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Review

Non-central nervous system fetal magnetic resonance imaging

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SUMMARY

Fetal magnetic resonance imaging (MRI) is currently offered in a limited number of centers but is predominantly used for suspected fetal central nervous system abnormalities. This article concentrates on the role of the different imaging sequences and their value to clinical practice. It also discusses the future of fetal MRI.

1. Introduction

Magnetic resonance imaging (MRI) of the fetal central nervous system (CNS) was first suggested in 1983 [1]. Its success was limited by fetal motion. In France, curare was injected into the umbilical cord to effectively paralyze the fetus for the duration of the scan [2]. In the USA, high doses of maternal sedation were preferred [3,4]. In the UK, fetal MRI did not really start until the late 1990s when ultrafast sequences were developed, effectively "freezing" fetal motion without any intervention [5]. A flurry of research followed from a small number of centers [6–9]. Initially, all imaging was T2-weighted (T2W) and this has remained the workhorse sequence of fetal MRI. The research was influenced by local laws pertaining to termination of pregnancy. In countries where terminations are only allowed in early pregnancy the imaging was done earlier in gestation – for example, Italy, where groups have published normative data prior to 24 weeks' gestational age [10]. Others, such as France, have provided more data from 24 weeks to birth and are gradually adding growth curves for earlier gestational ages [11].

There are numerous reviews [12–14] and research papers [15–17] on the value of fetal MRI for CNS abnormalities. A recent systematic review is an ideal starting point [18].

Movement into clinical practice has been gradual but by the early 2000s there was a smattering of centers in the UK offering MRI evaluation of the fetal CNS, often provided by neuroradiologists or paediatric neuroradiologists, and imaging of other areas of the fetal body were essentially neglected. A few centers developed their services because of an interest by obstetric radiologists, and these centers currently image a wider spectrum of pathology. With respect to fetal CNS imaging, research centers are looking beyond diagnoses based on gross structure and now examine CNS development using spectroscopy and tractography techniques. These are technically more challenging and often time-consuming. The success rate is low but there is the potential to diagnose the more complex abnormalities in greater detail. This may give parents more information upon which to base clinical decisions.

1.1. Current UK service and best practice

In the UK currently there are enough centers to provide adequate service for the population if patients are willing to travel, and if clinicians are aware of the available services and know whom to contact. We have not yet developed a robust network and referral pattern. Also needing further refinement are the imaging parameters and sequences best used for different pathologies.

Fetal MRI for all body-regions should be an adjunct to ultrasound and will remain a targeted examination, following an abnormal ultrasound examination, not a screening tool. However, all the information on the image should be used, so that, even if not formally examined, the placenta, uterine cavity, and other areas of the fetus that appear in the images should be given some consideration. Centers with easy access to good quality fetal MRI will use it more frequently and often supplant a repeat ultrasound examination. Fetal MRI should be used as part of the multi-disciplinary team (MDT) approach to patient management.

Most centers agree that the workhorse sequence is a T2-weighted (T2W) steady-state fast spin echo (SSFSE), in three orthogonal planes of the body area of concern. Most centers include

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a T1W image in at least one orientation. Good quality images can usually be obtained within 20–30 min.

Other useful sequences include diffusion-weighted imaging (DWI) and balanced gradient echo. A three-dimensional T2W, balanced gradient echo is also useful to allow reformatting; however, the spatial resolution remains low, and currently these are not good enough to replace single plane T2W SSFSE images, especially at 1.5 Tesla (T).

The choice of coil depends on local availability. Most centers use a surface array body coil placed over the area to be imaged; cardiac coils can also be used but require careful positioning and may need re-positioning during the scan, especially in later gestation, and this will increase the examination time.

In practice, we have observed that the fetus settles with repeated similar noises, so it is advisable to do all T2W sequences first, then moving on to T1W sequences and finishing with the DWI, as this is the loudest and longest sequence.

The resting state of the mother is also important as this affects the quality of the images. A relaxed mother will result in a relaxed, quiet fetus whereas a stressed mother causes increased fetal movements. Explaining the procedure and making the mother comfortable both increase the image quality. The woman should be placed feet-first into the scanner to avoid claustrophobia. If possible, she should be imaged in the most comfortable position for her; the semi-decubitus position will avoid hypotension from the uterus compressing the inferior vena cava and preventing venous return. Certain scanners are designed such that a semi-decubitus position is difficult because of the nature of the surface body coil, and if the woman is able to lie supine, she can be imaged in this position. Pads and cushions should be used to support the mother's body and to encourage her to relax. Women who return for a follow-up scan are often more relaxed than for the first scan, and this improves the imaging quality. Some American groups provide juice and cookies 15 min prior to the examination, whereas some French groups advocate nothing by mouth for a few hours prior to the examination (E. Whitby, personal communication).

Each set of images is based on the previously acquired set. This is a non-conventional approach to imaging for the MR radiographers, who are used to planning from several image sets to obtain a good anatomical imaging plane. As the fetus is in continual motion, speedy positioning from the last sequence is the most reliable way to obtain good images. Most radiographers can adapt to this technique, and, with experience, the speed at which they can select the sequences and position for them increases, enhancing the quality of the images.

2. Sequences for fetal MRI

2.1. T2-weighted imaging

The T2W image provides the most anatomical detail in all areas of the fetus. On this image, the brain, lungs, kidneys, bladder, stomach, small and large bowel, liver, and gall bladder are clearly seen. Other structures are sometimes seen but are not always evident, and these include the fetal adrenal glands and pancreas.

The detail seen in the fetal brain is aided by the inherent contrast difference between the parenchyma (dark) and the cerebrospinal fluid (CSF) (bright). Structural abnormalities are detected on this sequence and the location of organs with associated defects can also be determined such as the contents of an exomphalos (Fig. 1), the contents of the hemithorax in congenital diaphragmatic hernia (CDH), displacement by tumors, and so forth. The anatomical detail is often useful to plan postnatal surgery and to discuss this with the parents prior to delivery. In a few centers, a fetal MRI is performed at 34–36 weeks' gestation to avoid the need for postnatal imaging prior to surgery.

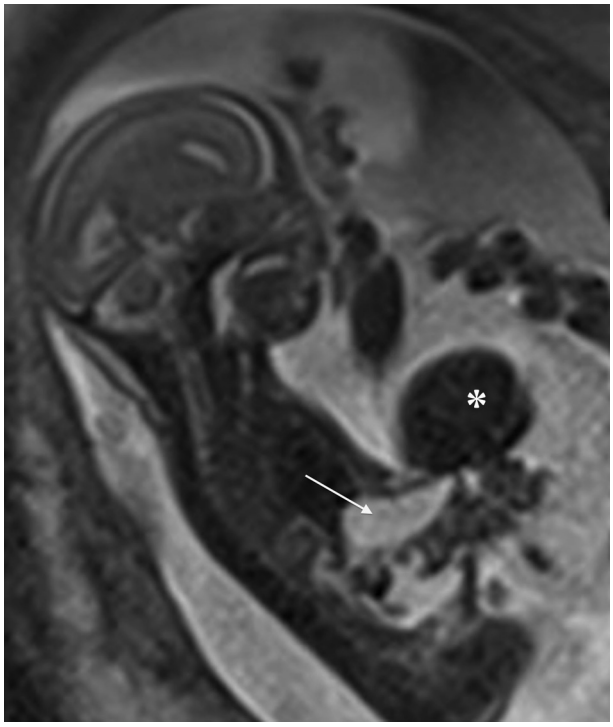

Fig. 1. Exomphalus, 20 weeks' gestation. T2-weighted image, sagittal section. All the liver *, most of the stomach (arrow) and some of the bowel are outside the fetal abdomen.

The T2W sequence is useful for all types of lung pathology. Fetal MRI can securely differentiate between congenital cystic pulmonary lesions (Fig. 2a) and a CDH with just the bowel in the thorax (Fig. 2c and d). It is also extremely useful for imaging any cystic lung lesion to define the cyst and its origin, e.g. neuroenteric, bronchogenic (Fig. 2b), or duplication cyst. Infradiaphragmatic pulmonary sequestrations can be assessed; they are the same signal intensity as the lung, usually located adjacent to the diaphragm and are often wedge-shaped. They are easier to define as separate from the adjacent organs with fetal MRI than with ultrasound.

There are still limitations with the T2W sequence even for structural information – the heart is seen as a dark signal area, and there is little detail in fetal bones. Pathologic diagnosis is often enhanced by additional sequences.

2.2. T1-weighted imaging

The detail in the T1W image is limited, partly because of low spatial resolution and partly because of little inherent T1 contrast in the tissues secondary to their large water content, leading some people to underestimate its clinical value. The normal thyroid tissue is evident as two small tiny areas of brightness in the fetal neck. The normal liver is bright on T1, and this is valuable to locate small areas of liver in CDH (Fig. 2d). Meconium is also bright on T1W imaging, raising possibilities for fetal MRI to be used to diagnose bowel pathology. However, be aware that fetal fat is not bright on T1 until mid-third trimester and this is often a source of error, especially in diagnosing lipomas associated with corpus callosal abnormalities and spinal defects.

Hemorrhage is bright on T1W imaging. It is useful to acquire a T1W image in at least one orientation for every fetal MRI scan