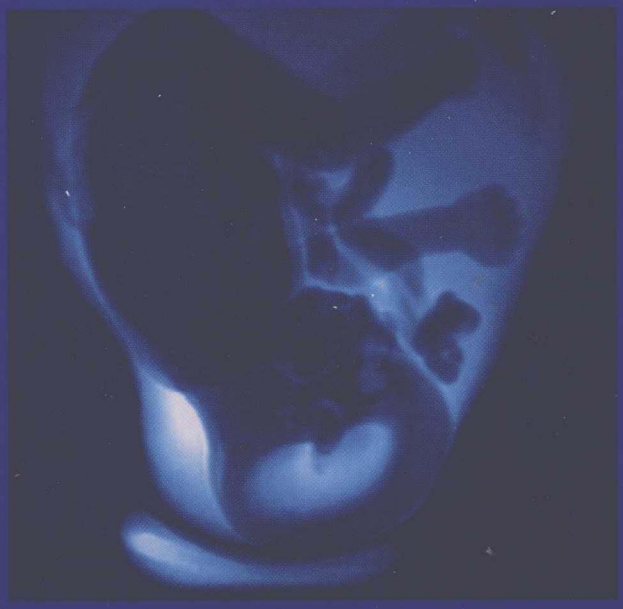
Medical Radiology

Diagnostic Imaging

A.L. Baert
M.F. Reiser
H. Hricak
M. Knauth

D. Prayer
Editor

Fetal MRI



Springer

Daniela Prayer (Ed.)

Fetal MRI

Foreword by
Albert L. Baert

Springer

Editor
Prof. Daniela Prayer
Medizinische Universität Wien
Klinik für Radiodiagnostik
Währinger Gürtel 18-20
1090 Wien
Österreich
daniela.prayer@meduniwien.ac.at

ISSN: 0942-5373

ISBN: 978-3-540-73270-9 e-ISBN: 978-3-540-73271-6

DOI: 10.1007/978-3-540-73271-6

Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2011921700

Cover design: eStudioCalamar, Figueres/Berlin

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword I

It is my great pleasure and privilege to introduce another volume, published in our book series: "Medical Radiology – Diagnostic Imaging," whose aim is to focus on cutting-edge developments in the field of medical imaging.

Fetal MRI is without doubt one of the most exciting applications in clinical MRI imaging. It offers superb and frequently unique anatomical information on several organs of the fetus such as the brain and the heart without the need for ionizing radiation.

Recent technical progress in equipment design, as well as in computer hardware and software laid the base for the development of fetal MRI as a clinical tool for routine radiological imaging.

The editor of this new volume – Dr. D. Prayer – is a pioneer and an internationally leading expert in the methodology and clinical applications of fetal MRI. She is well known for her excellent publications on translational research as well as clinical studies on fetal MRI. For the preparation of this book excellent contributions are provided not only by members of the fetal MRI team at the University hospital in Vienna but also by other internationally recognized experts in the field.

This book is the first handbook to offer a state-of-the art and comprehensive overview of the meticulous examination techniques and the specific sequences, which are essential for optimal image quality in fetal imaging. It further covers in depth all its current clinical applications as well as the safety issues.

The clear and informative text, the numerous well-chosen illustrations of superb technical quality, as well as the traditional Springer excellent standards of design and layout make this outstanding work a reference handbook for both certified general and pediatric radiologists. Also radiologists in training will find it very useful to improve their knowledge and their skills. Referring physicians such as gynecologists-obstetricians and pediatricians will benefit from it in order to better organize the clinical management of their patients.

It is my sincere wish and my firm conviction that this unique book will meet great success with the readership of our book series Medical Radiology – Diagnostic Imaging.

Leuven, Belgium

Albert L. Baert

Foreword II

Fetal MRI has made remarkable progress. Fifteen years ago, every case was a challenge: either the parent of the fetus (or both) required sedation; the mother needed to take shallow breaths for 2–3 min or try to hold her breath for the duration of an imaging sequence (while the radiologist and technologist held *their* breaths, hoping the fetus would not move). The development of the much faster half-Fourier acquisition single-shot sequences (HASTE, SSFSE) allowed images to be acquired in 1 s this revolutionized fetal imaging and made it practical for use in both medical centers and community hospitals. The addition of echo-planar techniques to evaluate for hemorrhage and diffusion-weighted imaging to assess for acute injury as well as for normal white matter development has made fetal MRI a flexible and highly useful tool in the assessment of normal fetal development and the detection of fetal disease. Moreover, the use of fetal MRI to assess fetal movements, thereby evaluating function as well as anatomy, has made fetal imaging a tool for understanding behavioral development, as is discussed in Chap. 9, by Drs. Einspieler and Prechtl.

This timely book by Dr. Prayer and her colleagues discusses many aspect of fetal imaging, from technical considerations to underlying developmental anatomy and pathophysiology to basics of fetal neurology. The technical aspects are very important to proper fetal imaging, and it is quite appropriate that four chapters be devoted to that topic. In addition, Chap. 5, which discusses the psychological state of the mother, will remind the imaging physician of the sensitivity required to properly perform one's role in any situation dealing with pregnancy. All organ systems are covered in the chapters of this book and all are written by physicians with both academic and practical experience. Importantly, the book goes beyond details of imaging the fetus. Chapter 23 discusses placental development and placental pathology, reminding us that the health of the placenta is strongly related to the health of the fetus. Chapter 24 deals with the difficult situation of multiplet pregnancies, which can create significant imaging, in addition to management, problems. Chapter 26 discusses postmortem MRI of the fetus, which is becoming an important tool for management of subsequent pregnancies, as it helps to establish a diagnosis in situations where autopsy is not possible. The book closes with a chapter on the impact of maternal diseases on pregnancy.

Overall, Dr. Prayer and her colleagues cover a wide range of timely and important topics. Although some of these are (currently) mainly of research interest, most are critical for proper diagnosis and management of fetal and maternal disorders. This book is another outstanding contribution to the growing field of prenatal diagnosis.

San Francisco, USA

A. James Barkovich

Preface

Driven by the ongoing technical and scientific progress, fetal MR imaging has evolved from an exclusively experimental prenatal imaging modality to a clinically important tool, which impacts decision making in the field of pre- and perinatal medicine. Nowadays, specialists involved in prenatal diagnosis are challenged with the demand to perform fetal MR examinations without the availability of basic reference with respect to methods, indications, MR appearance of maturing fetal and extrafetal organs, and pathological changes of intrauterine contents.

The aim of this book is to provide basic information about fetal MRI not only for the examiners but also for the referring clinicians. MR methods are described in detail and safety aspects are discussed. The prerequisites of fetal MRI are described including patient preparation as well as the appropriate selection of MR parameters for the respective clinical questions. In order to fully exploit the potential of this modality, the MR characteristics of normal and pathological organ development are described on various MR sequences, including advanced MR imaging techniques with illustration by numerous figures. The possibilities of intrauterine surgical therapy are described using the example of treatment of congenital diaphragmatic hernia. For better understanding of normal and pathological brain development, the histological basis of early human brain maturation is provided. Different aspects of fetal neuroimaging are discussed comprising ultrasound and MR approaches. Information that may help with interpretation of MR findings and their possible prognostic significance are summarized in chapters on genetics, maternal disease with possible impact on pregnancy, and postmortem MRI. In addition advice is given on how to treat postmortem specimens in order to obtain useful diagnostic clues. All authors have been working scientifically and practically in the field. Thus the reader should receive well-grounded information on each topic.

I would like to express my sincere gratitude to all the authors who contributed their work. In addition I would like to thank all colleagues, technicians, and students at my department who supplied their knowledge and time to get this project done.

I do hope that this book will become a companion for all who work in the field of prenatal diagnosis, and that it will provide helpful practical advice regarding the indications and performance of fetal MRI as well as the interpretation of findings.

Vienna, Austria

Daniela Prayer

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Indications for Fetal MRI

Daniela Prayer, Peter C. Brugger, and Ulrika Asenbaum

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Abstract

› Indications to perform fetal magnetic resonance imaging (MRI) can result from inadequate ultrasound assessment and/or intrinsic ultrasound disadvantages, compared to MRI, or can be associated with suspected malformative and/or acquired changes, and changes of extrafetal organs suspected or diagnosed by ultrasound. In addition, indications for fetal MRI can result from maternal or family history, and screening. MRI should be performed at the earliest time, an accurate diagnosis can be made, and, for special clinical questions, acutely or within 48 h. The highest MRI quality is required for fetal MRI. Absolute or relative contraindications should be considered before performing the MRI.

1 Introduction

"Modern" fetal MRI, beginning with the availability of T2-weighted ultrafast sequences (Levine et al. 1996) was primarily used for the examination of the fetal brain (Stazzone et al. 2000). T2-weighted contrast provides an excellent delineation between fluid (such as cerebrospinal fluid (CSF) and tissue (the developing brain)). Thus, sulcation/gyration, configuration, and width of

D. Prayer (✉) and U. Asenbaum
University Clinics for Radiodiagnostics, Medical University of Vienna, Währinger Gürtel 18-20, 1090 Vienna, Austria
e-mail: daniela.prayer@meduniwien.ac.at; ulrika.asenbaum@meduniwien.ac.at

P.C. Brugger
Integrative Morphology Group, Center of Anatomy and Cell Biology, Medical University of Vienna, Waehringerstrasse 13, 1090 Vienna, Austria
e-mail: peter.brugger@meduniwien.ac.at

D. Prayer (ed.), *Fetal MRI*, Medical Radiology,
DOI: 10.1007/174_2010_24, © Springer-Verlag Berlin Heidelberg 2011

the CSF spaces and deviations thereof, were studied first (Girard et al. 1995; Garel 2006). With the development of more contrasts (T1, diffusion, echoplanar) (Brugger et al. 2006), the MRI investigation of organs apart from the brain also became feasible (Hubbard et al. 1999; Shinmoto et al. 2000; Liu et al. 2001; Breysem et al. 2003; Levine et al. 2003; Osada et al. 2004; Gorincour et al. 2005; Kitano et al. 2005; Brugger and Prayer 2006; Kasprian et al. 2006; Prayer and Brugger 2007; Savelli et al. 2007).

Indications to perform fetal MRI may be divided into ultrasound (US)-related problems, confirmation/additional information for previously diagnosed or suspected pathologies, "specific" screening, which is related to a known genetic anomaly, pathologies that may lead to acute brain changes that might not be detectable by US, and assessment of lung development, especially in impending preterm birth (Kasprian et al. 2006).

2 MRI Indications When There are Ultrasound-Related Problems

2.1 Maternal Conditions

In cases, where the mother is obese, an elevated body mass index (BMI) might interfere with image quality on US. However, using MRI, examination of obese pregnant women may result in a poor image quality as well, as the receptor elements of the coil will be too distant from the region of interest. In addition, the use of a wrap-around coil will not be possible, and the built-in body coil does not allow a comparable image quality. However, in such cases, MRI usually provides more image detail than US (Fig. 1). Maternal abdominal scarring or dense hairs on the abdomen, sometimes a problem with US, are not difficulties for MRI.

2.2 Maternal/Fetal Conditions

MRI image quality is not impaired by oligohydramnios or anhydramnios. Furthermore, fetal position is unimportant. However, polyhydramnios may be associated with MRI imaging problems, as these fetuses tend to move more than those with a normal or a reduced amount of amniotic fluid. In addition, the fetus itself will be further away from the coil, and the circumference of the maternal abdomen will be large, resulting in problems as discussed above (Fig. 1).

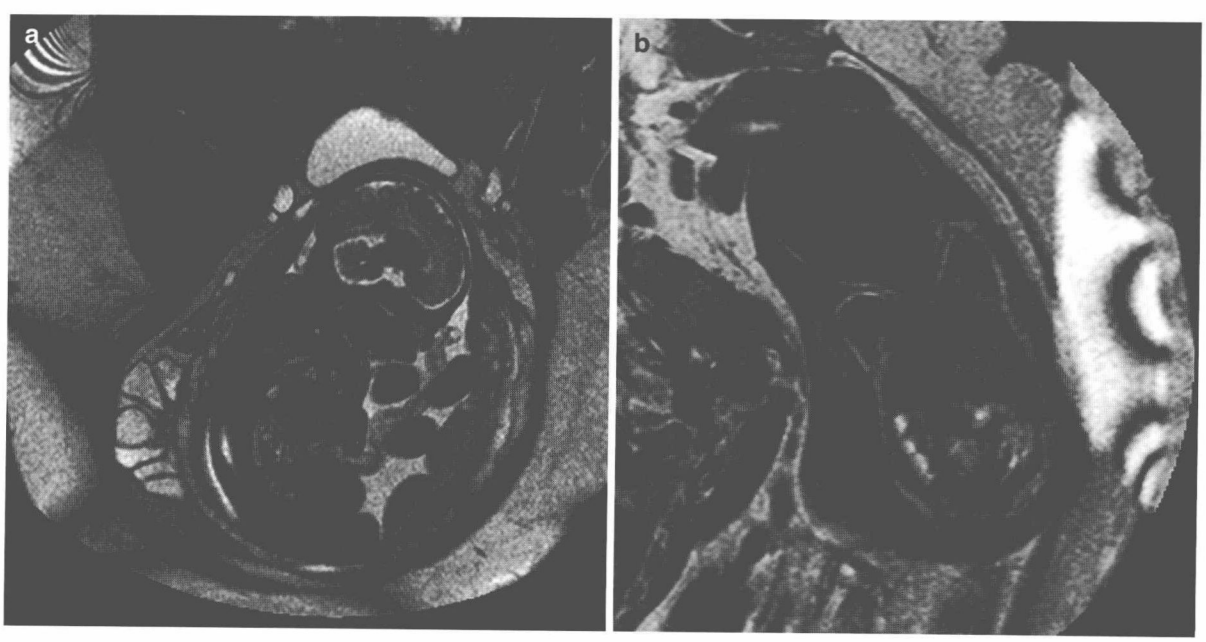

Fig. 1 Mother with high BMI at GW 35+5. Despite the reduced image quality, fetal structures can be evaluated sufficiently. (**a**) Sagittal T2-weighted image. (**b**) Coronal T1-weighted image with a fold-over artifact (*right lateral border* of the figure)

2.3 General Method-Related Conditions

US assessment uses a sector-shaped field of view that does not exceed a certain size. Thus, especially in the later second trimester, and in the third trimester, it is not possible to visualize the fetus as a whole at one time. This may impair, for instance, assessment of fetal behavior (de Vries et al. 1985).

3 MRI Indications When There are Sonographically Diagnosed or Suspected Pathologies

3.1 Cerebral Malformations

Gross malformations are readily detected by US (Angtuaco et al. 1994), most during the first trimester, when MRI is not used (American College of Obstetricians and Gynecologists 1995). Malformations of cortical development have also been reportedly visualized by US (Toi et al. 2004; Malinger et al. 2006). However, diagnosis of lissencephaly before the onset of gyration can be difficult. In that case, MRI may be helpful in demonstrating pathologic lamination of the brain mantle (Fig. 2). In addition, brainstem deformities, which are a salient feature of lissencephaly, can be easily delineated with MRI. Focal cortical dysplasia may not manifest itself before the late second trimester (Fig. 3). Other malformations, involving small structures, such as the olfactory bulbs, could be recognized earlier (Azoulay et al. 2006). Arachnoidal cysts may grow, and eventually obstruct CSF spaces and/or compress tissue that might undergo damage. These situations can be recognized with MRI. Preterm delivery to drain such cysts extrauterinely might be a consequence. Uni- or bilateral ventricular enlargement of more than 15 mm may be associated with any malformative or acquired pathology (Tauscher 2008). In isolated ventriculomegaly, smaller than 15 mm, the presence of a pathology is not likely (Tauscher 2008).

3.2 Cerebral Acquired Pathologies

Recent ischemic lesions (the presence of which may be indirectly indicated by deterioration of Doppler values

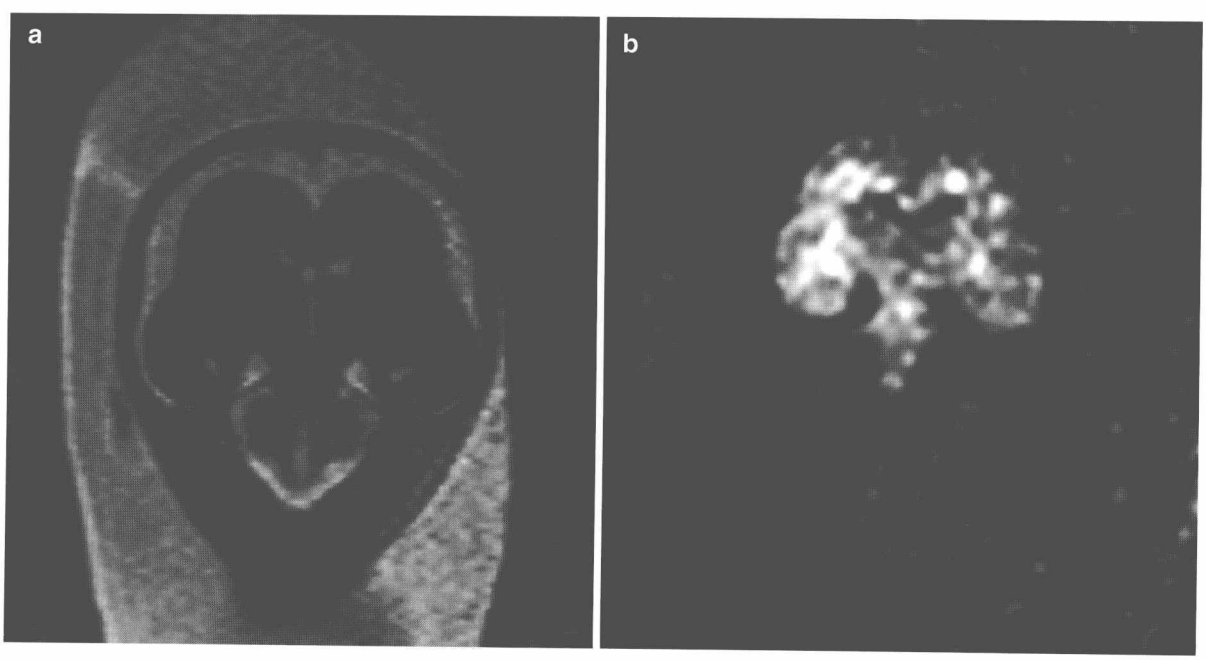

Fig. 2 Coronal T2-weighted images (**a**) and diffusion-weighted images (**b**) showing the disturbed lamination and too shallow insula indentation indicating the presence of lissencephaly I at GW 24+3

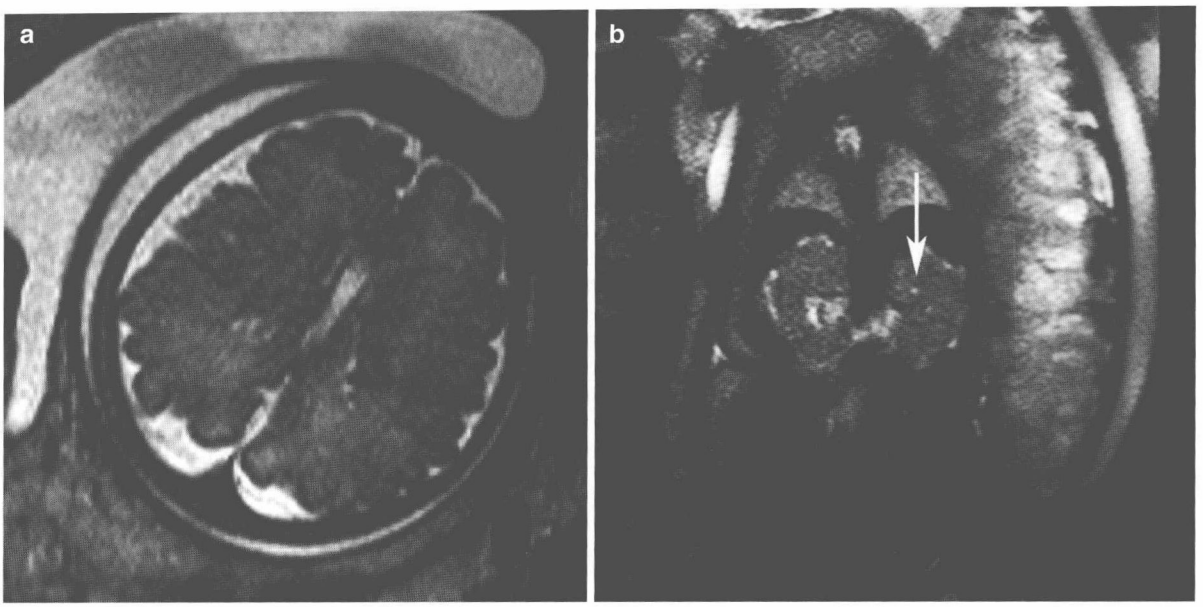

Fig. 3 Bourneville Pringle syndrome at GW 33+1. (**a**) Subependymal nodules, right frontal focal cortical dysplasia (axial T2-weighted image); (**b**) the kidneys with small cysts (*arrow*, coronal T2-weighted image)

in the medial cerebral artery, as has been described in growth-restricted fetuses (Mari and Hanif 2008)) appear bright on diffusion-weighted images before showing T2-weighted signal changes. Acute hemorrhage will display a signal loss on T2*, EPI-, and, to a lesser degree, also on T2-weighted sequences (Prayer et al. 2006). Brain edema will lead to a blurring of intracerebral signals on all sequences, obscuring lamination or no longer providing the delineation of premyelinating/myelinating structures (Fig. 4). In addition, inner and outer CSF spaces will become narrow. In case of cystic defects that are seen by US, MRI may point toward the acquired etiology by showing blood breakdown products (Fig. 5). While US can readily detect blood clots, hemorrhagic fluid might not be resolved. MRI identification of blood-breakdown products can also be helpful in cases of aqueduct stenosis (Fig. 6), when blood clots are identified or excluded as an underlying reason. Calcified lesions are detected more sensitively by US.

3.3 Metabolic Assessment of the Fetal Brain

Proton spectroscopy provides an insight into the metabolic changes associated with normal brain development (Kok et al. 2002). Deviations thereof may be recognized, and can provide insights into pathological processes associated with hypoxic ischemic injury (Garel 2006).

3.4 Extracerebral Pathologies

3.4.1 Malformations and Tumors Involving Single Organs or Organ Systems

Face

Clefts may involve only the lips or may include the maxilla and the soft and hard palate (Robson and Barnewolt 2004). Those involving just the hard palate, without involvement of surface structures, are easily missed by US (Fig. 7). MRI has been shown to provide additional information in the workup of facial clefts (Mailath-Pokorny et al. 2009). The tongue and its movements are readily identified. However, it should be noted that tongue hyperplasia, which leads to protrusion, might be present only from the late second trimester onward (Fig. 8). Malformations of the inner ear are detectable, as the fluid-filled cochlea and semicircular canals can be seen even in 20-week fetuses. Eyes (form, size, orbital content, intraocular distance) may be equally well determined by MRI as by US.

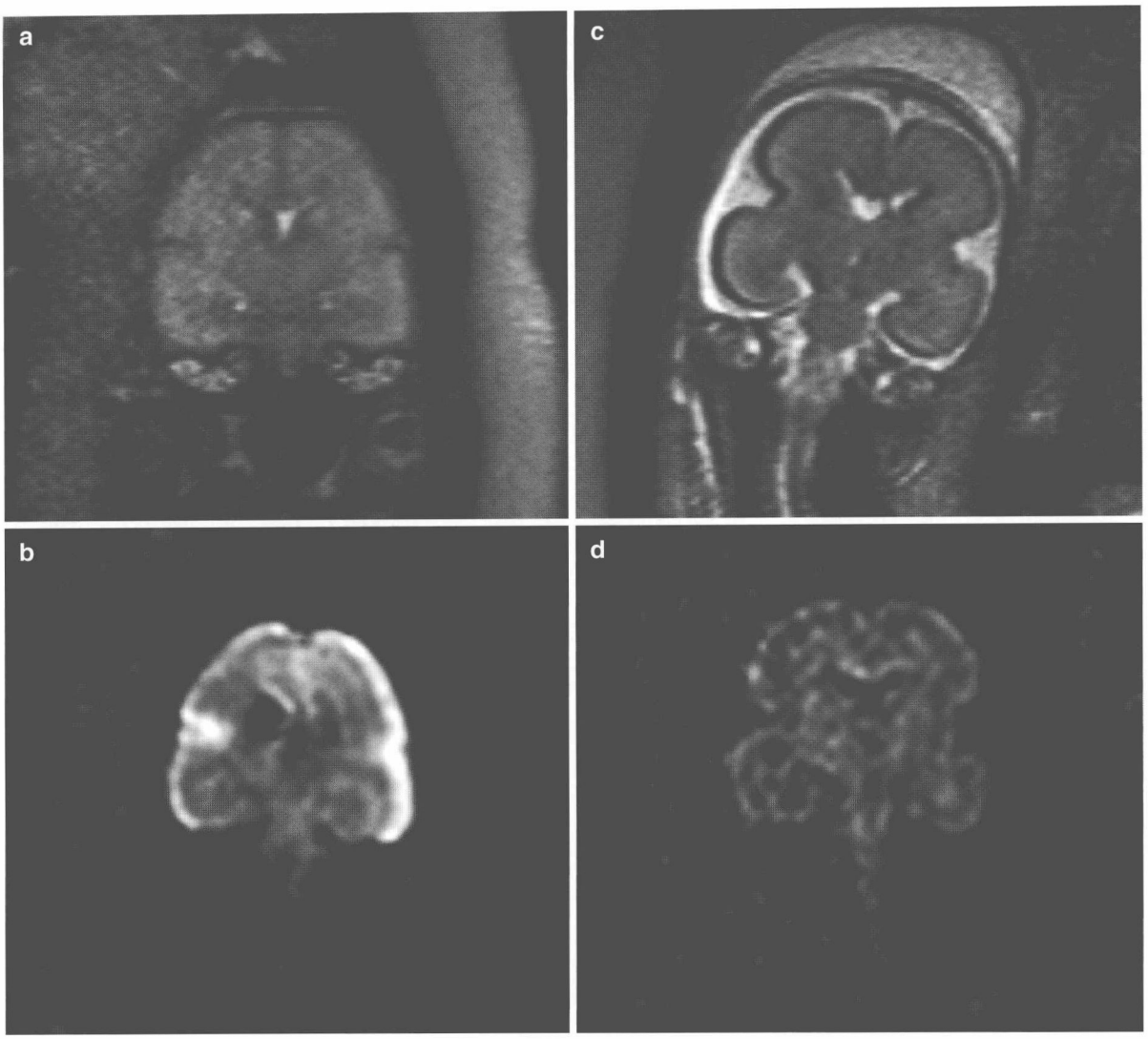

Fig. 4 (**a**, **b**) Global brain edema at GW 24+3; (**c**, **d**) normal subjects at GW 24+1 (**a**, **c**) coronal T2-weighted images. (**b**, **d**) coronal diffusion-weighted isotropic images. Lamination of the brain parenchyma cannot be delineated (**a**, **b**) in contrast to (**c**, **d**). Outer CSF spaces are consumed (**a**, **b**). Edema of the cortical plate in **b** (hyperintense signal)

Dacryocystoceles are detectable using MRI (Brugger and Prayer 2008).

Neck

Spaceoccupying lesions in this region tend to narrow and/or displace the trachea and/or the esophagus. Narrowing or displacement of the trachea carries the possible necessity of an ex utero intrapartum treatment (EXIT) procedure. In such cases, MRI has been shown to be able to locate the position of the trachea (Prayer and Brugger 2007). In case of esophageal obstruction, US will be able to describe only a small or undetectable stomach and polyhydramnios. MRI can be expected to prove the presence of a pouch sign in the esophagus in such cases (Fig. 9). In addition, MRI might be able to identify a small fluid-filled stomach by the characteristic appearance of its mucosa. With regard to the differential diagnoses of neck tumors, MRI may help in differentiating cystic (hem) angiolymphomas from teratomas (Fig. 10). The visualization of the carotids and jugular veins allows identification of pathologies, such as, for instance,

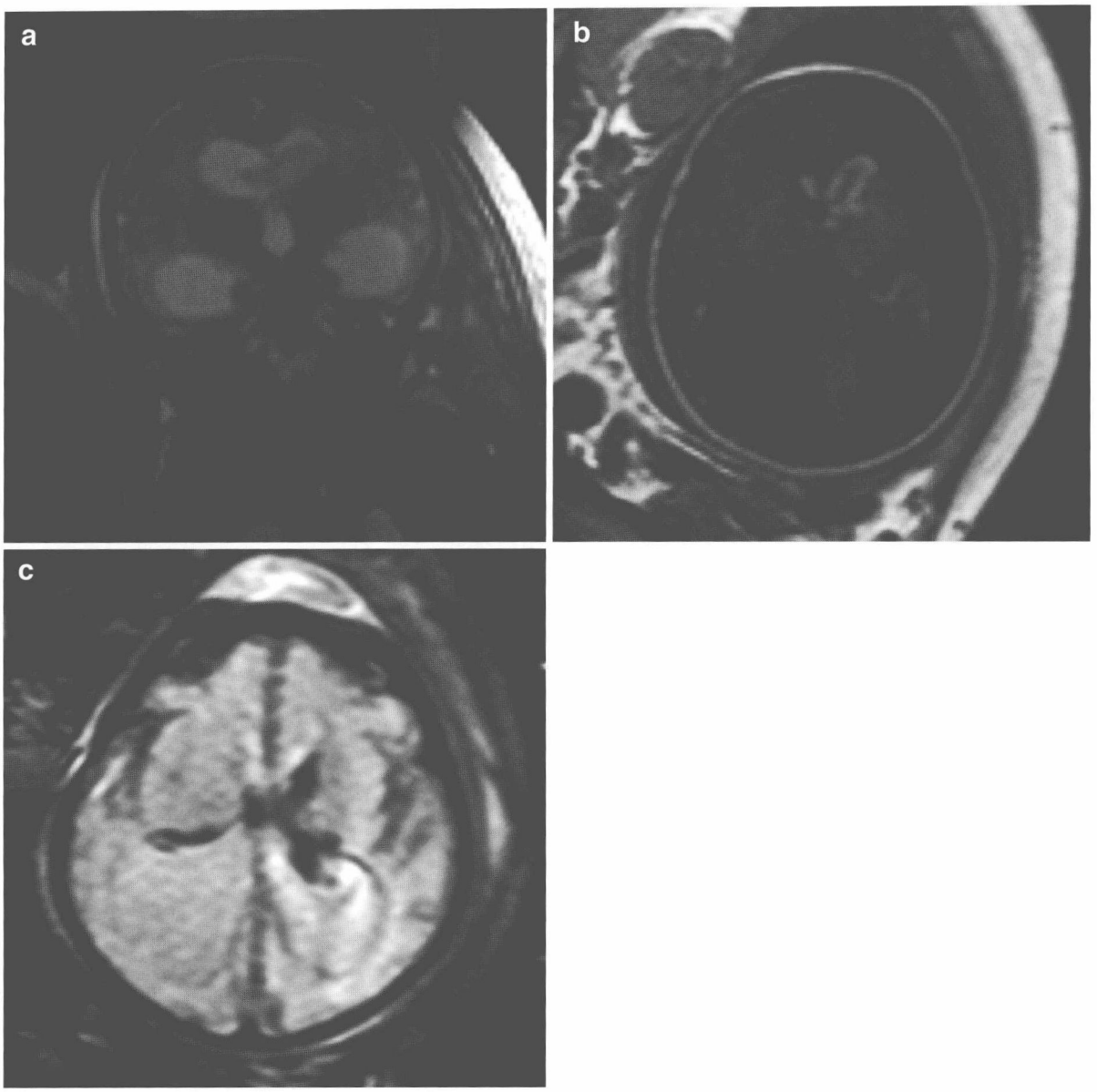

Fig. 5 Posthemorrhagic hydrocephalus at GW 36+6. Wide ventricles and blood-breakdown products adjacent to the ependyma (hypointense T2-weighted images) (**a**, coronal), and on the EPI sequence (**c**, axial), and hyperintense on T1-weighted images (**b**, axial)

wide jugular veins in the presence of a Galeni aneurysm (Fig. 11).

Thorax

Intrapulmonary malformations, such as congenital cystic adenomatoid malformations (CCAM), sequestrations, and bronchogenic cysts, can be readily differentiated from each other. MRI-based lung volumetry enables determination of the percentage of normal lung tissue in such cases. Follow-up studies may provide a clue to the relative growth of the lesion with respect to the normal lung. Cardiac malformations are currently not an indication to perform a fetal MRI. However, the position and diameter of the great

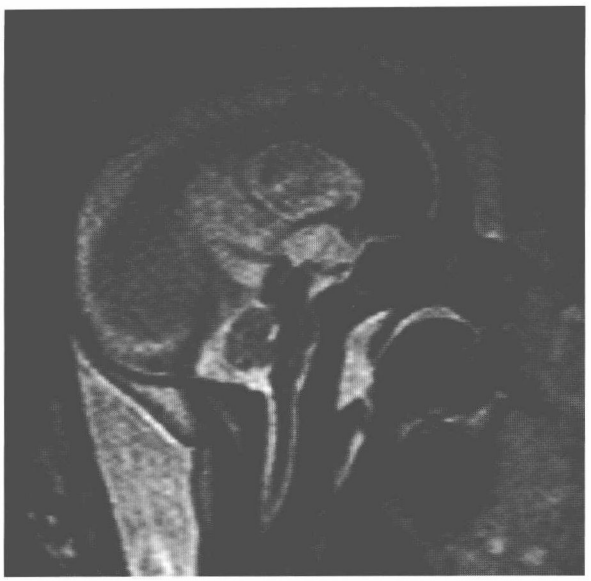

Fig. 6 Aqueduct stenosis with typical v-shaped configuration of the aqueduct in the cranial aspect (median sagittal T2-weighted sequence). Blood-breakdown products are not shown

vessels may be better determined with MRI than with US (Fig. 12). The thymus is difficult to delineate in second trimester fetuses: thus, the early detection of Di George syndrome (Chaoui et al. 2002) is not an indication to perform MRI.

Small and Large Bowels

Due to their age-dependent fluid or meconium filling, bowel loops can be identified. Thus, displacement, malrotation, changes of the luminal width, or agenesis can be recognized (Prayer and Brugger 2007). In case of enlargement, the visualization of peristaltic waves may allow the identification of the involved part of the bowel. Poststenotic widened parts often show abnormal meconium signals (T1-weighted not as bright as usual) (Fig. 13).

Liver and Spleen

As the liver can be clearly differentiated by its characteristic T1- and T2-weighted appearance compared to its surroundings, its position, size, and configuration can also be assessed. This is important in case of abnormal symmetry, indicating the presence of heterotaxy, or displacement into the thorax in congenital diaphragmatic hernia (Cannie et al. 2008). Pathological signals may be present, for instance in liver cirrhosis (Brugger and Prayer 2006) or in hemochromatosis (Marti-Bonmati et al. 1994; Coakley et al. 1999). Identification of the gall bladder is possible, regardless of its contents, because sludge,

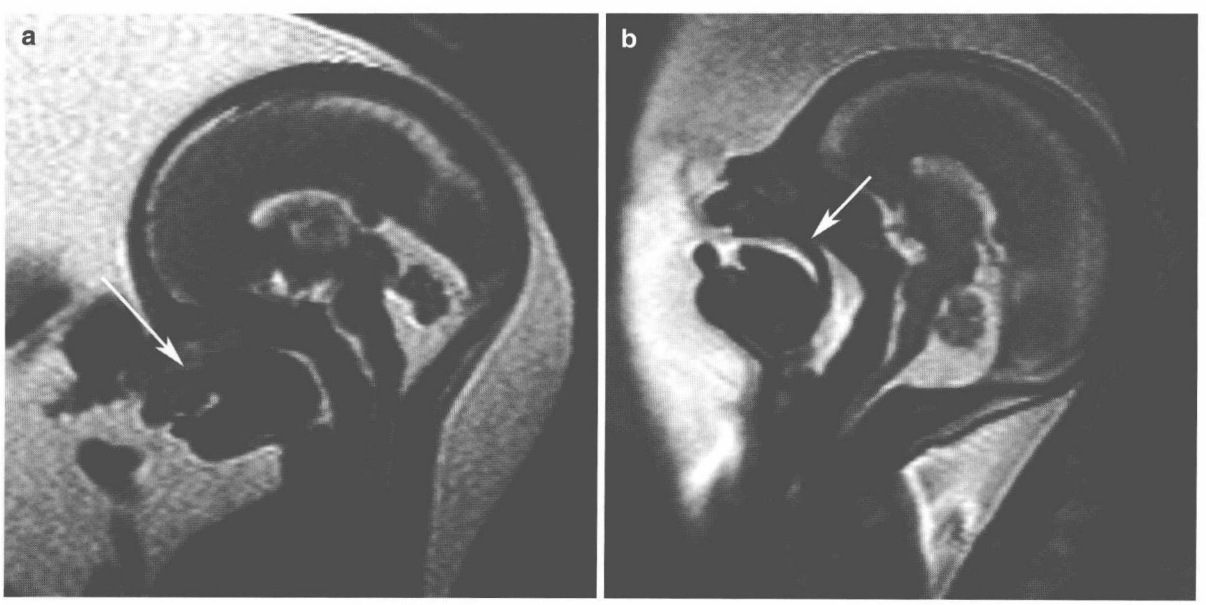

Fig. 7 Isolated hard palate cleft. Median sagittal T2-weighted-image (**a**) GW 24+0, hard palate absent (*arrow*), (**b**) GW 24+1, hard palate present (*arrow*)

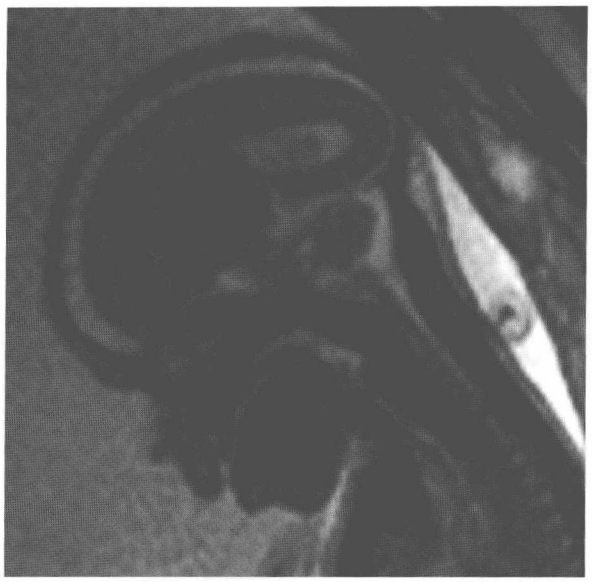

Fig. 8 Beckwidth–Wiedemann syndrome at GW 32+6: protruding tongue (median sagittal T2-weighted image)

which may prevent the identification of the gallbladder on US, shows characteristic signals on MRI (Brugger and Prayer 2006). Identification of the spleen(s) is required in heterotaxy, as the absence of a spleen might be associated with a worse prognosis than the presence of multiple spleens (Applegate et al. 1999).

Urogenital System

The identification of misplaced kidneys on US might be difficult in young fetuses (Poutamo et al. 2000; Cassart et al. 2004). Due to their appearance on diffusion-weighted images (Witzani et al. 2006), MRI can show kidneys at any fetal age (Fig. 14). This is especially important in case of oligohydramnios or anhydramnios, where US assessment is impaired. Ureters and the urethra can be identified when widened (Fig. 15). The bladder itself might have to be differentiated from other cysts, which can usually be accomplished successfully. In assessment of the genitals, MRI has no advantage compared to US. One exception to this is the delineation of complicated ovarian cysts (with intracystic hemorrhage, indicating torsion). They may present with signals typical of structures that contain blood breakdown products (Fig. 16).

Cysts and Tumors

Cysts may be a part of any malformation or of a tumor. The determination of the originating organ and the respective signals may help with differential diagnoses.

Thus, a bronchogenic cyst may display different signals from amniotic fluid, allowing differentiation from a CCAM cyst. Tumors may have a characteristic MRI appearance, such as, for instance, the wheel-like structure of a hepatoblastoma. Teratomas have cystic and solid parts, and lymph (hem) angiomas are primarily cystic with rare intracystic hemorrhages. Neuroblastomas are known to prefer certain localizations (Siegel and Jaju 2008) and display a rather solid appearance.

Musculoskeletal System

Using special sequences (based on EPI imaging), the parts of the bony skeleton can be identified with MRI. Based on the knowledge of the temporal appearance of the ossification centers, the presence of a skeletal dysplasia can be recognized. Whether MRI might be more sensitive in these cases than US, has yet to be proven. In case of spina bifida, the defect can be identified. By visualizing the neural structures at the same time, a differential diagnosis between the types of dysraphic malformation can be achieved. With increasing gestational age, skeletal muscles become isointense to bone. In case of muscle dystrophy, they may have different signals (Fig. 17).

3.4.2 Complex Pathologies

Complex pathologies may have a genetical background. Thus, one of the main tasks for MRI is the definition or exclusion of the presence of a syndrome with a known prognosis. From the MRI point of view, this means that in any case of pathology, the whole fetus must be examined. Malformations of the brain and face, may indicate, for instance the presence of trisomy 13 (Nemec et al. 2009). In case of certain abdominal pathologies, the lower spinal situation must be clarified to exclude or prove a caudal regression syndrome complex (Ertl-Wagner and