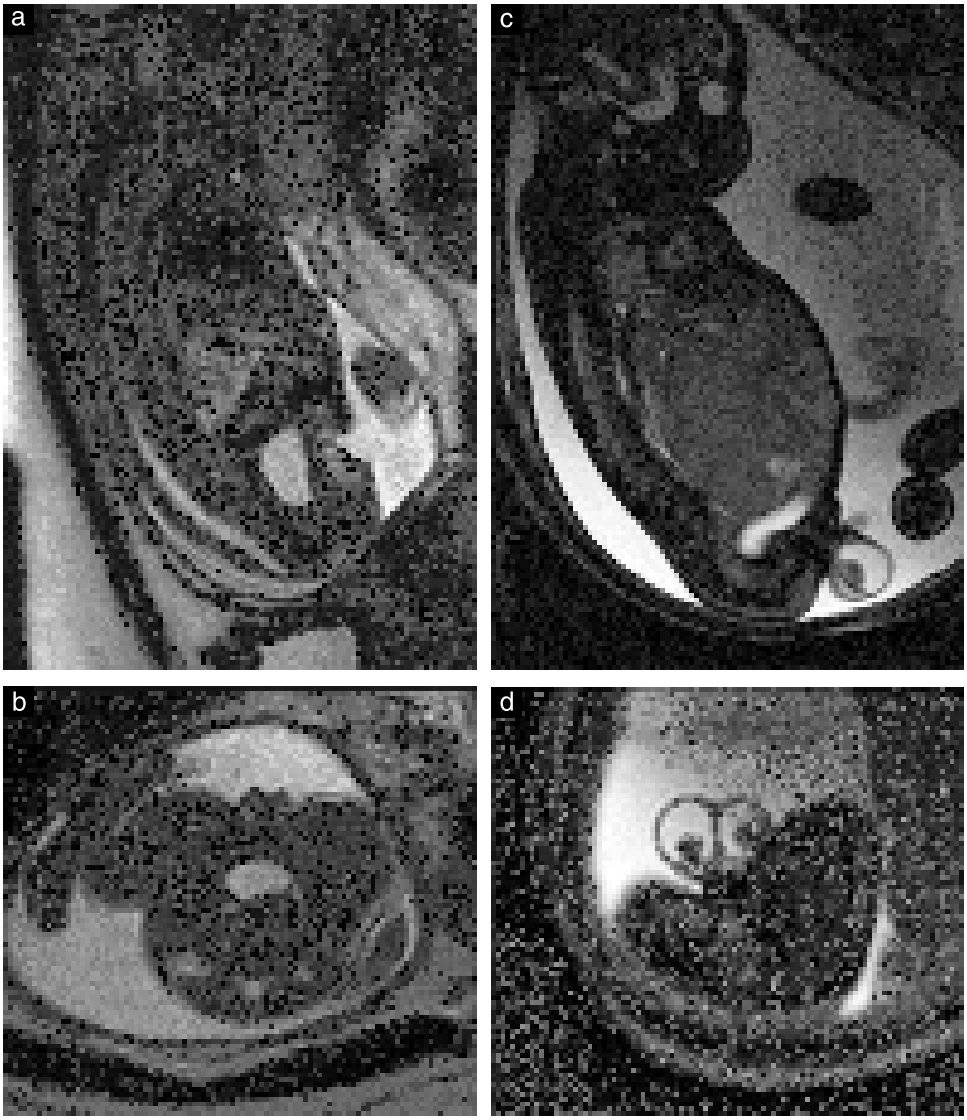

Figure 8 T2-weighted sagittal (a) and axial (b) magnetic resonance images in a normal 31 + 1-week female fetus, showing external genitalia. Steady-state free-precession sagittal (c) and axial (d) images in a 35 + 1-week male fetus with descended testes and hydrocele, in this case as a consequence of a liver tumor.

Although usually measurements will already have been made with ultrasound, measuring certain structures at the MRI examination may be of benefit in particular cases[12]. When measuring fluid-containing structures, it is important to remember that MRI measurements are usually around 10% greater than the corresponding ultrasound measurements. In lung volumetry, normal gestational-age related MRI measurements correlate with fetal body volume[29] and are considered predictive of outcome in cases of lung pathology[30].

Storage of magnetic resonance images

The whole examination should be stored according to local practice, preferably in electronic format. CDs of the examinations can be produced for the patient to enable second-opinion assessment (GOOD PRACTICE POINT).

Reporting

Two types of examination should be distinguished clearly and identified in the report:

1. A targeted examination, which looks only for a certain category of fetal anomaly. The aim is to target a specific organ or address a particular question and not to evaluate the entire fetus.
2. A detailed examination, which includes a standardized evaluation of the whole fetal anatomy in a similar way to that described by the ISUOG guidelines[5] for second-trimester ultrasound (or other locally used guidelines) (Table 3). This examination may include structures less amenable to MRI than to ultrasound examination, for example cardiac structures. Extrafetal structures, such as the umbilical cord, placenta and cervix, and the amniotic fluid (amount and signal intensity), should be described when indicated clinically. Structures not sought routinely in these examinations need to be indicated clearly in the report.

Standardized reports should follow the suggested structure outlined in Table 3 (GOOD PRACTICE POINT).

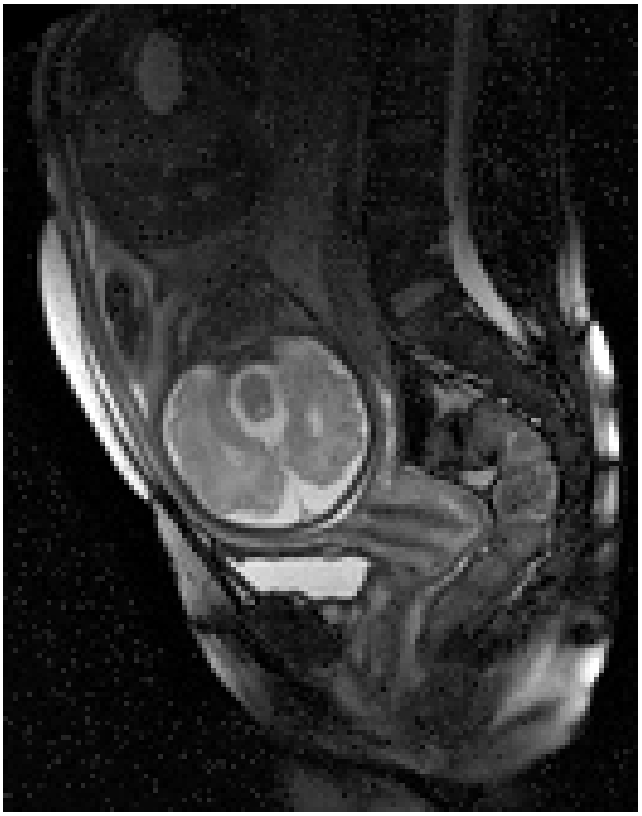

Figure 9 T2-weighted sagittal magnetic resonance image through maternal abdomen, showing normal cervix at 33 weeks' gestation.

As MRI is usually not a first-line examination, but a complementary examination following an ultrasound examination performed in the second trimester[31], the emphasis of the examination and report should be on structures that are more difficult to assess with ultrasound. A detailed anatomical assessment may be performed on demand.

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SUPPORTING INFORMATION ON THE INTERNET

The following supporting information may be found in the online version of this article:

Appendix S1 Survey conducted by the Fetal MRI Special Interest Group of the International Society of Ultrasound in Obstetrics and Gynecology in 2014