Fetal cerebral imaging – ultrasound vs. MRI: an update

Eléonore Blondiaux and Catherine Garel
Department of Radiology, Hôpital d’Enfants Armand-Trousseau, Paris, France
Correspondence to: Catherine Garel. Email: catherine.garel@trs.aphp.fr

Abstract
The purpose of this article is to analyze the advantages and limitations of prenatal ultrasonography (US) and magnetic resonance imaging (MRI) in the evaluation of the fetal brain. These imaging modalities should not be seen as competitive but rather as complementary. There are wide variations in the world regarding screening policies, technology, skills, and legislation about termination of pregnancy, and these variations markedly impact on the way of using prenatal imaging. According to the contribution expected from each technique and to local working conditions, one should choose the most appropriate imaging modality on a case-by-case basis. The advantages and limitations of US and MRI in the setting of fetal brain imaging are displayed. Different anatomical regions (midline, ventricles, subependymal area, cerebral parenchyma, pericerebral space, posterior fossa) and pathological conditions are analyzed and illustrated in order to compare the respective contribution of each technique. An accurate prenatal diagnosis of cerebral abnormalities is of utmost importance for prenatal counseling.

Keywords: Prenatal diagnosis, fetal brain, ultrasonography, magnetic resonance imaging, fetal diseases

Submitted June 22, 2012; accepted for publication July 21, 2012

The purpose of this article is to analyze the advantages and limitations of prenatal ultrasonography (US) and magnetic resonance imaging (MRI) in the evaluation of the fetal brain. Fetal MRI has been developing in routine prenatal practice for more than 20 years. Over the last two decades, the quality of US and MRI equipment and the level of experience of both sonographers and radiologists have dramatically increased, therefore reducing the gap between these two modalities. Evaluation of the fetal brain still remains the main field of application of fetal MRI. However, most of the following general considerations may also apply to the analysis of the rest of the fetal body. US and MRI should not be seen as competitive but rather as complementary. According to the contribution expected from each technique and to local working conditions, one should choose the most appropriate imaging modality on a case-by-case basis. An accurate prenatal diagnosis makes prenatal counselling as accurate as possible. In this article, different anatomical regions and pathological settings will be analysed in order to compare the respective contribution of each technique. Before entering the heart of the matter, we would like to offer some general considerations.

General considerations
There is no one way of practicing fetal imaging, nor is there one truth. There are wide variations in the world regarding screening policies, technology, skills, legislation about termination of pregnancy (TOP), and women’s attitude towards TOP. The rate of detection of certain malformations, which is very different from one place to another, reflects these variations (1, 2). In most places in the world, US is performed by gynecologists and MRI by radiologists. Very few perform both imaging modalities. This fact accounts for a particular way of working, each profession being partially unaware of the difficulties encountered by the other.

Both US and MRI are operator-dependent modalities, as is every medical activity. It is very difficult with prenatal US to acquire clear images in an anatomical plane identical to those obtained postnatally with CT and MRI. Of course, such images should help determine the anatomical localization of a lesion, which is one of the clues to reach many diagnoses. Some authors claim the supremacy of US in most instances and the uselessness of performing MRI. However, it must be stressed that if certain pathological conditions may be detected through US by only around 50 people in the world, it cannot be considered a reliable technique.

Performing MRI is also operator-dependent, as the use of some sequences or the acquisition of images in a certain plane is sometimes a clue for the diagnosis. Moreover, reader variability has been reported in the evaluation of cerebral abnormalities (3).
Let us not champion one modality over the other. Both prenatal US and MRI are complementary and the truth lies in between.

Advantages and limitations of prenatal US and MRI

US: advantages
- Real-time exploration of the fetus
- Easily accepted, pleasant
- May be easily and frequently repeated
- Easy access
- Low cost
- May have an excellent spatial resolution
- May depict calcification
- Possibility of visualizing the vessels and evaluate the Doppler spectrum (flux direction, increased velocities, arteriovenous fistula, etc.)

US: limitations
- Hampered by maternal body habitus (obesity is increasing worldwide) and oligohydramnios (however, analyzing the brain is often possible in this setting unless in case of breech presentation, when the fetal head cannot be mobilized in order to acquire images in different planes)
- May be hampered by fetal presentation
- Poor contrast resolution
- Poor evaluation of diffuse white matter abnormalities
- Impossibility of depicting certain structures: olfactory bulbs, pituitary stalk, and gland
- Artifacts hampering the visibility of the near-field hemisphere
- Visibility of the cerebral surface possible only if enlarged pericerebral space. The cortical ribbon is not directly analyzed
- Supratentorial space: impossibility of measuring the brain (biometry of the skull)
- Produces images that may be unclear for non-professionals and particularly for the parents

MRI: advantages
- Is not hampered by maternal body habitus and oligohydramnios
- Good contrast resolution: may depict hemorrhage, small cavitations, fat (not always)
- Can evaluate diffuse white matter abnormalities better than US (however, diagnostic difficulties also occur)
- Can depict certain structures: olfactory bulbs, pituitary stalk, and gland
- Provides good visibility of the whole brain independently of the fetal presentation
- Provides good visibility of the cortical ribbon, even when the pericerebral space is thin (end of pregnancy)
- Makes it possible to measure the brain itself in the supratentorial space
- Produces slices easily in the three planes of the space
- Produces easily understandable and explainable images

MRI: limitations
- Except for dynamic sequences, absence of real-time evaluation
- Generates maternal anxiety (4, 5)
- May not be possible to perform in case of marked maternal obesity (the diameter of the unit may be too small)
- Difficulties in repeating an examination
- Difficult access in some countries
- High cost
- Poor spatial resolution, depending on the fetal presentation and the distance between the fetal brain and the coil
- May be hampered by fetal motion (possibility of maternal sedation, used in some sites)
- May overlook calcifications
- May depict cerebral vessels but cannot evaluate the flux within the vessels

Contribution of US and MRI in the analysis of different anatomical regions and the evaluation of certain pathological conditions

The following lines are based on the literature but mainly on one (CG) of the author’s more than 20 years of experience in both prenatal US and MRI. Therefore, they are not the results of a systematic statistical analysis and they do not purport to reflect the full reality. The authors are aware that each assertion might easily be contradicted by at least one example.

The midline

The corpus callosum is well depicted by US and MRI. However, it must be emphasized that usually the rostrum, the genu, and the anterior part of the body are better delineated by US, while the posterior part of the body, the isthmus, and the splenium are better visualized by MRI (Fig. 1). The late development of the splenium and the absence of modeling of the corpus callosum during fetal life (6) result in a very thin splenium, which is better depicted by MRI due to its better contrast resolution.

For the same reason: certain types of partial callosal agenesis with only a part of the genu being present are better visualized by US and may be missed by MRI (7); and the boundaries of a complete but thin corpus callosum are sharper with MRI (Fig. 2) and measuring such types of corpus callosum with US is usually less accurate.

Unless US is performed under unfavorable conditions, it has the same accuracy as MRI for diagnosing callosal agenesis.

Pericallosal lipomas are usually well demonstrated by US and MRI, mainly during the third trimester of pregnancy.
MRI may help for the evaluation of frequently associated callosal dysgenesis (8).

Interhemispheric cysts that may also be associated with corpus callosum abnormalities are easily diagnosed by US and MRI. Additional polymicrogyria occasionally lining the cyst is better visualized by MRI (9) but may also be overlooked by this technique (7).

The cavum septi pellucidi is well demonstrated by each method and both can show septal agenesis, which may be partial or complete. Septooptic dysplasia is characterized by the association with optic nerves hypoplasia and/or hypothalamo-pituitary axis disorders. In this setting, MRI is more accurate than US being that the optic nerves and the pituitary gland are poorly if not depicted by US (Fig. 3). However, the accuracy of MRI in the evaluation of optic pathways remains low, and subtle abnormalities are also overlooked by this modality. Even if the pituitary stalk is visible on MR images (10), it is also likely that subtle abnormalities might be overlooked. Schizencephaly, also possibly associated with septal agenesis, can be diagnosed by US in open-lip types but is missed in close-lip types while it can be diagnosed by MRI.

The interhemispheric fissure is well analyzed by both modalities and even subtle types of holoprosencephaly can be diagnosed with US. However, MRI is more reliable in this setting and the fusion between the two hemispheres may be difficult to depict with US.

As mentioned above, the olfactory bulbs are visualized by MRI only.
The ventricles

On axial views, due to near-field artifacts, only the far-field ventricle is well delineated. For this reason, in routine practice (11, 12), only the deepest ventricle is measured. In order to overcome this drawback, it has been suggested to measure the atrium diameter on a coronal view (13). With MRI, both lateral ventricles are equally well delineated and measurements are usually acquired on T2-weighted coronal slices (14).

Four types of lesions, possibly associated with ventricular enlargement may be overlooked by US and justify performing MRI in unexplained ventriculomegaly: (i) intraventricular hemorrhage: most intraventricular hemorrhages are easily diagnosed by US. In some rare cases, the hemorrhagic findings are so subtle that they are missed at US and at MRI on T1 and T2-weighted sequences, appearing as areas of decreased intensity on gradient-EPI T2-weighted sequences (Fig. 4); (ii) aqueductal stenosis may be suggested when the third ventricle is also enlarged. This enlargement is not necessarily marked. The typical appearance of aqueductal stenosis with distal narrowing of the aqueduct is much better depicted by MRI (Fig. 5); (iii) periventricular heterotopia are commonly missed by prenatal US and discovered at postnatal MRI in patients referred for seizures. This results probably from the poor contrast resolution of US; and (iv) ischemic parenchymal damage may be detected by US when it is focal or diffuse and marked. In mild diffuse parenchymal damage, the changes may be too subtle to be depicted by US and MRI is required.

Choroid plexus cysts are usually much better seen and delineated by US than by MRI. MRI may reveal choroid plexus hemorrhage that may be overlooked by US due to these structures being physiologically echogenic.

The subependymal area

The subependymal area is spontaneously visible on MRI scans performed before 26–28 weeks of gestation and displays a typical marked periventricular T1-hyperintensity and T2-hypointensity. It progressively decreases in thickness and remains visible below the frontal horns, being less prominent after 32 weeks of gestation. It cannot be visualized as properly by US.

Four types of lesions are likely to be observed in this area: (i) subependymal hemorrhage is easily diagnosed by US. It is located below the frontal horns, in front of the caudothalamic groove and it displays exactly the same patterns as on postnatal scans. Of course, it can also be well depicted by MRI; (ii) subependymal tubers in tuberous sclerosis are most commonly missed by US while there are very nicely shown by MRI, typically appearing as markedly T1 hyperintense and T2 hypointense foci (Fig. 6); (iii) subependymal cysts are commonly observed and may be located either facing the frontal horns or below. They are well depicted by US that shows a typical “string of beads” pattern in...
case of multiple cysts. Usually, the septa, which separate the
cysts are not visualized by MRI (due to poor spatial resol-
ution) and the cysts falsely appear as a single large cyst.

In pathological conditions (mostly in congenital infections),
these cysts may also be present, facing the temporal and the occipital horns. When they are searched for with US,
they can be demonstrated with this imaging modality.
However, the temporal cysts of the far-field hemisphere
are usually more difficult to depict. In those locations,
they are well depicted by MRI (15); and (iv) subependymal
heterotopia may also be observed (see “Ventricles”).

Subependymal erosion, associated with marked paren-
chymal ischemic damage, is an uncommon condition that
may occasionally be depicted by US. In this setting, the
ependymal irregularities are better seen with US than
with MR, due to the better spatial resolution of US.

The cerebral parenchyma

Parenchymal calcifications are mostly observed in the
setting of congenital infections and are much better depicted
by US than by MRI. Similarly, echogenic nodular foci that
may be present in fetuses infected with toxoplasmosis are
often overlooked by MRI (Fig. 7). Moreover, lenticulostriate
vasculopathy, which is observed at US in certain fetuses
with congenital infection, does not generate signal
abnormalities in MRI.

Ischemic damage may be focal or diffuse and may involve
the white matter and the cortex. When ischemic damage is
focal, it may appear as cavitations, which may be detected
by US but may also be overlooked if they are too small or
if they are located in poorly visualized areas. Indeed, it is
very often impossible to evaluate the whole brain parench-
yma with US and analysis of some areas may be hampered
by the cranial vault. MRI is much more accurate than US
to evaluate the cerebral parenchyma. Calcified leucomalacia
appears as moderately echogenic foci at US while it is
markedly hyperintense on MRI T1-weighted sequences.
One of the main challenges is the identification of diffuse
ischemic lesions of the white matter. As mentioned above,
apart from cases of severe damage, most lesions are over-
looked by US and require T2-weighted sequences and
diffusion-weighted imaging in order to be identified.

Parenchymal hemorrhage may be isolated or may also be
observed in association with subependymal and intra-
ventricular hemorrhage or with ischemic damage.
Extended parenchymal lesions are usually well visualized

Fig. 4 Marked ventricular dilatation discovered very late at 40 weeks of
gestation. On US images (a, b), the lateral ventricles are enlarged, the
choroid plexuses display a normal size and echogenicity. The third ventricle
was also enlarged (not shown). On MRI T2- ((c) sagittal slice and (d) axial
slice) and T1-weighted ((e) axial slice), no findings suggesting hemorrhage
are visible. On gradient EPI T2-weighted slices ((f) axial slice), marked
hypointensities located within the choroid plexuses and lining the ventricles
(arrows) are consistent with intraventricular hemorrhage

Fig. 5 Aqueductal stenosis. US performed at 34 weeks of gestation: coronal (a) and midline sagittal views (b) showing enlargement of the third and lateral
ventricles. MRI performed at 32 weeks of gestation: T2-weighted midline sagittal slice showing the typical narrowing of the distal part of the aqueduct (arrow)
by US, but more subtle lesions may be missed and sometimes even by MRI. They may be depicted by T2-weighted sequences only.

Subcortical tubers and white matter abnormalities that are observed in tuberous sclerosis and extend from the ventricular surface to the cortex are often overlooked by US and are much better depicted by MRI.

**The cerebral cortex**

The constant visibility of the different sulci, independently of the fetal position, is one of the major advantages of MRI over US. Normal cerebral lamination assessment (16) and diagnosis of cortical malformations (17) are possible with US but remain uncertain. It is therefore an excellent indication for MRI. The progressive decrease in size of the pericerebral space throughout pregnancy and the development of secondary sulci result in the cortex being more difficult to analyze after 34–35 weeks, even with MRI. At US, when the pericerebral space is wide enough, the cerebral surface is readily visible, allowing for good delineation of the sulci of the lateral surface of the hemispheres. The medial surface can be analyzed in all cases while the inferior surface is usually more difficult to visualize. However, it must be stressed that the Sylvian fissure is always visible, at least in the far-field hemisphere (18). It is considered an

Fig. 6  Subependymal tubers in tuberous sclerosis at 35 weeks of gestation. Bilateral subependymal tubers are nicely demonstrated on this T1-weighted coronal slice (a) at the level of the foramina of Monroe. Even in retrospect, no abnormality was seen on US images (b)

Fig. 7  Congenital toxoplasmosis infection. 32 weeks of gestation. On US images (a–c), numerous echogenic nodular foci (white arrowheads, all the foci are not pointed) are well demonstrated. The periventricular white matter has a normal appearance. On MRI T2-weighted images (d–f), only few foci are visible (black arrowheads). These foci were overlooked on T1-weighted sequences (not shown). The periventricular white matter displays abnormal diffuse hyperintensity. Neuropathological examination following termination of pregnancy at 34 weeks of gestation showed diffuse ischemic and inflammatory lesions of the white matter
excellent marker for many cortical abnormalities. Therefore, the diagnosis of opercular dysplasia should be easily assessed by US. However, it is noteworthy that this diagnosis is often overlooked by US, probably because analysis of the Sylvian fissures is not part of routine screening for most sonographers.

Type I lissencephaly is very rare and its diagnosis can be suggested at US on the basis of microcephaly, shallow, poorly formed Sylvian fissure and absence of sulcation development. It is of course also easily established by MRI (19).

Overfolded cortical ribbon in polymicrogyria may be directly visible either at US or at MRI. Diagnosing polymicrogyria with US requires a good visibility of the cerebral surface and is therefore possible only before 26–28 weeks (20). In late pregnancy, after around 35 weeks, the visibility of the overfolded cortical may be hampered by the development of sulcation, notably the secondary sulci. Polymicrogyria may also appear as hyperechoic thick cortex due to the superimposition of multiple sulci (21) or as a pseudopachygyric cortex. In this setting, this diagnosis may be missed by US and it can be concluded that as soon as polymicrogyria is suspected, it is mandatory to perform MRI. Thanks to the spontaneous contrast between the cortical ribbon and the white matter on T2-weighted images, the diagnosis of polymicrogyria should be more reliable with MR. Polymicrogyria is also present in type II lissencephaly, in association with ventricular dilatation, ocular, and posterior fossa abnormalities. All these findings are detectable with US (Fig. 8), and ventricular dilatation is the main finding, usually leading to a second-line scan (22, 23).

The posterior fossa

Posterior fossa malformations are commonly observed during prenatal US screening and even if most sonographers do not routinely analyze the vermis, they always evaluate, at least subjectively, the posterior fossa fluid space and the cerebellar hemispheres. A systematic US analysis of the posterior fossa with axial and midline sagittal views makes it possible to achieve most diagnoses when the conditions are favorable (24). When a posterior fossa abnormality is suspected, the vermis, the tentorium, the fourth ventricle, the cerebellar hemispheres, the posterior fossa fluid space, and the brainstem must be systematically evaluated.

Some of these structures are as easily analyzed at US as at MRI: measurements of the cerebellar hemispheres and

Fig. 8 Pseudo-pachygyric type of polymicrogyria in type II lissencephaly at 34 weeks of gestation. Consanguineous parents. US shows abnormal vermis ((a) the vermian shape is abnormal, the primary fissure is not visible), ventricular dilatation (b), opercular dysplasia (c, arrow) and thickened perisylvian cortex (c, arrow-head). MRI (d–f) confirms all these findings and shows that polymicrogyria is diffuse. US was performed late in pregnancy and therefore the pericerebral space was thin and the cerebral surface was poorly visualized. However, the diagnosis of type II lissencephaly was suggested on the basis of US findings. The parents elected to continue the pregnancy and the diagnosis was confirmed after birth.
evaluation of their borders; measurement of the posterior fossa fluid space; evaluation of the position of the tentorium cerebelli is similar with both techniques even if it is subjectively evaluated at US and if a particular landmark (insertion of the nuchal muscles) is used with MRI; and shape of the fourth ventricle.

US displays advantages over MRI in the analysis of the posterior fossa fluid space. The visibility of the walls of the Blake’s pouch or of an arachnoid cyst are usually depicted much better at US. The difference in echogenicity of the cisterna magna and the fourth ventricle or the Blake’s pouch is much clearer at US. However, US and MRI have been reported to be similarly accurate in the categorization of posterior fossa fluid collections (25).

MRI displays advantages over US:

- in the evaluation of the vermis: in favorable conditions, the vermis may be exquisitely demonstrated at US and it is possible in most cases to assess that the vermis is normal. When the sulcation and/or the shape of the vermis seem abnormal at US, MRI is much more accurate than US to define the borders of the vermis and to differentiate the vermis from the adjacent hemispheres (Fig. 9);
- in the evaluation of the brainstem. At US, the brainstem is properly delineated on sagittal views, only when the posterior fontanellar approach is available. Otherwise, US provides but a rough evaluation of the brainstem. The cerebral peduncles are always clearly depicted on sono-graphic axial views. Assessment of the anteroposterior diameter of the pons and evaluation of the brainstem shape seem more accurate with MRI than with US even in favorable conditions, due to better MRI contrast resolution (26);
- in the evaluation of the cerebellar parenchyma. MRI makes it possible to detect old or chronic hemorrhage while changes in cerebellar echogenicity are usually non-specific and can be related to ischemic and/or hemorrhagic damage but also to foliation disorders.

Conclusion

US and MRI are complementary techniques and anybody performing one of those imaging modalities should be aware of their main advantages and limitations. One should adapt the imaging strategy on a case-by-case basis depending on the maternal body habitus, the fetal presentation, the type of abnormalities suspected, and the local possibilities of performing accurate US and/or MRI. It must be kept in mind that an accurate prenatal diagnosis is of utmost importance for prenatal counseling.

Conflict of interest: None.

REFERENCES


Fig. 9 Vermian dysgenesis with cerebellar hypoplasia at 32 weeks of gestation. The vermis (arrow) displays a very abnormal pattern at US (a). It is poorly delineated and the primary fissure is not seen. On the T2-weighted midline sagittal slice (b), the vermis (arrow) is easily differentiated from the cerebellar hemispheres (dotted arrow). The neuropathological examination was performed following termination of pregnancy at 33 weeks and confirmed vermian hypoplasia with abnormal foliation.
11 Cardoza JD, Goldstein RB, Filly RA. Exclusion of fetal ventriculomegaly with a single measurement: the width of the lateral ventricular atrium. Radiology 1988;169:711–4
12 Guibaud L. Fetal cerebral ventricular measurement and ventriculomegaly: time for procedure standardization. Ultrasound Obstet Gynecol 2009;34:127–30