Clin Neuroradiol
DOI 10.1007/s00062-015-0413-z

REVIEW ARTICLE

MRI of the Fetal Brain

C. Weisstanner · G. Kasprian · G.M. Gruber · P.C. Brugger · D. Prayer

Received: 27 March 2015 / Accepted: 12 May 2015

Abstract The purpose of this article is to provide an overview of the possibilities for fetal magnetic resonance imaging (MRI) in the evaluation of the fetal brain. For brain pathologies, fetal MRI is usually performed when an abnormality is detected by previous prenatal ultrasound, and is, therefore, an important adjunct to ultrasound. The most commonly suspected brain pathologies referred to fetal MRI for further evaluation are ventriculomegaly, missing corpus callosum, and abnormalities of the posterior fossa. We will briefly discuss the most common indications for fetal brain MRI, as well as recent advances.

Keywords Fetal MRI · Fetal brain · 3T · Postmortem MRI

Introduction

Although ultrasound (US) remains the predominant modality for evaluating disorders related to pregnancy, fetal MRI has been increasingly used and is considered a complementary technology. MRI of the fetus is not limited by fetal position, obesity, or oligohydramnios, and visualization of the brain is not restricted by the ossified skull. With its higher resolution, contrast abilities, as well as a large field of view, MRI facilitates the examination of fetuses with large or complex anomalies as well as visualization of lesions within the context of the entire fetal body. The purpose of this article is to provide an overview of fetal MRI of the brain.

D. Prayer, MD (✉) · C. Weisstanner · G. Kasprian
Department of Radiology, Division of Neuro- and Musculoskeletal Radiology, Medical University of Vienna,
Währinger Gürtel 18–20,
1090 Vienna, Austria
e-mail: daniela.prayer@meduniwien.ac.at

C. Weisstanner
University Institute for Diagnostic and Interventional Neuroradiology, Inselspital, University of Bern,
Bern, Switzerland

G.M. Gruber · P.C. Brugger
Center of Anatomy and Cell Biology, Integrative Morphology Group, Medical University of Vienna,
Vienna, Austria

History

Fetal MR was first described in 1983 [1]. Because of fetal motion, fetal MR was recommended in late pregnancy or in cases of oligohydramnios. To decrease fetal motion, benzodiazepines or curarization were used [2, 3]. Even with this limitation, fetal MRI was considered a valuable complement to US, especially for the further evaluation of problems first detected by US. One of the main advantages was that the whole brain could be visualized, even in late pregnancy. In addition, image quality is not impaired by the bony skull, and therefore, orthogonal sections can be acquired more easily. With the development of fast MR techniques and MRI software, here especially the half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequence, fetal MR could be performed without sedation, which has led to an increased usage of this imaging tool.

Normal Development

For proper interpretation of fetal MRI, a radiologist should have a deep understanding of normal developmental anatomy. A familiarity with primary neurulation, ventral induc-

Published online: 11 June 2015

tion, commissuration, cortical formation, premyelination, transient structures of the cerebral hemispheres, and sulcation is necessary. There are also valuable resources that delineate the normal fetal brain in MR for comparison purposes [4, 5].

From T2-weighed Imaging to Functional Imaging

Single-shot fast spin-echo (SSFSE) sequences are the most widely used in fetal MR imaging. Because of single-slice acquisition, fetal motion will only affect those slices acquired while motion occurs [6]. Improved sequences enabled assessment of the brain tissue not only by T2-weighted imaging, but also by T1-, diffusion-weighted, and fluid-attenuation inversion recovery (FLAIR) sequences. Because of the high contrast between cerebrospinal fluid and brain tissue, T2-weighted imaging is primarily used to describe the surface of the fetal brain [7]. T1-weighted sequences allow the detection of hemorrhage and fat deposition, and can depict fetal organs selectively with T1-hyperintensity, such as the pituitary gland (Fig. 1) and liver. With echoplanar (EPI) sequences, fetal skeleton information, hemorrhage, and/or calcifications, for example, in CMV-infection (Fig. 2), can be gathered. Structural imaging is the mainstay of MR diagnosis, but other modalities, such as diffusion tensor imaging with tractography [8, 9], single-voxel spectroscopy for brain metabolism [10], and blood-oxygen-level dependent (BOLD) imaging for functional imaging studies [11] may improve diagnostic accuracy in CNS pathologies. Imaging parameters of most sequences are listed in Table 1.

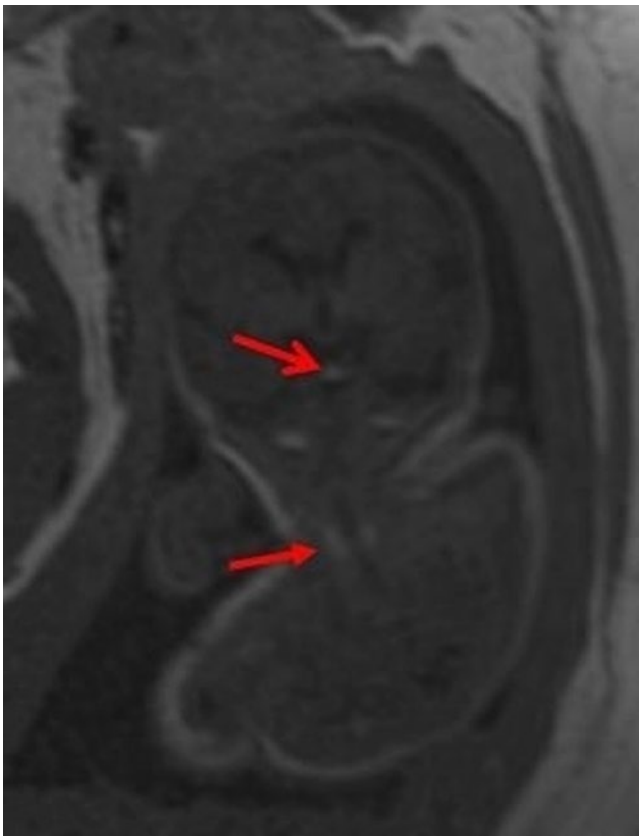

Fig. 1 Coronal T1-weighed image of a fetus at 35+3 GW. The hypophysis (*open arrow*) can be clearly discerned as a hyperintense focus. In addition to that, the lobes of the thyroid gland (*closed arrow*) can be seen as hyperintense foci

Fetal CNS Anomalies

Malformations of the central nervous system are very difficult to characterize prenatally. In tertiary referral centers with expert neurosonographers, fetal MRI has been shown to be advantageous with respect to clinical counseling of cases with CNS malformations [12].

The most common referrals for fetal brain imaging will be briefly discussed below and include disorders of cortical malformation, commissural abnormalities, ventriculomegaly, infratentorial pathologies and acquired pathologies.

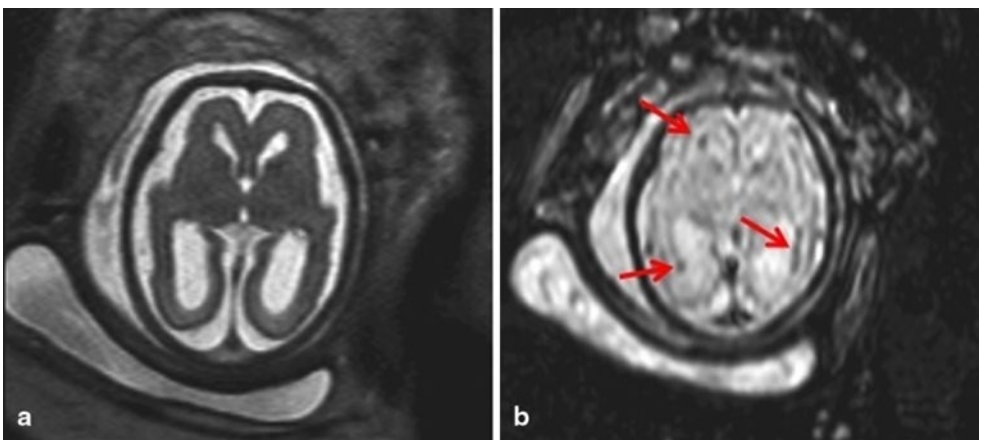

Fig. 2 **a** Axial T2-weighed image of a fetus at 27+5 GW with CMV-infection. In this image, no calcification can be detected. With the EPI sequence, **b** periventricular calcifications are seen as hypointense foci

Table 1 Imaging parameters of sequences used in fetal MRI of the brain (1.5 T, Philips, Gyroscan, Best, The Netherlands)

Sequence	TR (ms)	TE (ms)	Slice thickness (mm)	Matrix	FOV (mm)	Flip angle
T2 (SSFSE)	shortest	100/140	4	256 × 153	200–230	90
SSFPE	shortest	shortest	5	192 × 219	260	80
T1 FFE	shortest	4.6	4	208 × 165	325	80
SSH GRE EPI	3000	53	4	160 × 95	230	90
DWI (b = 700)	1470	125	5	128/81	250	90
DTI (b = 1000)	1649	90	5	112 × 67	230	90

FOV field of view, *TR* relaxation time, *TE* echo time, *ms* milliseconds, *DTI* diffusion tensor imaging, *DWI* diffusion weighted imaging, *EPI* echo planar imaging, *FFE* fast field echo, *SSFSE* single-shot fast spin-echo, *SSFPE* steady-state free-precession, *SSH* single-shot, *GRE* gradient echo, *mm* millimeter.

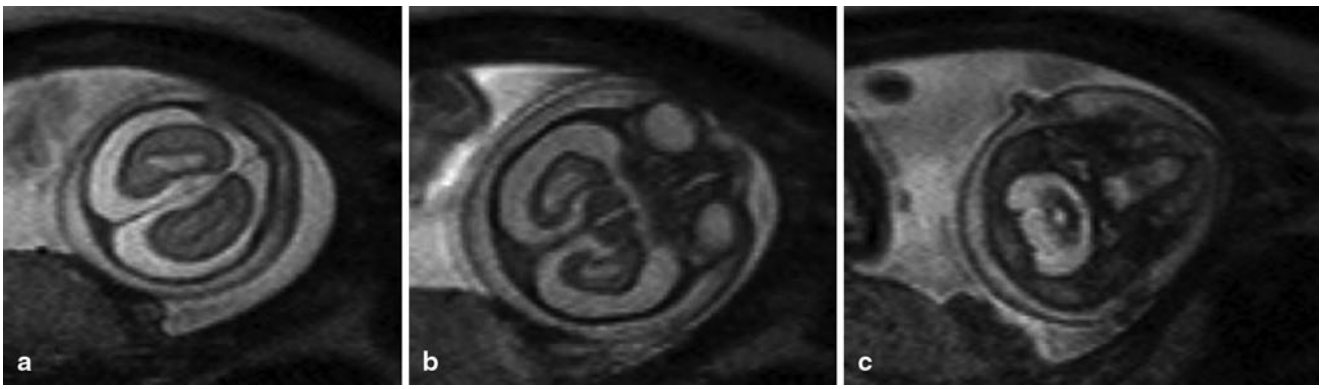

Fig. 3 SSFPE images of a fetus at 24 + 0 GW with (micro-)lissencephaly **a** and **b** and no visible sulcation. **c** Hypoplastic cerebellum

Disorders of Cortical Formation

Disorders of cortical formation are already present when fetal MRI is usually performed because cortical development starts in the eighth to ninth postconceptional week [13]. For example, lissencephalies (Fig. 3) may be suspected because of a disordered lamination of the fetal brain with a diminished discrimination of the subplate. Another hint about the presence of abnormal gyration may be atypical sulcation or the preterm appearance of gyri [14]. The detection of heterotopia, unless it involves larger parts of the brain, may be difficult before the third trimester.

Commissural Abnormalities

With an incidence of 0.5–70 in 10,000, agenesis of the corpus callosum is one of the most common congenital brain malformations [15]. Because the presence of associated intra- or extracranial anomalies determines the future neurodevelopmental outcome, the exclusion of associated abnormalities is crucial. With fetal MRI, important additional information can be gained [16]. With optimized sequence planning, such as strict use of orthogonal and midline sagittal slices to visualize the configuration of all commissures[17], the sensitivity of fetal MRI can be improved. In addition to that, associated cortical malformations, acquired pathologies [18], and brainstem and cerebellar abnormalities may be detected. Partial callosal agenesis [19] and a sufficiently sized, but an abnormally formed, corpus callosum [20] are among the most frequently missed pathologies by fetal MRI. In these cases, advanced MR imaging techniques, such as DTI with tractography, may depict the commissures and misguided fiber tracts [21, 22] and may provide additional information (Fig. 4).

Ventriculomegaly

One main indication for fetal MR is ventriculomegaly diagnosed by ultrasound. It is defined as an atrial width more than 10 mm and can be further categorized as mild (atrial width between 10 and 12 mm), moderate (atrial with up to 15 mm), and severe ventriculomegaly (atrial width over 16 mm) [23]. Since the majority (85 %) of cases with ventriculomegaly have an additional brain pathology [24], an exact search for such pathologies is indicated (Fig. 5). Signs of associated pathologies include pathologic shape/borders of the ventricle, obliteration of the 4th ventricle (Chiari II malformation), intraventricular material, commissural agenesis/dysgenesis, disorders of cortical formation, and malformation of the posterior fossa and/or midbrain.

Infratentorial Pathologies

Malformations of the posterior fossa are often suspected in fetal US. MRI is advantageous over US for the proper

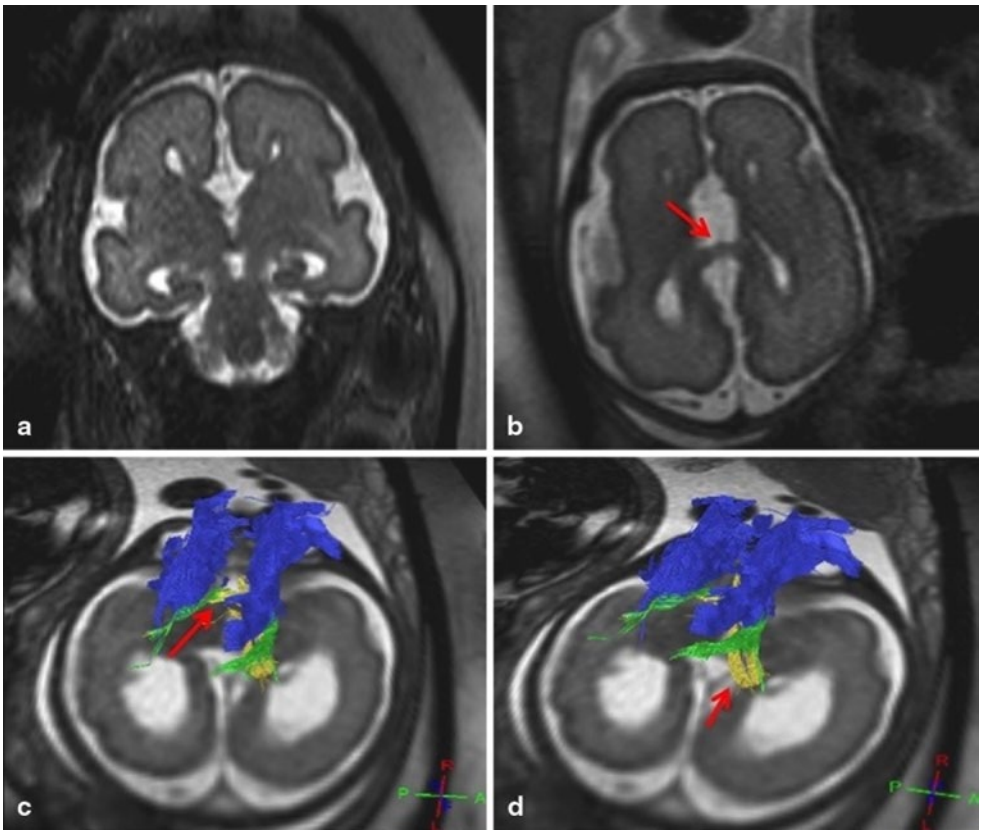

Fig. 4 **a** Coronal T2-weighed images of a fetus with callosal agenesis at 29 + 6 GW. **b** A parenchymal bridge between the right and left hemisphere can be seen. **c** Tractography verifies a forceps major (*green*) and a hippocampal commissure (*yellow*) (*arrow*). **d** A more oblique view for better depiction of the hippocampal commissure (*arrow*)

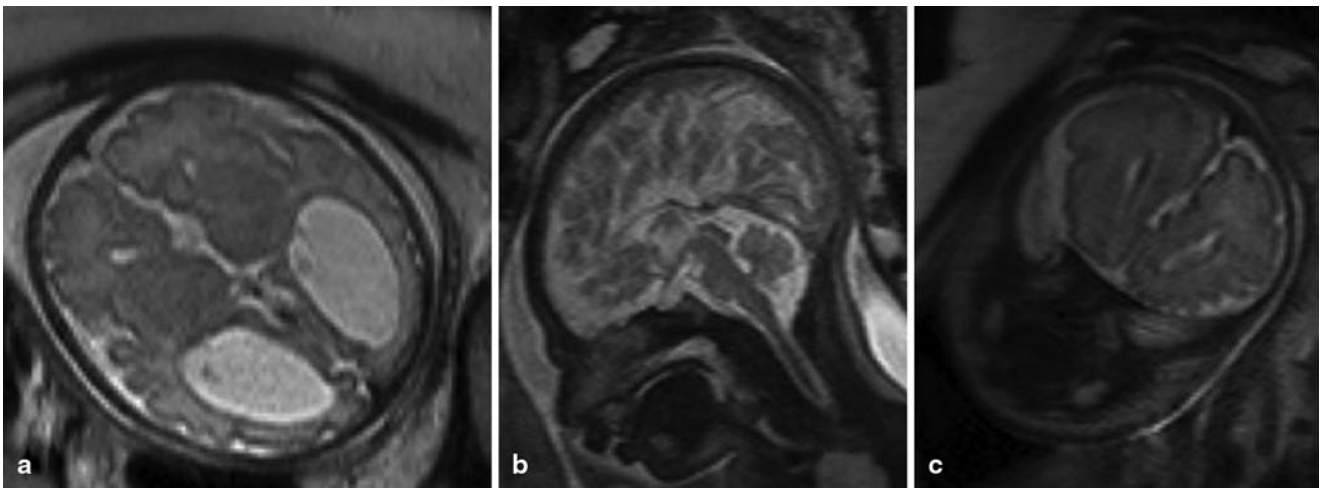

Fig. 5 **a** Axial SSFPE image of a fetus at 34 + 0 GW, with severe ventriculomegaly. **b** On this sagittal image, associated agenesis of the corpus callosum can be seen, with the typical steerhorn appearance of the frontal horns in (**c**)

evaluation and multidimensional analysis of the cerebellum, cerebellar parenchyma, vermis, and brainstem [25]. In pontocerebellar hypoplasia, the cerebellum is too small. An enlarged retrocerebellar fluid space can be seen with or without cerebellar pathology. Is the cerebellum involved with a dysplastic vermis, as in Dandy Walker malformation (Fig. 6)? Or is the cerebellum not involved, as in cisterna magna? The cerebellum might just be compressed because of a space-occupying arachnoid cyst, and a change in the normal signal intensity of the cerebellar parenchyma may be a result of hemorrhage or tumors [26].

Acquired Pathologies

The main acquired pathologies detected by fetal MRI are ischemic infarctions, hemorrhage, and brain tumors. Typi-

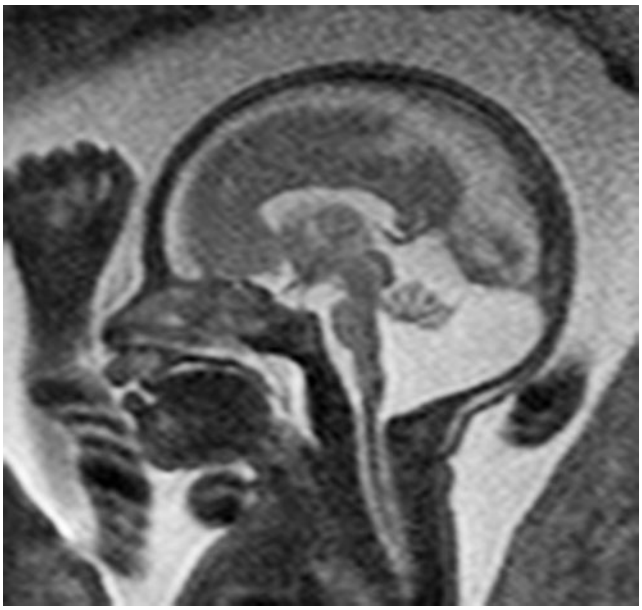

Fig. 6 Sagittal SSFPE image of a fetus at 28+3 GW with enlarged posterior fossa and dysplastic, upwardly rotated vermis, typical of a Dandy Walker malformation

cally, early-stage ischemic infarctions show restricted diffusion [27] at the beginning of the infarction to focal T2-weighted hyperintense lesions, and, in some cases, subsequently, to a reduction of brain tissue [28]. Because of changes in local susceptibility caused by blood breakdown products, echoplanar sequences are especially sensitive to hemorrhage [29], and can also be used to detect calcifications as a consequence of many acquired fetal or maternal diseases [30]. Brain tumors or vascular malformations lead to parenchymal changes [31], and, particularly in the case of vascular malformations, the demonstration of associated findings may direct therapeutic planning [32, 33] (Fig. 7).

Just CNS-Imaging? From CNS Imaging to "Whole Uterine-Imaging"

Especially in the case of complex malformations, a fetal MRI study should not be restricted to the brain. For example, in congenital muscular dystrophies caused by the fukutin-related protein gene (FKRP), mutations of a broad spectrum

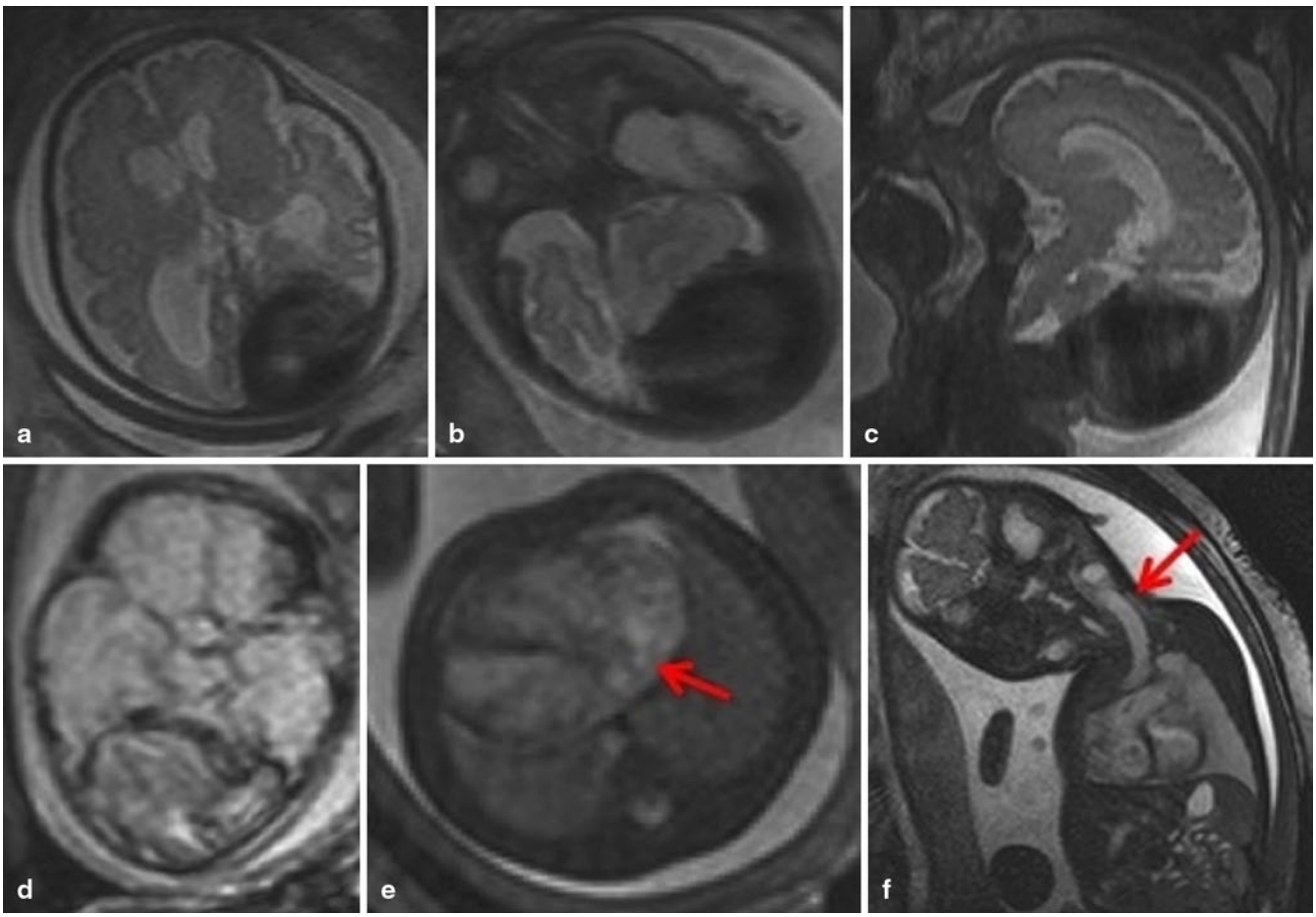

Fig. 7 Axial **a** and **b** sagittal **c** T2 weighed images of a fetus at 31+3 GW with a dural vascular malformation, enlarged torcular herophili and compression of the cerebellum. **d** On the EPI sequence, no hemorrhage can be detected. **e** Axial SSFPE through the thorax is depicted, as a consequence of the vascular malformation of a dilated heart (*arrow*) and engorged internal jugular vein (**f**: *arrow*)

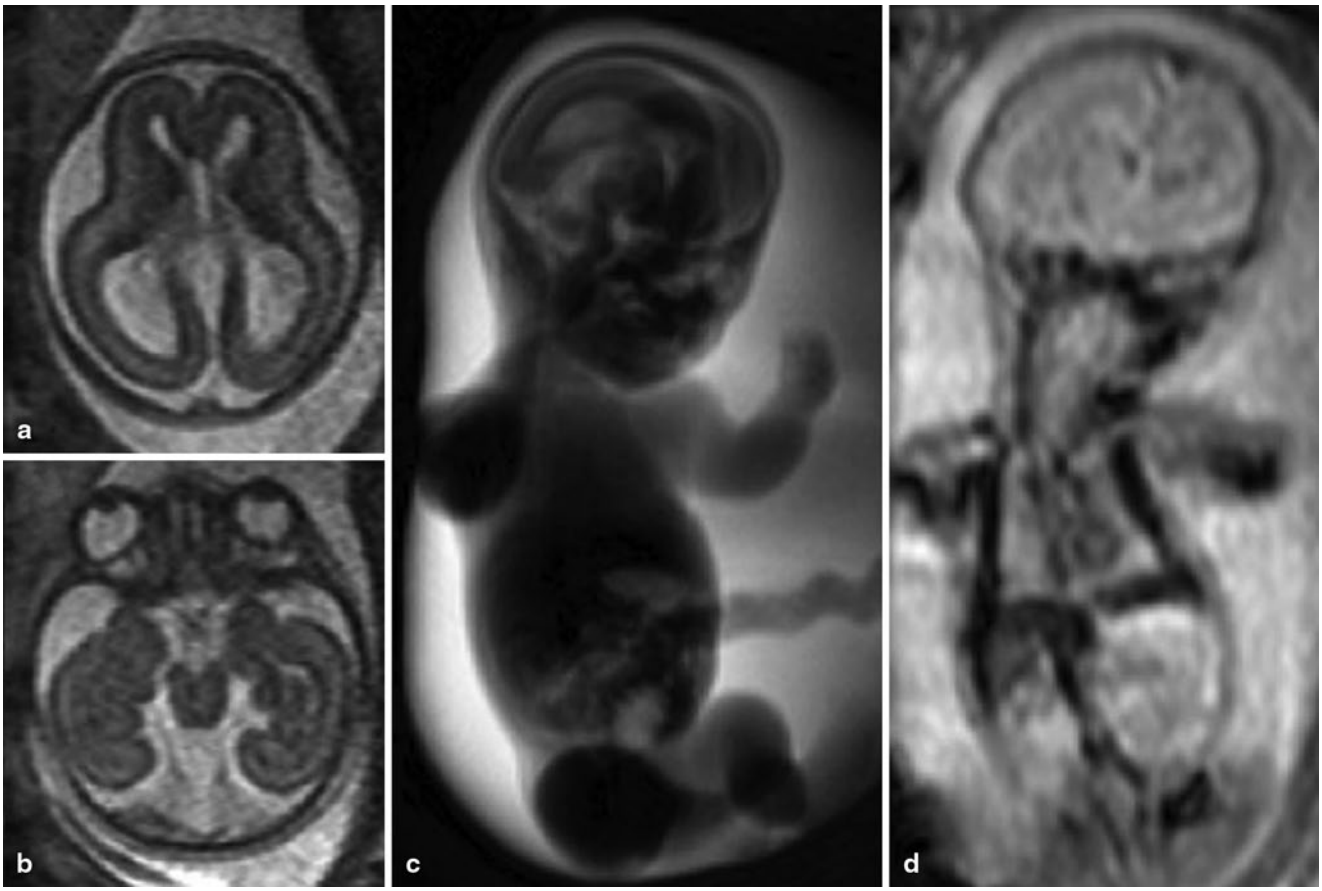

Fig. 8 **a** and **b** Axial SSFPE images of a fetus at 20+0 GW with thanatophoric dysplasia. In **a** mild ventriculomegaly can be seen and in **b** dysplasia of the mesial temporal lobes is evident. **c** Thick-slab heavy T2-weighed image demonstrates a narrow thorax and short extremities. **d** Coronal EPI sequence shows the bones as hypointense structures. The right humerus is bowed

of phenotypes, ranging from severe congenital muscular dystrophies to a much milder limb-girdle muscular dystrophy, in addition to eye and brain abnormalities, can be found [34]. Joubert syndrome, one of the axonal guidance disorders, can coexist with retinopathy, liver disease, kidney disease, polydactyly, obesity, and/or situs inversus [35]. Inferomesial temporal and occipital lobe abnormalities can be detected in hypochondroplasia [36], and of the temporal lobe in thanatophoric dysplasia [37] (Fig. 8). Congenital heart diseases lead to altered cerebral perfusion, which may lead to impaired brain growth [38], and congenital diaphragmatic hernias may also have an impact on brain development [39]. Thus, in any case, an examination of the brain by MRI should always include imaging of the whole fetus and placenta.

Pivotal Questions in Fetal Imaging

Indications

Indications for fetal MRI include the confirmation of inconclusive sonographic findings and the evaluation of sonographically occult diagnoses. Indications may vary widely, as a consequence of the different states of experience of the sonographers and the specialties of the respective perinatal center.

Safety Issues and Examination at 3 T

If the medical situation warrants fetal MRI, the ACR guidance document on MR safe practices 2013 declares, "pregnant patients can be accepted to undergo MR scans at any stage of pregnancy" [40]. At present, almost all fetal MRI are acquired on 1.5 T machines, but the desire for better anatomical delineation has led to imaging of the fetus at 3 T [41]. On the question of the maximum field strength that can be applied, the report of the Canadian Task Force on Preventive Health Care concludes "Fetal magnetic resonance imaging is safe at 3.0 T or less during the second and third trimesters" [42]. Gadolinium may be used when the benefits outweigh the potential risks, although the effects of gadolinium on the fetus are still unknown [40].

Postmortem MRI

Perinatal autopsy is essential to determine the cause of death, and also to provide additional information about disease processes [43]. Autopsy may also be used to evaluate modern imaging methods. But, despite this unquestionable role, autopsy rates have steadily declined over the last decade. Postmortem MRI is an acceptable alternative method to autopsy [44], and showed a diagnostic sensitivity of 100 %, and a specificity of 92 % with regard to fetal brain pathologies [45].

Conclusion

Fetal MRI allows excellent detailed visualization of the fetus *in utero,* as well as the extrafetal structures. With a systemic approach, and a thorough knowledge of the developing brain structures, fetal MRI is effective in the detection of subtle fetal brain abnormalities and in the assessment of complex lesions. Fetal MRI also helps in patient management and therapy decision-making.

Acknowledgment On behalf of all authors, the corresponding author states that there is no conflict of interest.

Conflict of Interest The authors declare that there are no actual or potential conflicts of interest in relation to this article.

Literature

1. Smith FW, Adam AH, Phillips WD. NMR imaging in pregnancy. Lancet. 1983;1(8314–5):61–2.
2. Weinreb JC, Lowe TW, Santos-Ramos R, Cunningham FG, Parkey R. Magnetic resonance imaging in obstetric diagnosis. Radiology. 1985;154(1):157–61.
3. Williamson RA, Weiner CP, Yuh WT, Abu-Yousef MM. Magnetic resonance imaging of anomalous fetuses. Obstet Gynecol. 1989;73(6):952–6.
4. Griffiths P. Atlas of fetal and postnatal brain MR. 1st ed. Philadelphia: Mosby/Elsevier; 2010.
5. Garel C. MRI of the fetal brain. Springer; 2004.
6. Yamashita Y, Namimoto T, Abe Y, Takahashi M, Iwamasa J, Miyazaki K, Okamura H. MR imaging of the fetus by a HASTE sequence. AJR Am J Roentgenol. 1997;168(2):513–9.
7. Mailath-Pokorny M, Kasprian G, Mitter C, Schopf V, Nemec U, Prayer D. Magnetic resonance methods in fetal neurology. Semin Fetal Neonatal Med. 2012;17(5):278–84.
8. Kasprian G, Brugger PC, Weber M, Krssak M, Krampl E, Herold C, et al. In utero tractography of fetal white matter development. Neuroimage. 2008;43(2):213–24.
9. Asenbaum U, Brugger PC, Woitek R, Furtner J, Prayer D. [Indications and technique of fetal magnetic resonance imaging]. Radiologe. 2013;53(2):109–15.
10. Pugash D, Krssak M, Kulemann V, Prayer D. Magnetic resonance spectroscopy of the fetal brain. Prenat Diagn. 2009;29(4):434–41.
11. Schopf V, Kasprian G, Schwindt J, Kollndorfer K, Prayer D. Visualization of resting-state networks in utero. Ultrasound Obstet Gynecol. 2012;39(4):487–8.
12. Paladini D, Quarantelli M, Sglavo G, Pastore G, Cavallaro A, D'Armiento MR, Salvatore M, Nappi C. The role of MRI in the clinical management of foetuses with central nervous system abnormalities in a tertiary referral center. Ultrasound Obstet Gynecol. 2014;44:188–96.
13. Kostović I, Judas M, Rados M, Hrabac P. Laminar organization of the human fetal cerebrum revealed by histochemical markers and magnetic resonance imaging. Cereb Cortex. 2002;12(5):536–44.
14. Righini A, Parazzini C, Doneda C, Avagliano L, Arrigoni F, Rustico M, Consonni D, Re TJ, Bulfamante G, Triulzi F. Early formative stage of human focal cortical gyration anomalies: fetal MRI. AJR Am J Roentgenol. 2012;198(2):439–47.
15. Schell-Apacik CC, Wagner K, Bihler M, Ertl-Wagner B, Heinrich U, Klopocki E, Kalscheuer VM, Muenke M, von Voss H. Agenesis and dysgenesis of the corpus callosum: clinical, genetic and neuroimaging findings in a series of 41 patients. Am J Med Genet A. 2008;146A(19):2501–11.
16. Glenn OA, Goldstein RB, Li KC, Young SJ, Norton ME, Busse RF, Goldberg JD, Barkovich AJ. 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.
17. Ghi T, Carletti A, Contro E, Cera E, Falco P, Tagliavini G, Michelacci L, Tani G, Youssef A, Bonasoni P, Rizzo N, Pelusi G, Pilu G. Prenatal diagnosis and outcome of partial agenesis and hypoplasia of the corpus callosum. Ultrasound Obstet Gynecol. 2010;35(1):35–41.
18. Tang PH, Bartha AI, Norton ME, Barkovich AJ, Sherr EH, Glenn OA. Agenesis of the corpus callosum: an MR imaging analysis of associated abnormalities in the fetus. AJNR Am J Neuroradiol. 2009;30(2):257–63.
19. Dhouib A, Blondiaux E, Moutard ML, Billette de Villemeur T, Chalard F, Jouannic JM, Ducou le Pointe H, Garel C. Correlation between pre- and postnatal cerebral magnetic resonance imaging. Ultrasound Obstet Gynecol. 2011;38(2):170–8.
20. Senapati GM, Levine D, Smith C, Estroff JA, Barnewolt CE, Robertson RL, Poussaint TY, Mehta TS, Werdich XQ, Pier D, Feldman HA, Robson CD. Author information Frequency and cause of disagreements in imaging diagnosis in children with ventriculomegaly diagnosed prenatally. Ultrasound Obstet Gynecol. 2010;36(5):582–95.
21. Mitter C, Kasprian G, Brugger PC, Prayer D. Three-dimensional visualization of fetal white-matter pathways in utero. Ultrasound Obstet Gynecol. 2011;37(2):252–3.
22. Kasprian G, Brugger PC, Schopf V, Mitter C, Weber M, Hainfellner JA, Prayer D. Assessing prenatal white matter connectivity in commissural agenesis. Brain. 2013;136(Pt 1):168–79.
23. Farrell TA, Hertzberg BS, Kliewer MA, Harris L, Paine SS. Fetal lateral ventricles: reassessment of normal values for atrial diameter at US. Radiology. 1994;193(2):409–11.
24. Pier DB, Levine D, Kataoka ML, Estroff JA, Werdich XQ, Ware J, Beeghly M, Poussaint TY, Duplessis A, Li Y, Feldman HA. Magnetic resonance volumetric assessments of brains in fetuses with ventriculomegaly correlated to outcomes. J Ultrasound Med. 2011;30(5):595–603.
25. Vatansever D, Kyriakopoulou V, Allsop JM, Fox M, Chew A, Hajnal JV, Rutherford MA. Multidimensional analysis of fetal posterior fossa in health and disease. Cerebellum. 2013;12(5):632–44.
26. Beni-Adani L. Neurofetal counseling for cerebellar and posterior fossa malformations–where do we stand today? Commentary on "the fetal cerebellum: development and common malformations" by Garel et al. J Child Neurol. 2011;26(12):1480–2.

27. Weisz B, Hoffmann C, Ben-Baruch S, Yinon Y, Gindes L, Katorza E, Katorza E, Shrim A, Bar Yosef O, Schiff E, Lipitz S. Early detection by diffusion-weighted sequence magnetic resonance imaging of severe brain lesions after fetoscopic laser coagulation for twin-twin transfusion syndrome. Ultrasound Obstet Gynecol. 2014;44(1):44–9.
28. Garel C, Delezoide AL, Elmaleh-Berges M, Menez F, Fallet-Bianco C, Vuillard E, Luton D, Oury JF, Sebag G. Contribution of fetal MR imaging in the evaluation of cerebral ischemic lesions. AJNR Am J Neuroradiol. 2004;25(9):1563–8.
29. Prayer D, Brugger PC, Kasprian G, Witzani L, Helmer H, Dietrich W, Eppel W, Langer M. MRI of fetal acquired brain lesions. Eur J Radiol. 2006;57(2):233–49.
30. Carletti A, Colleoni GG, Perolo A, Simonazzi G, Ghi T, Rizzo N, Pilu G. Prenatal diagnosis of cerebral lesions acquired in utero and with a late appearance. Prenat Diagn. 2009;29(4):389–95.
31. Brunelle F. Brain vascular malformations in the fetus: diagnosis and prognosis. Childs Nerv Syst. 2003;19(7–8):524–8.
32. Sachet M, Tardieu M, Durand P, Ozanne A, Soubrier F, Tissieres P, Chevret L, Husson B, Adamsbaum C, Bellesme C, Senat MV, Ducreux D, Saliou G; Centre de référence des maladies neurovasculaires malformatives de l'enfant. [Medical care of brain malformative vascular diseases discovered during the pre- or neonatal period]. Arch Pediatr. 2013;20(1):74–81.
33. Lasjaunias PL. Brain and Spine AVMs, Vein of Galen Malformation. Treatments and Embryological Considerations. Interv Neuroradiol. 2003;9(3):263–72.
34. Kava M, Chitayat D, Blaser S, Ray PN, Vajsar J. Eye and brain abnormalities in congenital muscular dystrophies caused by fukutin-related protein gene (FKRP) mutations. Pediatr Neurol. 2013;49(5):374–8.
35. Poretti A, Boltshauser E, Huisman TA. Congenital brain abnormalities: an update on malformations of cortical development and infratentorial malformations. Semin Neurol. 2014;34(3):239–48.
36. Philpott CM, Widjaja E, Raybaud C, Branson HM, Kannu P, Blaser S. Temporal and occipital lobe features in children with hypochondroplasia/FGFR3 gene mutation. Pediatr Radiol. 2013;43(9):1190–5.
37. Wang DC, Shannon P, Toi A, Chitayat D, Mohan U, Barkova E, Keating S, Tomlinson G, Glanc P. Temporal lobe dysplasia: a characteristic sonographic finding in thanatophoric dysplasia. Ultrasound in obstetrics & gynecology: the official journal of the International Society of Ultrasound in Obstetrics and Gynecology. 2014;44(5):588–94.
38. McQuillen PS, Goff DA, Licht DJ. Effects of congenital heart disease on brain development. Progress in pediatric cardiology. 2010;29(2):79–85.
39. van den Hout L, Sluiter I, Gischler S, De Klein A, Rottier R, Ijsselstijn H, Reiss I, Tibboel D. Can we improve outcome of congenital diaphragmatic hernia? Pediatric surgery international. 2009;25(9):733–43.
40. Expert Panel on MR Safety, Kanal E, Barkovich AJ, Bell C, Borgstede JP, Bradley WG Jr, Froelich JW, Gimbel JR, Gosbee JW, Kuhni-Kaminski E, Larson PA, Lester JW Jr, Nyenhuis J, Schaefer DJ, Sebek EA, Weinreb J, Wilkoff BL, Woods TO, Lucey L, Hernandez D. ACR guidance document on MR safe practices: 2013. J Magn Reson Imaging. 2013;37(3):501–30.
41. Victoria T, Jaramillo D, Roberts TP, Zarnow D, Johnson AM, Delgado J, Rubesova E, Vossough A. Fetal magnetic resonance imaging: jumping from 1.5 to 3 T (preliminary experience). Pediatr Radiol. 2014;44(4):376–86; quiz 3–5.
42. Patenaude Y, Pugash D, Lim K, Morin L; Diagnostic Imaging Committee, Lim K, Bly S, Butt K, Cargill Y, Davies G, Denis N, Hazlitt G, Morin L, Naud K, Ouellet A, Salem S; Society of Obstetricians and Gynaecologists of Canada. The use of magnetic resonance imaging in the obstetric patient. J Obstet Gynaecol Can. 2014;36(4):349–63.
43. Thayyil S, Sebire NJ, Chitty LS, Wade A, Olsen O, Gunny RS, Offiah A, Saunders DE, Owens CM, Chong WK, Robertson NJ, Taylor AM. Post Mortem magnetic resonance imaging in the fetus, infant and child: a comparative study with conventional autopsy (MaRIAS Protocol). BMC Pediatr. 2011;11:120.
44. Ben-Sasi K, Chitty LS, Franck LS, Thayyil S, Judge-Kronis L, Taylor AM, Sebire NJ. Acceptability of a minimally invasive perinatal/paediatric autopsy: healthcare professionals' views and implications for practice. Prenat Diagn. 2013;33(4):307–12.
45. Griffiths PD, Variend D, Evans M, Jones A, Wilkinson ID, Paley MN, Whitby E. Postmortem MR imaging of the fetal and stillborn central nervous system. AJNR Am J Neuroradiol. 2003;24(1):22–7.