WHAT’S NEW IN?

MR imaging of the neonatal brain at 3 Tesla

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Summary 3 Telsa MR scanners are now becoming more widely available and 3 Telsa is likely to become the filed strength of choice for clinical imaging of the brain. The neonatal brain can be safely and successfully imaged at 3 Tesla. The improved signal to noise afforded by a higher field strength may be used to improve image quality or shorten acquisition times. This may be exploited for conventional T1 and T2 weighted imaging and also for advanced techniques such as diffusion tensor imaging, angiography and functional magnetic resonance studies.

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Introduction

Magnetic resonance (MR) imaging has revolutionised neuropediatrics. The worldwide availability of MR facilities has resulted in detailed images of the brain in a wide range of neurological disorders. These more specific phenotypes have resulted in the identification of new syndromes and the realisation that a specific genetic defect may manifest in a variety of phenotypes. Most clinical MR imaging is performed at 0.5-1.5 T. More recently a generation of 3 T MR scanners has become available and current opinion is that 3 T MR imaging will become the clinical standard, initially in neuroimaging, and eventually throughout the body.

The greater signal-to-noise (SNR) afforded with higher field strengths may be exploited to improve image quality or to shorten acquisition times. There are now several reviews and studies comparing 1.5-3 T imaging of the brain in adults.1-3 Systems with 3 T have been exploited to increase detection of multiple sclerosis lesions,4 to improve the blood oxygenation level dependent (BOLD) effect for functional magnetic resonance imaging (fMRI) and to improve enhancement following contrast administration.5 There is as yet little information about the role and use of 3 T imaging in the paediatric population.

Increased field strength provides not only increased SNR, but increased susceptibility caused by paramagnetic effects due to local heterogeneity in magnetic field from, for instance, the frontal sinuses. Highfield imaging also results in increased chemical shift and increased heat deposition [specific absorption rates (SARs)]. Radiofrequency (RF) power varies with the square of the field strength, therefore imaging at 3 T, produces four times more RF power and sequences may have to be adjusted to operate within radiological safety guidelines. These limits are usually preset into the scanner software. The SAR at 3 T is not prohibitive for neonatal and infant scanning, as sequences can be
adjusted and still produce good quality images, but it is a problem for fetal imaging, making it unlikely that fetal imaging will be performed at 3 T for the foreseeable future. Studies modelling heat deposition within the pregnant uterus during imaging at 3 T are required. Increased susceptibility is not a major problem in neonatal imaging, as neonatal and infant sinuses are not formed and aerated until later in childhood.

The increased SNR afforded by imaging at 3 T can be used to obtain information in a shorter time. This is very valuable when imaging unsedated children who may have difficulties lying still or for sedated sick neonates: in each circumstance time is of the essence. The combination of parallel imaging with phased array coils at 3 T may improve SNR further but perhaps at the expense of signal homogeneity, which is a potential disadvantage for quantification studies.

Conventional imaging

Imaging at 3 T provides superb detail of the immature brain. Figs. 1 and 2 show examples of images obtained at 3 T and a comparison of images obtained at 1.5 and 3 T in the same examination. The increased SNR allows high-resolution images to be obtained in acceptable acquisition times such as a multisliced T2 weighted sequences suitable for reformatting (Fig. 3). Increased acquisition times are acceptable when imaging postmortem and excellent quality images can be produced (Fig. 4). The field of postmortem imaging is in its infancy but the advantage of imaging at high field when SAR is not an issue is evident. T1 relaxation times lengthen with increased field strength and parameters have to be optimised. Indeed image contrast optimisation of conventional spin echo T1 weighted imaging is difficult, and an inversion recovery sequence is preferable to achieve T1 weighting at 3 T. Representative values for parameters at 1.5 and at 3 T are shown in Table 1.

At 3 T, T1 weighted images are noticeable for the increased conspicuity of vessels, even when a rest slab is used (Fig. 5). Prospective studies are required to assess the significance of these vessels. The common sites to detect vessels are in the basal ganglia, the cerebellum and the brainstem.
Figure 2  Images obtained at 1.5 (on left) and 3 Tesla (on right) in an infant with a neonatal encephalopathy. The number of slices, slice thickness and sequence acquisition times are shown beneath each image.

Figure 3  Multi sliced T2 sequence acquired in the transverse plane (a) reformatted into the sagittal plane (b).
We have found an inversion recovery sequence to be a good alternative for T1 weighted images without vessel contamination. This increased vessel conspicuity, however, may be exploited and MR angiography and venography at 3 T gives superb definition of the vascular tree.

MR angiography is a very well established non-invasive technique for imaging the intra-cranial vasculature at 1.5 T and lower magnetic field strengths in adult studies, in cohorts of healthy volunteers and patients. The same technique in neonatal imaging has been underused and there are very few reports in the literature. Neonatal brain vessels are rather small, with lower blood flow velocities in comparison to adult cerebral vessels and frequently presenting with turbulent flow. This makes MR angiography of the neonatal brain a highly demanding and technically challenging area of MR imaging not only for the anatomic depiction of the vasculature, but also for performing quantitative diameter and flow measurements. Currently time-of-flight and phase contrast angiography are the two imaging techniques regularly used for imaging neonatal brain vessels.

Vascular theories for the regional susceptibility of the neonatal brain to ischaemic injury have been discussed for years but there has been little study of the morphology and physiology of the brain vessels in the normal brain, in the high-risk neonate or following a significant brain lesion. Middle cerebral artery infarction is the most frequent form of neonatal stroke, the left side being far more frequently involved than on the right particularly in those infarcts with a posterior distribution. However, there have been no angiography studies in these infants to try and explain this predilection. Arteriovenous malformations are relatively rare but angiograms of the circle of Willis and carotid arteries and venograms of the dural sinuses would be extremely useful for describing anatomic variations, and whether these predispose to brain injury in a given clinical situation.

Furthermore, the use of high magnetic field strength at 3 T appears to be a very promising area, due to the inherently high SNR, which may help in improving vessel conspicuity of the neonatal intracranial vessels or further reduce scanning time. MRA protocols must be tailored to the needs and adapted to the specific features of the neonatal

<table>
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<th>Table 1</th>
<th>Image parameters for T1 weighted volume acquisitions at 1.5 and 3 T.</th>
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<tbody>
<tr>
<td></td>
<td>1.5 T</td>
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<tr>
<td>Sequence</td>
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</tr>
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<tr>
<td>Gap</td>
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<td>Scan duration (min)</td>
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<tr>
<td>Field of view</td>
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<tr>
<td>Number signal averages</td>
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brain, such as implementation of short scan times to prevent motion artefacts, use of low flip angles and out of phase imaging to better saturate the subcutaneous fat that obscures in some cases the visibility of the vessels in the three-dimensional maximum intensity projection, implementation of ramped RF pulse and multiple thin volume strategies to maintain intra-vascular signal at the distal cortical branches. In this way, more subtle response of intra-cranial vasculature to acquire pathology in the immature brain can be studied (Figs. 7 and 8).

Diffusion weighted imaging is able to measure the random molecular motion of water within tissues as an apparent diffusion coefficient. DWI requires the use of diffusion sensitive gradients, measured by a $b$ value. The higher the $b$ value the more sensitive the DWI sequence to water motion.

In acute ischaemia there is a reduction in ADC values, corresponding to reduced water motion as in perinatal stroke. This reduction in measurable water motion results from a relative decrease of mobile extracellular water and an increase in more restricted intra-cellular water that occurs with cellular swelling.

The directional dependence of water motion or anisotropy may be measured with diffusion tensor imaging. Anisotropy results from restricted motion in one direction, e.g. across a white matter tract as opposed to along white matter tract. Relative anisotropy (RA) or fractional anisotropy (FA) may be used to assess both tissue maturity with

Figure 5  T1 weighted MP RAGE images showing high signal intensity from normal vessels within the cerebellum and within the basal ganglia (arrows).

Figure 6  MR angiogram in a neonate with periventricular leucomalacia. There is a rare variation of the right posterior communicating artery (arrow) which is arising directly off the internal carotid. The left posterior communicating artery is absent and the Circle of Willis therefore incomplete.
increases in FA and RA with myelination and tissue integrity with decreases in FA and RA with some pathological processes.

Diffusion imaging at 3 T opens up possibilities for improving SNR in neonatal imaging. This may be used to shorten examination times but the increase in SNR can be used to reduce partial-volume effects, which is beneficial for fibre tracking. This increased SNR allows diffusion weighted imaging at high \( b \) values with adequate resolution of the images. For diffusion sequences imaging at 3 T, allows sufficient SNR to increase \( b \) values to over 1000 mm\(^2\)/s. Fig. 9 shows a series of diffusion images of the neonatal brain obtained at different \( b \) values. It can be seen that the tissue contrast within the images changes with increasing \( b \) values (Fig. 10). In addition, we have shown that high \( b \) value imaging increases conspicuity of perinatally acquired lesions and in some children identified lesions that were not visible at lower values.

Increased lesion conspicuity has also been reported with higher \( b \) values in adult studies. Further improvements in diffusion imaging may also be made by using phased array coils, which allow parallel imaging techniques such as SENSE to be used. This technique can be used to reduce imaging time, however, it is probably more beneficial to reduce the EPI factor and hence reduce image distortions.

**Contrast administration**

Administration of a gadolinium-based contrast agent produces higher contrast between tumour and normal brain at 3 T than at 1.5 T, helps to detect more cerebral metastases at 3 versus 1.5 T in single and cumulative triple dose, improves the evaluation of macroadenomas of the hypophysis, and makes MR venography at 3 T clinically
attractive with increase in spatial resolution within the same measurement time, thus providing more detailed information.\textsuperscript{2} (Fig. 8). It’s role in studying more specific pathologies within the neonatal and infant brain has yet to be established.

**Spectroscopy at 3 T**

With high magnetic fields improved SNR can allow greater accuracy in quantitative measurements and can be used to reduce voxel size, and thus minimise partial-volume effects in heterogenous structures such as the brain. Increased chemical shift dispersion reduces the overlap of resonances obtained in spectroscopy and thus increases the number of metabolites that can be identified and accurately quantified.\textsuperscript{2} This would allow depiction of resonances from for instance glutamate.\textsuperscript{15}

**Functional magnetic resonance imaging (fMRI)**

Functional magnetic resonance imaging (fMRI) uses BOLD contrast. BOLD fMRI at 1.5 T can achieve a spatial resolution of up to 3-5 mm. Studies at 3 T will increase SNR and thereby enhance spatial resolution and specificity of fMRI.\textsuperscript{16,17} This will provide improved resolution of cortical anatomy.\textsuperscript{18} In addition as field strength increases, the field gradient around the capillaries becomes larger and extends further into the parenchyma, thus increasing the participation of the brain tissue in the functional signal. There are no reports as yet of functional imaging in neonates and infants at 3 T.

**Summary**

The neonatal brain can be imaged safely at 3 T. Problems with increased relaxation times and increased heat deposition can be overcome but altering sequence parameters. Increased susceptibility is not a problem because of the immature sinuses. The increased SNR afforded at higher field strength allows fast or more detailed images. Specific improvements in anatomical definition and in lesion detection and conspicuity may also be obtained in more advanced techniques such as diffusion weighted imaging, angiography and venography.

![Figure 8](image1.png) **Figure 8** MR angiogram of a neonate with a posterior perinatal infarct imaged at 23 days of age. There is a “blush” of high signal intensity (arrow) in the region of the infarct that may represent neovascularisation.

![Figure 9](image2.png) **Figure 9** Diffusion imaging of a normal brain of a term born infant imaged at 3 Tesla. Single shot EPI (TR 2500/TE 100) Slice thickness 4 mm. Signal averages 2-8. Variation in tissue signal intensity with increasing b value (range 350-3000 mm\(^2\)/s).
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References


