

# Ultrafast Magnetic Resonance Imaging of the Neonate in a Magnetic Resonance-Compatible Incubator With a Built-in Coil

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**ABSTRACT.** *Background.* Magnetic resonance (MR) imaging of the neonate is important clinically, because this group of patients often has complex and multiple problems due to prematurity and developmental abnormalities. MR imaging usually involves moving neonates away from their controlled environment to the scanner.

*Objective.* In this study we present the results of our initial experience with an MR-compatible incubator used on a 1.5-T system.

*Methods.* Seven neonates were imaged at 1.5 T without sedation or anesthesia. Images were obtained by using single-shot fast spin echo, 3-dimensional Fourier transfer gradient echo, and diffusion-weighted sequences. In 4 cases, time-of-flight angiography was performed.

*Results.* All 7 neonates were stable throughout the scan time (10–21 minutes). Experienced observers graded the images for quality, and all were graded excellent or good. In no case was the image quality poor.

*Conclusion.* Neonates can be imaged safely by using an MR-compatible incubator and fast image sequences. This method should allow neonates to be imaged by MR in sites at which a dedicated neonatal MR scanner is not available. *Pediatrics* 2004;113:e150–e152. URL: <http://www.pediatrics.org/cgi/content/full/113/2/e150>; *magnetic resonance, neonate, incubator.*

ABBREVIATIONS. MR, magnetic resonance; SSFSE, single-shot fast spin echo; TR, repetition time; TE, echo time; SLT, slice thickness; NEX, number of excitations; ETL, echo train length; FA, flip angle; FLAIR, fluid attenuation inversion recovery.

The premature neonate provides a challenge to modern medicine. New methods and technical developments are resulting in younger gestational-age neonates surviving. They have multiple problems as they try to adapt to the world outside the protection of their mother's womb. Their surrounding environment needs to be controlled care-

fully, because they cannot maintain body homeostasis.<sup>1</sup> Early diagnosis and treatment reduce morbidity and mortality.<sup>2</sup> Imaging is essential to diagnosis and magnetic resonance (MR) is superior to ultrasound for many pathologies<sup>3</sup>; however, imaging by MR necessitates movement of the neonate. Lammers Medical Technology (Lubeck, Germany) has produced an MR-compatible incubator with a built-in head coil that also can be used as a transport incubator.

The aim of this study was to evaluate the combination of fast imaging methods and an MR-compatible incubator at 1.5 T to image nonsedated neonates.

## METHODS

Local region Ethics Committee approval was obtained, and informed written consent was given by the parents. Seven neonates were imaged at 1.5 T (Edge Eclipse, Phillips Medical Systems, Eindhoven, The Netherlands) in an MR-compatible incubator (Lammers Medical Technology) (Fig 1) by using fast imaging techniques (T1, single-shot fast spin echo [SSFSE], 3-dimensional Fourier transfer gradient echo, and diffusion-weighted imaging) and, in 4 cases, time-of-flight angiography. No sedation or anesthesia was used.

A standard spin-echo T1-weighted sequence was acquired with repetition time (TR) = 400 milliseconds, echo time (TE) = 16 milliseconds, slice thickness (SLT) = 4 mm, in-plane resolution = 0.9 mm, and number of excitations (NEX) = 2. The T2-weighted SSFSE sequence used TR = 20 000 milliseconds, TE = 75 milliseconds, in-plane resolution = 1 mm, SLT = 5 mm, echo train length (ETL) = 132, and NEX = 1. The 3-dimensional Fourier transfer gradient echo sequence used radio frequency spoiling and had TR = 238 milliseconds, TE = 3.4 milliseconds, in-plane resolution = 0.9 mm, SLT = 6 mm, NEX = 2, and flip angle (FA) = 70°. Diffusion-weighted imaging used TR = 3000 milliseconds, TE =



Fig 1. The neonatal incubator.

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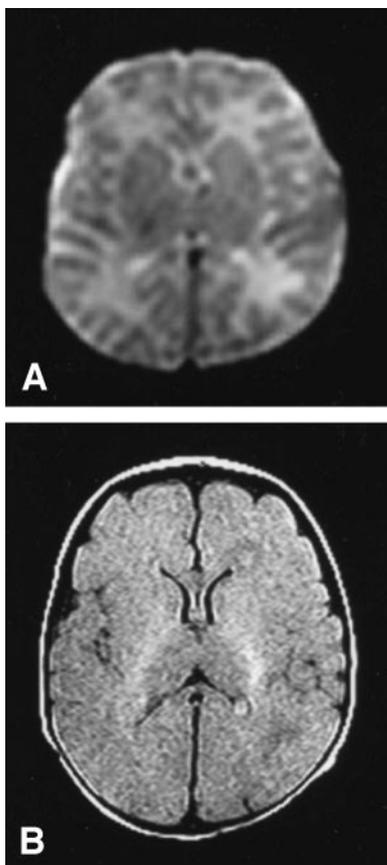
100 milliseconds, in-plane resolution = 2 mm, SLT = 5 mm, ETL = 64, NEX = 1, and  $b = 1000 \text{ seconds}\cdot\text{mm}^{-2}$ . The sliding interleaved KY angiography sequence<sup>4</sup> was acquired with TR = 29 milliseconds, TE = 6.7 milliseconds, in-plane resolution = 0.43 mm, SLT = 1 mm, NEX = 1, FA = 33°. For the fluid attenuation inversion recovery (FLAIR) sequence, TR = 6000 milliseconds, TE = 90.4 milliseconds, field of view = 20, matrix = 192 × 256, and slices were 6 mm thick.

A custom-built incubator with temperature and humidity control and a dedicated head coil, birdcage receive only (Advanced Imaging Research Inc, Cleveland, OH), were used. The neonates were monitored throughout by using MR-compatible pulse oximetry. The temperature and humidity of the incubator were maintained as appropriate for the needs of the neonate and monitored throughout.

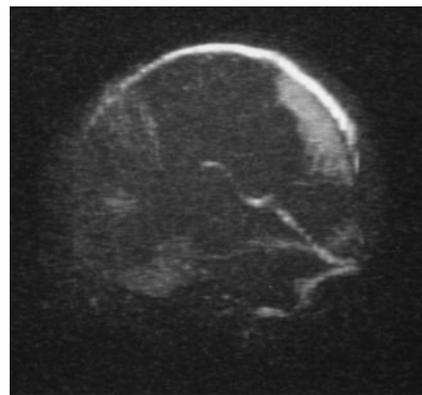
The images were scored for quality by 2 neuroradiologists (P.D.G. and D.J.A.C.) and 1 neonatal radiologist (E.H.W.), and a radiologic diagnosis was reached by consensus in each case.

## RESULTS

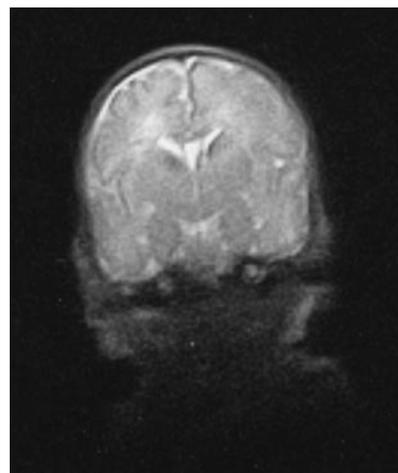
The neonates were aged 2 days to 4 months from birth and ranged from 24 weeks' gestational age to term at birth. They were all stable neonates imaged before discharge home from the unit. The neonates remained stable throughout the scan time (range: 10–21 minutes). Good or excellent T1- and T2-weighted images were obtained in all cases. Diffusion weighted imaging was successful and gave good-quality images (Fig 2A), as did the FLAIR se-



**Fig 2.** All the images are taken from a study of a premature neonate, born at 30 weeks' gestation, and imaged 19 days after delivery. The images show a normal study. A, Diffusion-weighted imaging (TR = 3000 milliseconds, TE = 100 milliseconds, in-plane resolution = 2 mm, SLT = 5 mm, ETL = 64, NEX = 1, and  $b = 1000 \text{ seconds}\cdot\text{mm}^{-2}$ ). B, FLAIR (TR = 6000 milliseconds, TE = 90.4 milliseconds, field of view = 20, matrix = 192 × 256, and slices were 6 mm thick.)



**Fig 3.** MR venography showing a subdural collection (TR = 29 milliseconds, TE = 6.7 milliseconds, in-plane resolution = 0.43 mm, SLT = 1 mm, NEX = 1, and FA = 33°).



**Fig 4.** Germinal matrix bleed on the right, T2 fast spin-echo sequence (TR = 20 000 milliseconds, TE = 75 milliseconds, SLT = 5 mm, ETL = 132, and NEX = 1).

quence (Fig 2B). MR angiography and venography (Fig 3) was successful in the 4 cases attempted. T1 data were best obtained from a spin echo sequence (acquisition time of 2 minutes and 46 seconds) and T2 weighted from SSFSE (20 seconds) (Fig 4).

Final diagnoses were normal (3), subdural hematoma (3), and germinal matrix hemorrhage (1).

## DISCUSSION

Fast imaging methods and a dedicated MR-compatible incubator with coil allows safe and efficient MR imaging of the nonsedated neonate, providing essential information and aiding management; the constant environment reduces the risk of adverse events occurring during the transport and imaging of the neonate.

There have been several attempts to overcome the problem of imaging the neonate, including dedicated scanners on neonatal intensive care units both in our institution<sup>5</sup> and others.<sup>6</sup> In general, these dedicated units are ideally located and are flexible to the needs of the neonate. However, they are not yet widely available and may be restricted in their image sequences. The neonatal incubator used in this study

would allow sites without a dedicated MR scanner to image neonates safely. However, a few problems remain. The neonate is not easily visible from the control room, and it is safer to have a member of staff in the room throughout the scan. The incubator controls temperature and humidity, but additional monitoring is required for electrocardiography and oxygen saturation. In this study we used MR-compatible pulse oximetry (MR 3500, MR Resources Inc, Gardner, MA).

Additional development is ongoing to overcome these problems and improve image quality. However, the availability of this incubator will allow many institutions to image the neonate by MR and obtain information useful for clinical management.

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