Physiological stability of preterm infants during magnetic resonance imaging

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Abstract

Aim: This study looked for evidence of physiological disturbance in preterm infants undergoing magnetic resonance imaging (MRI). Methods: Intensive care was continued, as appropriate, throughout scanning in each infant. The heart rate, oxygen saturation (SaO₂), temperature and mean arterial blood pressure (BP) was monitored during MRI in preterm infants, median gestational age at birth 27 (range 23–32) weeks and median postnatal age at initial MRI, 3 days (range 1–42). The acoustic noise level during imaging was also measured. Results: 2087 min of data were obtained from 39 examinations in 23 infants. The median heart rate was 159 and no bradycardia < 100 or tachycardia > 200 bpm occurred. Although 42 episodes of desaturation < 90% were detected only three were < 80, and these occurred in one infant due to endotracheal tube blockage. The median axillary temperature was 36.9°C (range 35.7–37.8) and median BP (n = 6) was 37 mmHg (24–48). The ambient noise level in the MR system during scanning was 67–72 dBA. Conclusion: In preterm infants who required intensive care during scanning, MRI could be performed without major physiological instability. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Magnetic resonance imaging; Physiological stability; Preterm infants

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1. Background

Magnetic resonance imaging (MRI) produces detailed images of the body without the use of ionising radiation. The procedure is frequently performed in infancy and childhood and is considered to be safe. However, there are no published data available regarding the physiological status of preterm infants undergoing MRI, and only minimal information is available for term infants [1].

In order to image preterm infants we have installed in our neonatal intensive care unit (NICU) a MR system specifically designed for neonatal use [2,3]. The system provides easy access to the infants during imaging and allows full neonatal intensive care to be maintained. To determine whether physiological disturbance occurred in a group of preterm neonates during MR imaging, we have measured heart rate, arterial oxygen saturation (SaO₂), body temperature and mean arterial blood pressure (BP) during the imaging procedure. In addition, as noise exposure has been reported to cause increased stimulation leading to physiological instability [4], we measured the acoustic noise level within the scanner during a standard imaging protocol.

2. Subjects and methods

Ethical approval for the study of infants with MRI was given by the Hammersmith Hospitals Research Ethical Committee and parental consent was obtained in each case.

The study group consisted of 23 premature infants cared for at the Hammersmith Hospital NICU. Infants underwent MRI for clinical indications or as part of a cohort study of preterm brain injury. Gestational age (GA) was calculated from the date of last menstrual period and confirmed using data from early antenatal ultrasound scan.

The median birth weight of the study group was 920 g (range 610-1780). The median GA at birth was 27 weeks (range 23–32) and median postnatal age at initial MRI 3 days (range 1–42). The mean duration of each scan was 53.5 min. At the time of study 12 of the infants were receiving mechanical ventilation, three continuous positive end expiratory pressure and 12 nasal cannula oxygen, while 12 were breathing room air.

The 1-Tesla neonatal MR system (Oxford Magnet Technology/Picker) is located in the NICU and has a 380-mm length bore, which allows good access to the infant for monitoring and ventilation during a scan. The sequence parameters for T1-weighted conventional spin echo (CSE), T2-weighted fast spin echo (FSE) and inversion recovery sequences FSE are summarised in Table 1.

Infants were transferred to the MR system nursed in a semi-cylindrical cot which rested on a specialised trolley that incorporated facilities for mechanical ventilation and pulse oximetry. On arrival at the scanner the cot was inserted directly into the bore of the magnet. The infant’s body temperature was maintained during the scan by heating the scanner room to 28°C and wrapping the infant in warm blankets. Additional bubble wrap, woollen hats and pre-warmed gel bags were used as needed.

Mechanical ventilation during the scan was performed in seven infants using a
Table 1
Pulse sequence parameters

<table>
<thead>
<tr>
<th>Pulse sequence</th>
<th>TR (ms)</th>
<th>TI (ms)</th>
<th>TE/TE\text{eff}</th>
<th>Slice thickness (mm)</th>
<th>No. of slices</th>
<th>NSA</th>
<th>Phase echo</th>
<th>Inter echo spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1-weighted CSE</td>
<td>600</td>
<td>20</td>
<td>4</td>
<td>2</td>
<td>192</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>T2-weighted FSE</td>
<td>3500</td>
<td>208</td>
<td>4</td>
<td>2/4</td>
<td>256</td>
<td>16</td>
<td>16</td>
<td>—</td>
</tr>
<tr>
<td>IR FSE</td>
<td>3500</td>
<td>950</td>
<td>32</td>
<td>4</td>
<td>256</td>
<td>16</td>
<td>16</td>
<td>—</td>
</tr>
</tbody>
</table>

CSE, conventional spin echo; FSE, fast spin echo; IR, inversion recovery; NSA, number of sequence averages; TR, repeat time; TI, inversion time; TE, echo time; TE\text{eff}, effective echo time.

conventional ventilator (SLE 2000, SLE, UK) that was radiofrequency shielded, positioned away from the magnet and connected to the infant using extended ventilator tubing. In a further five infants an MR-compatible ventilator (babyPAC neonatal, pneuPAC Limited, UK), which could be placed adjacent to the infants, was used. All infants were accompanied by at least one experienced paediatrician throughout the procedure and full intensive care, including inotrope administration, continued as appropriate. Sedation with chloral hydrate was occasionally needed in the more mature infants although the majority were successfully imaged following a feed or whilst sedated for ventilation.

Physiological data were recorded by a MR-shielded Hewlett-Packard Merlin life support system. Heart rate, SaO\text{2}, BP and temperature channels were utilised as clinically indicated for the individual infant. SaO\text{2} was measured by pulse oximetry. Heart rate was obtained via chest ECG leads and was independent of the pulse rate acquired from pulse oximetry. Temperature was measured by placing a MR-compatible temperature probe in the axilla. BP was measured in six infants with indwelling arterial lines using a standard pressure transducer. The data were recorded continuously, displayed on monitors in both the scanner room and control room and sampled at 1-min intervals. Periods of time when the pulse oximetry trace was artefacted were automatically discarded. To evaluate evidence of physiological disturbance median values and trends in each of the parameters during the procedure were calculated. Trends over time were also calculated using multiple linear regression analysis with indicator variables to account for inter-Individual variation. In addition, arbitrary limits were assigned for heart rate (100–200 beats per min (bpm)), oxygen saturation (90–97%) and temperature (36–38°C) and the time outside these limits calculated. Limits were not set for mean blood pressure due to the small numbers and heterogeneity of infants sampled. Statistical analysis was carried out using the Stata Statistical Package (Stata Corporation, TX, USA).

The acoustic noise level was measured using a Bruel & Kjaer model 2231 sound level meter loaded with a BZ7110 module of capabilities. The microphone was attached to the instrument by a 10-m cable to allow measurements without adverse magnetic field interactions. Although the sensitivity of preterm infants to noise is not known, the frequency range is likely to be comparable to that in adults. Hence, ‘A’ frequency weighting, a filtering method to simulate the receptive characteristics of the adult human ear, was selected. The maximum root mean squared (MAXL) and
average sound pressure ($L_{eq}$) levels for background noise and during scanning were sampled over 10-s intervals. Measurements were obtained from the MR scanner during routine scan sequences and for comparison MAXL was measured from the transport incubator and an open incubator in the neonatal nursery during routine ventilation of a preterm infant. Machine reproducibility was ±0.5 dBA, and results were rounded to the nearest integer.

3. Results

A total of 2087 min of physiological data were obtained from 39 examinations performed in 23 infants. Heart rate and SaO$_2$ were recorded and analysed for all 39 scans. However, due to infant movement, heart rate data were not obtained for 1 min (0.05%) and pulse oximeter data for 32 min (1.5%) of the total monitoring time.

The median heart rate for the study group was 159 bpm and the individual trends in heart rate during each of the 39 scans are given in Fig. 1. There were no sudden changes in heart rate or oxygen saturation observed at the onset of the procedure and no bradycardia less than 100 or tachycardia greater than 200 bpm occurred during the scans. However, a small increase in heart rate equivalent to 0.2 bpm min$^{-1}$ (95% confidence limits 0.18–0.22) was detected during the procedure.

Minor changes in ventilation were often performed at the beginning of the scan, after handling the infant, but these could be quickly reversed once the infant had settled and the scan commenced. The individual trends in SaO$_2$ during each of the 39 scans are given in Fig. 2. Although 42/2087 epochs demonstrated desaturation less than 90% only eight were less than 85 and 3/2087 less than 80%. The three events recorded less than 80% occurred in a single infant whose endotracheal tube blocked and required changing during the scan. There were 736/2087 epochs of SaO$_2$ > 97%. These episodes mainly occurred in infants breathing room air and only for very brief periods in infants receiving oxygen supplements. Overall there was a slight increase in SaO$_2$ equivalent to 0.066 (95% confidence limits 0.061–0.071) during the procedure.

Invasive BP measurement was performed in the six infants who had indwelling arterial lines. The median BP mean was 37 (range 24–48) mmHg. One sick infant demonstrated marked variability in BP during the scan although this did not correlate with the commencement of imaging sequences and was similar to the infant’s clinical condition before transfer to the MR system. A further infant who was hypotensive during the scan was successfully treated by an increase in the dose of inotropes given. There were no marked changes in BP during the scans in the other four infants.

Axillary temperature data was obtained for 35 of the 39 scans. The median axillary temperature during the MRI was 36.9°C (range 35.7–37.8). Overall, infant cooling was not a problem, in fact a slight trend towards warming was demonstrated equivalent to 0.002°C min$^{-1}$ (95% confidence limits 0.0013–0.0028). However, one sick infant who was imaged for clinical purposes did drop to 35.8°C during scanning. A summary histogram of infants’ temperature during the 35 scans is shown in Fig. 3.

The acoustic noise levels were expressed as MAXL and $L_{eq}$ for the study
Fig. 1. Individual trends in heart rate during each of the 39 scans. In each individual graph, the $x$-axis scale runs from 1 to 72 min and the $y$-axis scale runs from 100 to 200 bpm.
Fig. 2. Individual trends in oxygen saturations during each of the 39 scans. In each individual graph, the x-axis scale runs from 1 to 72 min and the y-axis scale runs from 66 to 100%.
sequences. These values and MAXL for noise exposure in the NICU and the transport ventilator are summarised in Table 2.

4. Discussion

This study monitored physiological variability and measured acoustic noise exposure for a group of preterm infants undergoing MR imaging on a system specifically designed for neonatal use. The data obtained from these infants did not reveal untoward disturbances in the physiological status during the procedure. Acoustic noise level during the MR scanning on this neonatal system was not excessive.

<table>
<thead>
<tr>
<th>Pulse sequence</th>
<th>MAXL (dBA)</th>
<th>$L_{eq}$(dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1-weighted CSE</td>
<td>70</td>
<td>67</td>
</tr>
<tr>
<td>T2-weighted FSE</td>
<td>72</td>
<td>70</td>
</tr>
<tr>
<td>IR FSE</td>
<td>71</td>
<td>67</td>
</tr>
<tr>
<td>Open incubator</td>
<td>62</td>
<td>—</td>
</tr>
<tr>
<td>Transport incubator with alarm and compressor</td>
<td>66</td>
<td>—</td>
</tr>
</tbody>
</table>

MAXL, maximum root mean squared level; $L_{eq}$, average sound pressure level during the measurement period; dBA, ‘A’ weighted decibel.
To minimise handling, infants were transferred to the MR system nursed in a semi-cylindrical cot which rested on a specialised trolley. On arrival at the scanner the cot was inserted directly into the bore of the magnet. Using this system, infants were only handled when being moved from their bed to the trolley and back to their bed after completion of the scan.

The provision of neonatal intensive care within a magnetic field required several precautions. Firstly, the potential for attraction of ferromagnetic objects toward the magnet centre meant all equipment had to be MR compatible. Secondly, because of the deleterious effects on implanted ferromagnetic devices, infants were examined to exclude indwelling metallic objects particularly umbilical artery lines with terminal electrodes. Thirdly, the magnetic field may disturb the function of monitors and ventilators, or conversely such equipment may produce radiofrequency interference with the magnetic field. Furthermore, ferromagnetic materials within or near the scanner distort the magnetic field and monitoring wires can act as antennae resulting in image degradation. Using a Hewlett-Packard Merlin life-support system, that was radiofrequency shielded, a level of monitoring equivalent to that performed elsewhere in the NICU was provided.

Gradient activation may cause induced currents within metal, this causes artefact, heating and potentially skin burns. To avoid this care should be taken with the selection and arrangement of leads and contacts [5]. We used MR-compatible ECG electrodes (Blue Sensor, Medicotest, Olstykke, Denmark) with no bare metal contact. Furthermore, ECG leads with current-limiting resistors (NDM Division, American Hospital Supply Corporation, Daytona, OH, USA) were employed. These leads were plaited and contact with the skin kept to a minimum as previously described [6]. In addition, to minimise artefact ECG electrodes were placed as close to the centre of the magnetic field as possible. Using this system we were able to obtain good quality images without deleterious effects on or from the monitoring system. This is comparable to previously published experience [7].

Ventilation was provided by one of two methods, a conventional ventilator located away from the magnet and connected to the infant with extended ventilator tubing, or alternatively by using a MR-compatible ventilator. Both methods proved successful in our study group which was less mature than any previously reported [8–10]. However, the MR-compatible ventilator eliminated the need for extended tubing and associated extra dead space.

One previous study of term infants has reported physiological changes including raised heart rate, BP or desaturation probably due to stimulation whilst undergoing MRI scanning [1]. Heart rate changes after a sudden noise may be an indicator of both sympathetic or vagal activity. It is reported that sudden noise (85 dBA) causes a biphasic heart rate response and autonomic nervous reflex may be either negative (parasympathetic) in infants with recurrent prolonged apnea or positive in infants with clinical signs of increased sympathetic nervous activity [11]. However, infants in our study did not show excessive disturbance in heart rate whilst undergoing scanning, and the commencement of the sequence did not prompt a response. This may be because the system allows gradient operation with little increase in noise. The trend
in heart rates shown in Fig. 1 show an increase in heart rate towards the end of scanning time but this slight increase was not clinically significant.

SaO\textsubscript{2} levels were monitored effectively throughout the scan using conventional oximeter probes adapted by the application of shielding to reduce induced currents following gradient operation. Although the signal was occasionally degraded by movement this resulted in loss of data for less than 2% of total study time. Several infants breathing room air had SaO\textsubscript{2} as high as 100% but every effort was made to keep infants receiving supplemental oxygen within the accepted range for our unit (92–97%). In contrast, desaturation, tachycardia and bradycardia could all result from excess stimulation or inadequate intensive care. Although several episodes of desaturation were detected only one (occurring due to endotracheal tube blockage) was less than 80%. Reintubation was performed uneventfully within the MR suite, using MR-compatible equipment, and the infant recovered quickly. The majority of the other episodes were between 85 and 90% and probably reflect the clinical status of the study group rather than any deleterious effect of imaging. The very slight increase in saturation seen during the scan was not clinically significant.

In this study we have not reported blood gas analysis as only a small number of infants had indwelling arterial lines and samples were only taken if clinically indicated. Future studies with regular sampling would be needed before it would be possible to make a comment on the carbon dioxide tension and pH.

BP was continuously monitored in the six infants who required BP monitoring in the NICU prior to imaging and had indwelling arterial lines. These six infants were those that required continuous BP. We were able to perform BP monitoring comparable to that performed on the neonatal unit enabling the dose of inotropes, in the two infants receiving inotropic support, to be titrated against BP.

Maintenance of temperature is an important factor in the care of preterm infants. In this study infants were continuously monitored allowing minor changes in axillary temperature to be detected without disturbing the infant. Overall temperature was adequately maintained although one sick infant was poorly perfused and the axillary temperature did drop below 36°C during the scan. The slight increase in temperature seen in most infants during the scan was not clinically significant.

Sedation with chloral hydrate was only occasionally needed in the more mature infants and the majority of infants were successfully imaged whilst sedated for ventilation or following a feed.

Noise exposure in adults is thought not likely to present significant risk unless greater than 90 dBA or prolonged, but there are few data available for preterm infants and the risk is therefore unquantifiable. Due to the design our neonatal MR system is relatively quiet compared to adult systems. To minimise the noise production specific measures, including lagging and gradient cable immobilisation, have been performed. In fact, ambient noise in the MRI was only a little greater than that measured in the transport incubator or on an open incubator in the neonatal unit and is comparable to that reported during neonatal transport [12] or in other neonatal nurseries [13]. Notwithstanding this, an effort was made to minimise the infants’ exposure to loud impulsive noises. The size of the preterm ear canal is approximately 2 mm and, as
this precludes the use of ear plugs, we used a bag filled with polystyrene balls which could be air evacuated to snugly fit around the baby’s head.

The results of this study suggest that examination of preterm infants with MRI can be performed, on a suitable system, without major physiological upset.

References