

# Transport, monitoring, and successful brain MR imaging in unsedated neonates

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Received: 18 October 2007 / Revised: 7 November 2007 / Accepted: 13 November 2007 / Published online: 19 December 2007  
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**Abstract** Neonatal cerebral MR imaging is a sensitive technique for evaluating brain injury in the term and preterm infant. In term encephalopathic infants, MR imaging reliably detects not only the pattern of brain injury but might also provide clues about the timing of injury. In premature infants, MR imaging has surpassed US in the detection of white matter injury, a common lesion in this population. Concerns remain about the safety and transport of sedated neonates for MR examination to radiology suites, which are usually located at a distance from neonatal intensive care units. We present our own institutional experience and guidelines used to optimize the performance of cerebral MR examinations in neonates without sedation or anesthesia.

**Keywords** Brain imaging · Newborn

## Introduction

As an imaging technique, MR imaging remains unparalleled in its diagnostic and clinical value. The demand for good-quality MR imaging of the newborn brain in infants within the neonatal intensive care unit (NICU) at risk of cerebral injury is increasing worldwide. The safety of patients and staff is paramount, and standard safety rules governing MR suites are established in most units [1]. In many radiology departments, MR scans in newborns are carried out with sedation or anesthesia in an effort to reduce patient motion under appropriate guidelines that have been established for each unit [2–5]. This, however, increases the risk to the patient, adds to the cost of the study and limits the hours during which an infant can be scanned. Thus, it is desirable to perform MR scans in the newborn without sedation. We have developed guidelines for nonsedated MR scanning in the newborn. They are based on collective experience over several years of MR research in premature and term-born infants, including the safe performance of more than 1,000 brain MR examinations without sedation [6–8]. Although there is a learning curve with equipment, good-quality MR scans can be performed safely and efficiently with these guidelines. More recently, MR-compatible incubator systems with integrated radiofrequency coils have become commercially available, and initial experience with them has been favorable [9]. The application of these principles requires close cooperation between newborn medicine and radiology, including the nurse, MR imaging technologist and radiologist.

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## General principles

It is important to ensure that any infant who is being considered for MR imaging is medically stable, or if the infant is unstable that consideration is given to the indication for the MR scan. Is the information to be gained from the brain MR scan critical to the immediate clinical management of the neonate? For example, infants on inotropes should only be transported to the MR scanner if the benefits of the scan outweigh the risks of transport. In these situations, transport of an unstable neonate to the MR scanner can be accomplished safely with appropriate MR-compatible equipment such as an incubator (Advanced Imaging Research, Cleveland, Ohio), ventilator (babyPAC, Smiths Medical PM, Waukesha, WI), fiberoptic temperature monitoring (Luxtron m3300 OEM, LumaSense Technologies, Santa Clara, CA), intravenous pumps, experienced nursing personnel, and a neonatologist or anesthesiologist. If the information from the MR scan is not vital in the unstable baby, then it should be delayed until the patient becomes more stable.

Movement is more likely in the nonsedated patient and thus not all scans will be successful the first time. The failure rate in our experience, as defined by excessive motion artefact, is less than 10%. In the event of an unsuccessful scan, we repeat the scan at another time, and have not required sedation in any of our newborn infants.

Our guidelines, as outlined below, are generic for all MR scanners but for compatibility of specific equipment it is important to confirm the compatibility at your local MR scanner's field strength (e.g., 1.5 or 3 T). Most MR-compatible equipment is FDA-approved for use at 1.5 T but not necessarily at the higher field strength of 3 T. FDA approval for use of most MR-compatible equipment at 3 T should be available for all equipment listed except for the specially designed head coil that we use under a human research protection protocol. All personnel need to observe universal MR safety guidelines as per institutional regulations.

## Equipment

The equipment needed includes the following:

1. An MR-compatible ventilator (babyPAC) with CPAP mode, MR-compatible gas tanks, and tubing.
2. MR-compatible intravenous infusion pumps as needed *or*, alternately, connecting extension tubing 9 m in length attached via a port-hole to regular intravenous pumps located outside the magnet room.
3. A MR-compatible pulse oximeter (INVIVO or MEDRAD) with an infant SpO<sub>2</sub> "Grip" sensor.
4. MR-compatible EKG leads (INVIVO).

5. Head-stabilizing equipment. There are two options currently available. A specially designed VacFix (Par Scientific) vacuum cushion with a suction port or an infant-size Medvac vacuum bag (MVB) (Contour Fabricators).
6. Ear muffs for noise attenuation (MiniMuffs, Natus).
7. Infant Porta-Warmer if needed.
8. Infant sheets and blanket (prewarmed in linen warmer for the very small premature infant).
9. A resuscitation bag with MR-compatible equipment consisting of a self-inflating Ambu bag, MR-compatible laryngoscope with Miller blade 0 and 1 and endotracheal tubes sizes 2.5, 3.0 and 3.5 mm.
10. m3300 Lab Kit (LumaSense Technologies) consisting of a fluoro-optic temperature probe, extension cable, and software installed on a laptop for continuous temperature monitoring of the infant during the MR scan.
11. Ideally, a purpose-built neonatal head coil *or* an MR-compatible incubator (Advanced Imaging Research) with a built-in RF head coil. Alternately, use the smallest quadrature RF coil that is available.

## Transport personnel

A nurse (neonatal ICU or transport) should accompany the infant from the NICU and be available in the MR scanning room for emergencies during the acquisition of the MR scan. In addition, infants on ventilator support should be accompanied by a neonatal fellow, neonatal nurse practitioner, or neonatologist along with a respiratory therapist. In addition to the MR technologist, a radiologist should ideally be available to review the quality of the scan prior to moving the infant out of the scanner.

## Procedure

*For critically ill neonates (premature or full term)*

Preparatory time required prior to leaving the ICU: 1 hour

The neonate is transferred to an MR-compatible ventilator at comparable NICU ventilator settings at least 45 min before leaving for the MR scanner. A blood gas analysis is performed after 15–20 min, ensuring that the infant has successfully transitioned to the transport ventilator.

The number of intravenous solutions that need to be taken with the infant should be minimized. Larger-volume (20-ml) syringes are loaded from intravascular infusions for the medications and solutions that are critical to continue (for example, total parenteral nutrition, inotropes, sedation, etc.) and MR-compatible syringe pumps are primed. If MR-

compatible infusion pumps are not available, long intravenous extension tubing (usually about 9 m, or five or six extensions sets, but that might vary with the size of the MR suite) is used to connect with the intravenous pumps, which must be placed outside the MR room.

The infant is undressed down to a diaper and any metallic monitoring leads and any dome fastener containing clothing items are removed. The MR-compatible pulse-oximetry probe and cable is attached to one foot. We use an MR-compatible pulse oximeter to monitor the infant's oxygen saturations and heart rate during transport and the MR scan. The pulse oximetry probe is applied and taped to the lateral aspect of either foot, which is then covered with a sock to secure it in place. We ensure a reliable and consistent oximetry signal prior to moving out of the NICU. The placement of the probe in the NICU prior to departure ensures that there is no disturbance to the infant for the last 20 min before the MR scan that could awaken the infant. MR-compatible EKG leads (INVIVO, Orlando, FL) are used to monitor the heart rate while in the scanner, particularly in premature infants who might be more prone to episodes of apnea and bradycardia. These too are placed prior to departure from the NICU.

Attach the tip of the fluoro-optic temperature probe on the infant's abdominal wall with Tegaderm (3M, St. Paul, MN). Make a loop and tape it on the thigh to ensure that it is anchored securely. Place MiniMuffs (Natus, San

Carlos, CA), over the neonate's ears as recommended by the manufacturer. Wrap the infant snugly in one or two infant sheets in a firm swaddle, with the first swaddle wrapped firmly around the infant's head in an old-fashioned manner, folding over each side of the head closely. The second wrap does not need to go around the head (Fig. 1). Scans can be successfully performed with or without an MR-compatible incubator system.

If an MR-compatible incubator is *unavailable*:

- Use prewarmed infant sheets to wrap the baby.
- Place the infant on the MVB (CFI Medical Solutions, Flint, Mich.) or the VacFix bag (Par Scientific, Houston, TX).
- Wrap the bag firmly around the infant's torso, making sure to have enough of the material above the head to wrap around the head, as well. It is important to place the bag around the back of the head and up around the infant's neck to keep the head still.
- While holding the bag wrapped around the head and torso, evacuate the air by applying vacuum to the port on the outside.
- Transfer the infant into a regular transport incubator.

If an MR-compatible incubator is *available*:

- Repeat steps as above, wrapping the infant in a sheet alone or a sheet and the MVB. Place the infant inside

**Fig. 1** Procedure for placing a nonsedated neonate in the MR coil prior to placement in a scanner. **a** Placement of the MiniMuffs on the neonate's ears. **b** Placement of the neonate wrapped snugly in a sheet on the MVB. **c** The neonate stabilized in the MVB. **d** The stabilized neonate in the head coil



the incubator and slide in the coil around the infant's head. Place the Velcro straps around the infant prior to closing the incubator cover.

Ensure that the MR room is ready to receive the infant to minimize waiting outside the scanner room. Transport the infant to the MR room observing MR precautions prior to entering the scanner room. Disconnect the intravenous syringes from the pumps (if not MR-compatible) and feed the syringes through the port holes in the magnet room, reinstalling them on the pumps placed in the console room. Connect the pulse oximetry probe and the EKG leads to the INVIVO or MEDRAD (Warrendale, PA) monitor and adjust alarms to neonatal settings. Secure the cable to the surface of the table with tape to avoid it getting caught or pulled when the table slides into the scanner. Ensure that the signal waveform on the monitor is robust. If the infant is on a ventilator, disconnect the ventilator tubing from the portable tanks and connect to a wall source of oxygen and compressed air.

Once the incubator is lifted off the base and transferred to the table, the power supply is switched to a wall socket and the base trolley removed from the MR suite. Connect the fluoro-optic temperature probe to the extension cable that feeds out of the port hole connecting to the m3300 temperature monitor. Connect the monitor to a laptop computer to get a continuous readout of temperature. Adjust the acquisition interval to 5 min (300 s). Position the RF coil at the magnet isocenter (usually done by the MR technologist). A neonatologist and a neonatal nurse should stay with the patient in the MR suite during the scan. Ear muffs are recommended for everyone in the scanner room during the scan.

*For noncritically ill neonates (usually, premature infants near term)*

Preparatory time: 30 min

Adjust the feed schedule the morning of the MR scan to ensure that the infant will be fed 30–45 min before the scan time. Place the MR pulse-oximetry probe on one foot, and the fiberoptic temperature probe on the abdominal wall, and snugly wrap the infant in one or two infant sheets and place in the MVB as described above. Place the infant in the transport incubator or crib and transport the infant to the MR scanner as described above.

### Sequence acquisition

The optimum parameters for MR image acquisition differ between newborns and older children. For example, the water T2 relaxation time constant is greater in newborn infants than older children. As a result, optimum contrast in

T2-weighted images is obtained at longer echo times (TE), on the order of 160 ms. Similarly, T1 relaxation time constants are greater. Thus, the inversion times (TI) used for T1-weighted images of newborns should be longer, on the order of 1,100 ms. In addition, the T1 relaxation time constant varies with magnetic field strength, being greater at higher field strengths, such as 3 T. Finally, water diffusion coefficients tend to be higher in newborns. The b value that provides the best measure of diffusion at term,  $0.8 \text{ ms}/\mu\text{m}^2$ , is smaller than the commonly used adult b value of  $1.0 \text{ ms}/\mu\text{m}^2$ . Overall, the image acquisition parameters to be used for newborns should be carefully tested to ensure that optimum contrast-to-noise ratio is obtained for the pulse sequences to be employed and the magnetic field strength available.

### Emergencies

The emergency resuscitation cart, suction, and oxygen are available immediately outside the MR suite. If the scan needs to be interrupted due to an event such as apnea/bradycardia or if the infant needs to be resuscitated, the infant needs to be brought out of the MR suite. Although all the resuscitation equipment is MR-safe, the risk of an accident occurring during resuscitation is too high [10].

### Special observations

The bird-cage head coil manufactured by Advanced Imaging Research (Cleveland, OH) is FDA-approved for use at 1.5 T. A premature infant fits well inside with the MVB. However, a full-term infant in the MVB is a tight fit in this coil. On occasion, when neither the MVB nor the VacFix cushion can be used in the coil we have successfully used cushions that come with the incubator/RF coil to stabilize the infant's head while using prewarmed infant sheets to firmly snuggle the infant's torso. For larger head coils, the MVB and VacFix are good options for stabilizing the infant and reducing motion artefact during the MR scan. To keep the infant from moving his/her head in the AP plane (dorsal and ventral movement of the neck), it is important to move some of the beads in the MVB under the neck and to wrap some of the MVB over the top of the head (Fig. 1). We recommend using a pacifier for bigger infants if needed, although sucking can result in some motion artefact. If the infant awakens and cries through an MR sequence he or she might need to be brought out and gently rocked while still in the MVB until he or she settles.

At the conclusion of the scan, the MR table is moved out, ventilatory, monitoring and intravenous connections are

moved back to the transport oxygen and compressed air tanks, pulse oximeter and intravenous pumps, respectively, for transport back to the NICU. We allow parents to accompany the infant to the scanner if they desire. Please refer to manufacturers' guidelines for the equipment listed above.

## Summary

Neonatal brain MR scanning provides valuable information for the neurological evaluation of the at-risk newborn. However, it entails transporting the infant from the NICU to the MR scanner, which is often several floors away. Sedation adds another layer of complexity to the performance of this investigation. Intravenous sedation administered and supervised by an anesthesiologist or sedation team does offer the advantage of more efficient time slot utilization in the MR scanner, but the actual process of sedation, monitoring and recovery from sedation might offset this advantage. The issues of patient safety and sedation in neonates for MR scanning have been reviewed by several authors [11–13]. A few institutions have reported success with scanning infants without sedation, but have not detailed the procedure followed [14, 15].

In our institution we have successfully performed brain MR studies in unsedated neonates for the last 14 years. We initially scanned stable preterm and term infants, under research protocols, after regular scanner hours because there was less constraint on scanner time. As clinical MR imaging surfaced as a standard diagnostic modality in neonates, the number of scans requested increased and we moved to day-time slots. One issue we faced was having the infant asleep to be efficiently scanned in a 1-h clinical time slot. A collaborative effort among neonatology, neuroradiology, and nursing resulted in comprehensive guidelines for MR scanning of unsedated neonates. As part of the process, we built in 30 min in the NICU prior to transport to the MR scanner. The MR technologists call the NICU if the scanner runs late, as open communication between the MR suite and NICU enhances success. Getting the baby ready for the scan, including application of the pulse-oximeter, EKG leads, and temperature probe prior to swaddling the infant and placing him or her in the immobilization device in the NICU saves scanner time. Most importantly, it leads to minimal disturbance of the infant in the scanner and greatly improves the likelihood of a successful scan. Communication and integration of the new equipment for neonates undergoing MR imaging with radiology and the NICU team is also important. These new devices can improve patient safety and image quality, but training and understanding of the equipment is needed by both teams.

The NICU nursing staff and MR technologists are key players in this procedure and need several training sessions

on use of equipment. Identifying a core group of nursing staff and neonatologists who serve as resources has been a key factor in getting infants to the scanner on time.

A recognized limitation of this review is the mention of specific vendors for equipment. Although we realize that there are other vendors who manufacture MR-compatible equipment, our aim in mentioning these specific vendors is solely reflective of equipment usage in our unit. We do not receive any financial or other compensation from any of the vendors mentioned in this review. In our institutional experience, given appropriate equipment, training and staff, neonatal brain MR scans are routinely and safely performed without any sedation with the guidelines outlined.

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