Chapter 4

Magnetic resonance imaging of the brain in newborn infants: practical aspects

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Abstract

Magnetic resonance imaging is becoming more widely available and increasingly important for imaging the neonatal brain. In newborn infants it poses challenges regarding patient preparation, safety, optimal timing, and sequence optimization. These issues are addressed in this paper and indications for performing neonatal magnetic resonance imaging are presented.
Introduction

Cranial ultrasound (cUS) is a reliable and safe tool to demonstrate cerebral injury and to follow brain development in preterm neonates and in full-term neonates with increased risk of brain injury or with suspected congenital malformations (1). Magnetic resonance imaging (MRI) demonstrates the site and extent of abnormalities more precisely and shows maturational processes in detail (2-8). MR imaging of the neonatal brain has become increasingly important over the past several years, especially as higher field strength MRI systems (1.5 and 3 Tesla), providing high-quality images, are becoming more widely available for clinical imaging (3-4,7,9-12).

However, although MRI as such is a safe technique, the procedure can be burdening to the infant and, if not performed under optimal circumstances, a hazardous procedure in sick, instable neonates. In each case the indication for MRI examination should be well considered, and the timing of the examination depends not only on the information expected from MRI, but also on the clinical condition of the infant.

During the last 3 years, more than 300 neonates, admitted to our tertiary neonatal unit, underwent a cerebral MRI procedure, using 1.5 or 3 Tesla Philips MR systems. In this paper we share our experience on neonatal MRI and address the following issues:

1. Indications and timing
2. Safety
3. Patient preparation and transportation
4. Feeding and sedation
5. Technical aspects, sequences, and scan protocols

Indications and timing for neonatal MRI

Preterm neonates

In preterm neonates, MRI performed during the neonatal period before term equivalent age (TEA), poses special challenges in terms of safety (including temperature regulation, maintaining of vital functions, and monitoring). If performed around TEA, MRI provides essential information on brain growth and maturation (7-8,13). Therefore, unless MRI is
needed to confirm possible life-threatening conditions, or to make important medical decisions, including continuation or withdrawal of intensive care treatment, we do not recommend MRI in preterm infants before TEA (2).

Diffuse and/or subtle white matter injury can be detected by MRI but is possibly not as reliably detected by cUS (2,14-16). Involvement of white matter tracts in parenchymal brain injury is of importance for neurological outcome and is not reliably demonstrated by cUS (9,13). In cases of (severe) post-haemorrhagic ventricular dilatation, the field of view of cUS is often largely taken up by the dilated ventricular system and cUS may fail to demonstrate additional white matter injury. Cerebellar injury, an increasingly recognized serious complication of prematurity, can be accurately diagnosed by cUS, especially if the mastoid fontanels are used as acoustic windows, but even then small haemorrhages and hypoxic-ischaemic injury may remain beyond the scope of cUS (1,17-18). Abnormalities at the brain’s convexity, such as subdural and subarachnoidal haemorrhages, may also be difficult to detect with cUS (1,18). Therefore, MRI is indicated in infants born very prematurely and in preterm infants with (suspicion of) the abovementioned conditions.

### Full-term neonates

While in preterm neonates injury is often located in and/or around the ventricular system, brain injury in full-term neonates is more often located in the deep grey matter and/or the cortical and subcortical regions (7,19-21). These areas are more difficult to visualize with cUS. In addition, arterial infarction is not always reliably detected with cUS (22). Therefore, MRI is often indicated in full-term neonates with seizures, other neurological symptoms, and/or suspicion of brain injury (1).

In some conditions, timing of the MR examination is of great importance. In suspected hypoxic-ischaemic or hypoglycaemic brain injury, optimal timing is probably 4 to 7 days after the incident. Shortly after the incident, conventional \( T_1 \) - and \( T_2 \)-weighted images may underestimate hypoxic-ischaemic injury, while diffusion-weighted imaging (DWI) may already “pseudonormalize” at 6 to 10 days after the incident (7,11,23-24).

We recommend to perform MRI in the following conditions (1):

- Prematurity, < 30 weeks’ gestational age
- Hypoxic-ischaemic encephalopathy (HIE) stage 2 or 3 in (near) full-term neonates (25)
MRI of the brain in newborn infants: practical aspects

- cUS diagnosis of significant parenchymal brain injury, such as inhomogeneous periventricular echodensities, cystic periventricular leukomalacia, periventricular haemorrhagic infarction, and arterial infarction
- cUS diagnosis of severe post-haemorrhagic ventricular dilatation
- Traumatic delivery
- Clinical or cUS suspicion of abnormalities in the posterior fossa
- Clinical or cUS suspicion of abnormalities at the brain's convexity
- Severe and/or symptomatic hypoglycaemia
- (Suspected) metabolic disease
- Clinical or cUS suspicion of brain inflammation (meningitis, encephalitis, brain abscess)
- Congenital malformations with possible involvement of the brain
- Neurological symptoms such as seizures, abnormal consciousness, and/or asymmetry, not sufficiently explained by cUS findings

Safety

MRI does not involve radiation and is therefore relatively safe. However, the strong magnetic field needed for high-quality images and the need to transport patients to and from the MR department necessitate several precautions. Newborn infants are prone to hypothermia, may be haemodynamically unstable, and/or may require respiratory support. In each case, it needs to be considered when the MRI is best performed. This largely depends on the optimal timing of the MR examination in order to obtain the most valuable information (see above), presence and severity of neurological symptoms, cUS findings, clinical condition of the infant, and consequences of MR findings with respect to clinical decision-making and treatment.

Safety during sedation, transportation and scanning is essential (26). Presence of a physician and/or nurse experienced in neonatal resuscitation during transportation and throughout the MR procedure is needed, as are close communication and cooperation between neonatal and MR staff. During the scanning procedure, monitoring devices can be checked from the control room either through a window between the control room and the scanner room, or directly if the monitor is positioned in the control room. The infant can be seen on a television screen (Figure 1).
Metal
As the MR system generates a strong magnetic field, metal containing objects should be kept out of the scanner room. Therefore, the number of people in the scanner room needs to be kept to a minimum and before entering the scanner room, the infant and others present during the MR procedure need to be checked thoroughly for metal inside the body (i.e. clips, implants, shunts) and on or close to the skin (i.e. watches, jewellery, hair wear, clothes with metal buttons or poppers, etc.). Special metal-free t-shirts are available for infants.

Maintenance of body temperature
Temperature can be maintained by swaddling the infant in blankets, and by covering it with warm hotpacks or ‘gel bags’ (3M Nederland B.V., Zoeterwoude, the Netherlands) (Figure 2). The temperature in the MR scanner room should be timely increased.
Figure 2. Ventilated neonate undergoing preparations for MRI examination. The infant is covered with a warm “hot pack” and will be swaddled in warm blankets. The infant’s ears are covered with neonatal earmuffs. The MR-compatible, fibre-optic probe with lead of the pulse oximeter is attached to the right foot.

Monitoring
The infant’s heart rate and oxygen saturation need to be monitored throughout the procedure, including transportation. During transportation, a portable saturation monitor can be used. These monitors are generally not MR-compatible. At the MRI department, the saturation monitor should be changed to a MR-compatible monitoring device (Nonin 8600FO pulse oximeter with fibre-optic sensor and lead; PT Medical B.V.,
Leek, the Netherlands) (Figure 3). Most MR-compatible monitoring devices have not yet been tested for 3 Tesla field strengths. Therefore, if a 3 Tesla MR system is used, the monitor can be placed in the control room and the fibre-optic lead with probe, which is guided to the scanner room via a hole in the wall between control and scanner room, is connected to the MR-compatible monitor (Figure 4). To prevent possible skin burns caused by these wires in rapidly changing magnetic fields, it is best to attach the sensor of the pulse oximeter to the infant’s foot, outside and away from the coil (Figure 2). In addition, it can then be easily reached and readjusted without bothering or moving the infant.

Heart rate and oxygen saturation, and the proper functioning of the monitor need to be checked before the infant is positioned in the scanner.

**Figure 3.** MR-compatible pulse oximeter with fibre-optic lead, positioned in the control room of the 3 Tesla MR unit. Also showing standard (not MR-compatible) intravenous pumps.

**Figure 4.** Ventilation hoses, intravenous lines and fibre-optic lead, guided from scanner room to MR control room through a hole in the wall.
Incubator

Special MR-compatible incubators are available (LMT Lammers Medical Technology, Lübeck, Germany). These can be combined with MR-compatible transport trolleys, monitors, ventilators, intravenous (iv) pumps, and gas cylinders, and with neonatal head coils (Figure 5). These systems are suitable for transporting babies up to 4.5 kg and 55 cm and can stay in the scanner room. At the neonatal unit, before transportation, the baby is installed in the incubator and head coil, connected to the monitor and, if ventilated, to the ventilator (Figure 5). Iv lines are connected to the MR-compatible iv pumps. After arrival at the MR unit, before the scanning procedure starts, the incubator itself is tilted from the trolley. Scanning is performed while the infant is in the incubator and continuously connected to the same monitor, ventilator, and iv pumps (Figure 6). Consequently, transportation and the scanning procedure as such are less burdening for the newborn and less time-consuming for the attending staff. However, these incubators are expensive and may not be compatible with all field strengths and MR systems. Alternatively, standard transport incubators can be used. As these are not MR-compatible, the infant needs to be taken out of the incubator in a room adjacent to the scanner room, and subsequently installed on the scanning table (Figures 2, 7 and 8).
Figure 5. Neonate installed in MR-compatible incubator and head coil. The baby is snugly swaddled in blankets and in supine position, the nose facing the ceiling.

Figure 6. MRI incubator, removed from the trolley and installed on the MR table. Also showing the MR-compatible ventilator.
Figure 7. Ventilated neonate on the MR table, the head installed in the coil. Note the headphone covering the earmuffs and the moulded foam between the headphone and the coil. The infant is snugly swaddled in blankets and in supine position, the nose facing the ceiling.
Figure 8. The ventilated neonate is installed in the scanner. Note the extended ventilation hoses and intravenous lines guided to the hole in the wall.

Resuscitation equipment
Resuscitation equipment, appropriate for newborn infants, needs to be available during transportation and the scanning procedure. Minimal requirements for neonatal resuscitation equipment at the MRI department include a positive-pressure oxygen delivery system with flow meter, wall suction, and variously sized suction catheters, laryngoscopes, oral airways, and positive-pressure bags. In addition, back-up portable oxygen cylinders and suction equipment, an emergency medication box, and emergency telephone numbers should be close at hand. Since most items are not MR-compatible, the resuscitation equipment is kept outside the scanner room, in a magnetic field free space. In case of emergency, the infant is taken to an adjacent room for stabilization.
Ventilation equipment
For neonates requiring artificial ventilation or continuous positive airway pressure, special MR-compatible ventilators and gas cylinders are available (see paragraph on incubator). Alternatively, a standard neonatal ventilator with appropriately adapted ventilation circuits and extended hoses can be used. The ventilator is positioned in the control room and the extended hoses are guided to the scanner room and towards the infant through a hole in the wall between the rooms (Figures 3 and 4).

Intravenous pumps
MR-compatible iv pumps are available (see paragraph on incubator). Alternatively, regular iv pumps with extended lines, again guided through holes in the wall, can be used (Figures 3, 4 and 8).

Ear protection
Some MR pulse sequences are very noisy. To protect the infant from excessive noise, ear protection should be used (27). Neonatal earmuffs (Natus MiniMuffs; Natus Medical Inc, San Carlos, CA, USA) are placed over the ears (Figure 2). For additional protection, after installation on the MR table, the earmuffs are covered by headphones (Figure 7).

Patient preparation and transportation
In most hospitals, neonatal MR examinations are performed at the MRI department, at some distance from the neonatal unit. To avoid unnecessary waiting, the infant and attending staff should leave the neonatal unit or ambulatory ward only shortly prior to the planned MRI procedure. Timing of transportation is planned in close dialogue with the MR staff.

Ventilated and/or unstable neonates
MRI in sick, unstable, and/or ventilated newborns is a complicated and time-consuming procedure. It can be hazardous if safety precautions and/or patient preparations are insufficient. Intensive monitoring, maintenance of vital functions, and presence of staff experienced in neonatal resuscitation are of utmost importance. In
most hospitals, neonatal MRI examinations are conducted without the availability of MR-compatible incubators. If so, preparations need to start timely (i.e. about 1 hour) prior to transportation and the planned MR procedure. These necessary preparations subsequently include:

1. Iv catheters are removed from the infant’s head in order to avoid signal distortions
2. The number of iv pumps is kept to a minimum. Generally, one pump with a glucose with mineral solution, and one or two pumps with essential medication is sufficient. If possible, other fluids and medication are temporarily discontinued during transportation and the scanning procedure
3. Iv lines and ventilation hoses are sufficiently extended (Figures 4 and 8)
4. Monitor electrodes are replaced by MR-compatible electrodes
5. Clothing containing metal parts is removed
6. If necessary, (additional) sedative medication is administrated (see chapter on sedation); Timing of sedation should be optimal and is planned in close dialogue with the MR staff
7. Neonatal earmuffs are applied (Figure 2)

After these necessary preparations, the infant can be positioned in the transport incubator and transported to the MR department, while ventilated with a mobile neonatal ventilator or mask and bag and closely monitored with a mobile saturation and ECG monitor. It is important that the MR department and staff are ready and available for the infant on arrival.

After arrival at the MR department:

1. The imaging staff performs a metal check on the infant and accompanying people before they enter the scanner room
2. The incubator, iv pumps and ventilator are positioned in the adjacent control room (Figures 1 and 3)
3. The infant is positioned on the MR table. In order to obtain the best image quality, we prefer a supine position, the nose facing the ceiling (Figures 5 and 7)
4. The extended iv lines and ventilation hoses are guided through holes in the wall between the control room and the scanner room and connected to the iv pumps and ventilator in the control room (Figures 3, 4 and 8)
5. The infant is connected to a MR-compatible saturation monitor or to a saturation monitor with extended fibre-optic lead (Figures 2 and 3). If necessary, the infant is also connected to an ECG monitor with extended leads.

6. To prevent the infant from moving, waking up and/or cooling, it is snugly swaddled in pre-warmed blankets and covered with warm hot packs or ‘gel bags’ (Figures 2 and 7).

7. A headphone is placed over the ears and earmuffs (Figure 7).

8. The infant’s head is immobilized in the coil by applying moulded foam between the headphone and the coil (Figure 7).

9. The coil is placed over the head (Figure 7).

10. As soon as these precautions and preparations are completed, and adequate monitoring, ventilation, and maintenance of vital functions are ensured, the actual MR procedure can start (Figure 8).

After the MR procedure, the infant is repositioned in the transport incubator, while maintaining ventilation and monitoring. The infant is then transported back to the neonatal unit.

**Stable, non-ventilated neonates**

If the infant was already discharged or transferred to another hospital, it needs to be readmitted on the day of the MRI examination. It is recommended that the infant and its caretakers arrive timely to allow a medical history and physical examination.

About 1 hour prior to the MRI examination, the following preparations need to be performed:

1. To make sure there are no contra-indications for sedation and/or MRI, a detailed medical history is taken. This includes previous operations, illnesses, and possible implants. Relative contra-indications for an elective MRI procedure under sedation include certain drugs (including anti-epileptic and/or sedative medication), respiratory disorders/distress, apneas, (suspicion of) increased intracranial pressure, seizures, increased risk of aspiration, metabolic deregulation, liver and kidney disorders, and muscular disorders. In these cases it is recommended to perform the MRI procedure while the infant is under general anaesthesia and supervised by an
anaesthesiologist. Contra-indications for the MRI examination as such include metal (containing) or electronically activated pacemakers. Nowadays, most implants, clips and shunts are MR-compatible

2. The infant and its caretakers are thoroughly checked for metal containing clothes or medical implants by taking a detailed clinical history (see above) and/or using metal check forms

3. A physical examination is performed

4. MR-compatible monitoring electrodes are applied

5. To prevent the infant from waking up and/or cooling during installation and scanning, it is snugly swaddled in pre-warmed blankets and earmuffs are applied

6. Sedation (see chapter on sedation) is administered 30 to 40 minutes prior to the planned MR procedure. This should be optimally timed and is planned in close dialogue with the MR staff

7. The infant’s heart rate and oxygen saturation are monitored throughout the period of sedation

8. The infant can now be transported to the MR department, again in close dialogue with the MR staff

After arrival at the MR department:

1. The imaging staff performs a metal check on the infant and accompanying people before they enter the scanner room

2. The already swaddled infant is transferred from the cot to the MR table (the cot stays in the control room)

3. The infant is covered with warm hot packs or ‘gel bags’ (Figure 2)

4. The infant is preferably laid supine, its nose facing the ceiling (Figure 7). However, if the infant objects, it is better to allow it to settle into its preferred position. If so, in order to obtain straight MR images, imaging settings need to be adjusted with the survey images

5. The infant is connected to the MR-compatible saturation monitor (see above) and monitoring is maintained throughout the procedure (Figures 2 and 3)

6. Supplemental oxygen may be needed while the infant is sedated, especially if there is a history of chronic lung disease, prematurity, snoring, and/or apneas. During the
scanning procedure, this can be supplied using an extended oxygen hose. The hose is guided to the infant’s face and securely kept in place by taping it onto the blanket or the head coil (Figure 9). Subsequently, steps 7 to 10 as mentioned for ‘Ventilated and/or unstable neonates’ are carried out.

Figure 9. Infant installed in head coil. Supplemental oxygen is administered using an extended hose, positioned in front of the infant’s face.

After the procedure, the infant needs to be continuously monitored until it is well awake (generally within 2 hours after scanning). Criteria for discharge after sedation include that the infant has returned to the baseline established prior to administering sedation, which depends on the level of development of the infant (26). We consider discharge safe when the infant is well awake and orientated with stable vital signs and has been drinking without problems. Before discharge, caretakers should get information on the sedation and MRI procedure, and telephone numbers to use in case of problems or questions.
Feeding and sedation

In most neonates anaesthesia is not necessary for a safe and effective MR procedure. In order to reduce movement artefacts we prefer “conscious sedation” using chloral hydrate (see below). However, other regimens may also be effective and in each individual case it should be decided whether sedation is necessary or not.

Ventilated and/or unstable neonates

Some very sick newborns are comatose due to their clinical condition (i.e. severe encephalopathy) and these infants may not need sedative medication. Many other ventilated and/or unstable newborns will be on sedative and/or anti-epileptic medication according to local protocols. In most of these cases, additional sedation is not necessary. If the infant is still uncomfortable or restless, sedation needs to be adapted by increasing the dosage of administered sedatives and/or by adding medication in accordance with local protocols.

Stable, non-ventilated neonates

In stable, non-ventilated infants up to 5 kg and/or 3 months post-term age we use the following regimen:
1. Last feed 4 hours prior to sedation
2. Chloral hydrate 50 to 55 mg/kg, administered orally 30 to 40 minutes prior to the MR procedure

Chloral hydrate is a frequently used drug in neonates for sedation during MRI procedures (28-29). It is widely available, easy to administer and has proven safe (29). It is best given on an empty stomach (dissolved in glucose 5% solution in a bottle, sprayed into the side of the infant’s mouth, or administered via a naso-gastric tube). It is then rapidly absorbed and effective: most neonates fall asleep within 15 to 30 minutes, are well sedated throughout the procedure, and awake rapidly afterwards. If oral administration is undesirable, rectal administration is an alternative. Using this regimen we have only rarely encountered mild respiratory depression that was easily managed with supplemental oxygen (see paragraph on patient preparation).
If, despite this regimen, the infant does not sleep or lie still, we do not recommend additional sedation. In these cases oral sucrose is given and the infant is settled by staying patient and calm and by holding and rocking it to sleep. In our experience, abortion of the MR procedure is hardly ever necessary.

**Technical aspects, scanning protocols, and sequences for 1.5 Tesla and 3 Tesla MR systems**

**MR systems and coils**

At our hospital, 1.5 Tesla and 3 Tesla field strengths are available for neonates (Philips Intera 1.5 Tesla and Philips Achieva 3 Tesla; Philips Medical Systems, Best, the Netherlands). The higher the field strength, the better the signal-to-noise ratio (SNR) and/or the shorter the scan time. Therefore, except for very sick, unstable infants, needing more intensive monitoring, the 3 Tesla system is preferably used (10). For optimal SNR, properly sized, small head coils are needed. This can be a paediatric head coil or an adult knee coil (Figures 2, 5, 7 and 9).

**Sequence optimization for imaging the neonatal brain**

The water content of the neonatal brain is much higher than of the adult brain. Consequently, $T_1$ and $T_2$ values are higher and therefore echo times (TE) and repetition times (TR) need to be higher than in adult and paediatric patients (11,30-31). Due to ongoing maturational processes, including myelination, taking place in the immature brain, $T_1$ and $T_2$ values decrease significantly over the first few months after birth up to 2 years of age. This results in marked changes in $T_1$ and $T_2$ relaxation times (30). The small field of view to be used when scanning the newborn infant’s brain reduces the SNR. Thus, specific and optimized protocols (accommodating the changes in $T_1$ and $T_2$ values) are needed for different field strengths. Fast and turbo imaging techniques are helpful to reduce artefacts due to movement of the infant.
Scan protocols

In our hospital, all neonatal MRI examinations are performed according to standard protocols for imaging the neonatal brain. These protocols have been thoroughly optimized over the past years for both preterm and full-term infants and for 1.5 Tesla as well as 3 Tesla MR systems. Protocols can be adjusted in individual cases based on clinical findings and the findings on cUS examinations.

As mentioned above (see chapter on indications and timing), prematurely born infants are preferably scanned around term corrected age. Scan protocols for preterm and full-term neonates include at least T1-weighted 3 dimensional images, allowing reconstruction in every desired orientation, or T1-weighted sagittal and axial images, and T2-weighted images, DWI, and susceptibility-weighted images in the axial plane. If a field strength of 3 Tesla is used, two DWI scans are performed, with the water-fat shift in two different directions (anterior-posterior and left-right), to avert clinical misinterpretations caused by echo-planar distortions in the frontal lobe. We routinely perform susceptibility (T2*) scans as small punctate lesions (such as calcifications and punctate haemorrhages) are more easily detected with this technique (32). For reliable detection of small lesions, slice-thickness is kept at a minimum with minimal (1.5 Tesla) or no (3 Tesla) interslice gaps. Because of the high water content of the immature brain, fluid-attenuated inversion recovery (FLAIR) images are of limited use in the first year after birth, and therefore we do not routinely perform these in neonates (11). In addition, it has recently been demonstrated that FLAIR and contrast enhanced images do not contribute to detection of hypoxic-ischaemic brain injury in (near) full-term neonates (33).

Details of the sequence parameters as used in our hospital for neonatal brain examinations are presented in Tables 1 and 2. Table 3 demonstrates the concise scan protocol used in sick full-term neonates with hypoxic-ischaemic encephalopathy for reliable detection of hypoxic-ischaemic brain injury (33).
Table 1. Standard protocol optimized for imaging the newborn infant's brain using a 1.5 Tesla MR system
(EPI, echo planar imaging; FFE, fast field echo; FOV, field of view; Max, maximum; min, minute; ms, millisecond; NSA, number of signal averages; s, second; Sag, sagittal; SE, spin echo; SPIR, spectral pre-saturation inversion recovery; TE, echo time; TFE, turbo field echo; TR, repetition time; Tra, transverse; TSE, turbo spin echo)

1.5 Tesla field strength

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Table 2. Standard protocol optimized for imaging the newborn infant’s brain using a 3 Tesla MR system (dir, directions; DTI, diffusion-tensor imaging; EPI, echo planar imaging; FFE, fast field echo; FOV, field of view; Max, maximum; min, minute; Min, minimum; ms, millisecond; NSA, number of signal averages; s, second; Sag, sagittal; SE, spin echo; SPIR, spectral presaturation inversion recovery; TE, echo time; TFE, turbo field echo; TR, repetition time; Tra, transverse; TSE, turbo spin echo)

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<tr>
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<tr>
<td>TE (ms)</td>
<td>120</td>
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<td>64</td>
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<td>Flip angle (°)</td>
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<tr>
<td>TR (ms)</td>
<td>6269</td>
<td>9.7</td>
<td>735</td>
<td>2406</td>
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<td>Turbo factor</td>
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<td>EPI factor</td>
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<td>37</td>
<td>37</td>
<td>56</td>
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<tr>
<td>Water/fat shift</td>
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<td>Max</td>
<td>2</td>
<td>Min</td>
<td>Min</td>
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<tr>
<td>Fat suppression</td>
<td>SPIR</td>
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<td>SPIR</td>
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<tr>
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<td>Scan time (min,s)</td>
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<td>4.32</td>
<td>2.01</td>
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Table 3. Concise protocol for optimal detection of hypoxic-ischaemic brain injury in the early neonatal period in full-term infants with asphyxia (DwSsh, diffusion-weighted single-shot; ms, millisecond; SE, spin echo; SPIR, spectral presaturation inversion recovery; TE, echo times; TR, repetition time; Tra, transverse)

<table>
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<tr>
<th>1.5 Tesla field strength</th>
<th>T1</th>
<th>T2</th>
<th>DWSh</th>
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<tr>
<td>Plane</td>
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<td>Tra</td>
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<td>Technique</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
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<td>4-5</td>
<td>6</td>
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<tr>
<td>Gap (mm)</td>
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<td>0.4-0.5</td>
<td>0.4-0.5</td>
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<tr>
<td>TE (ms)</td>
<td>14-20</td>
<td>100-120</td>
<td>74</td>
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<tr>
<td>TR (ms)</td>
<td>550-560</td>
<td>5406-6883</td>
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Summary and conclusions

MRI does not involve hazardous radiation. However, in neonates MR imaging can be challenging with respect to safety, temperature regulation, transportation, and image quality. It requires flexibility, patience, and close communication between neonatal and MR staff. Scan protocols need to be adapted to the immature neonatal brain. Special MR-compatible intensive care incubators facilitate the procedure for patients and staff. If these are not available, ventilation and monitoring equipment needs to be adapted for neonatal MRI and properly sized head coils need to be used. If the necessary safety precautions are thoroughly followed, imaging is well timed, and appropriately sized head coils and proper scan protocols are used, MRI is a safe procedure and provides invaluable information on brain maturation and injury in (preterm) neonates.
Chapter 4

References


