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TECHNICAL INNOVATION

Improved MRI of the neonatal heart: feasibility study using a knee coil

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Abstract As a first step towards the development of a neonatal cardiac MRI (CMRI) coil, we investigated the utilization, handling and image quality of a knee coil for CMRI in infants at 3 Tesla. Scout imaging and cine imaging with optimized pulse sequence parameters were performed in two neonates and the resulting images were evaluated for diagnostic purposes. All images were of high diagnostic quality. Complete examinations took less than five minutes. The excellent signal-to-noise ratio provided by this coil allowed all cine studies to be acquired with only three averages. In conclusion, a knee coil can be successfully applied in neonates for CMRI, but the coil design could be improved further to facilitate routine clinical use.

Keywords Cardiac magnetic resonance imaging · Neonate · Transmit and receive MRI extremity coil · 3-Tesla MRI

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Introduction

Over the last decade, cardiac MRI (CMRI) has become an important tool in the diagnosis, prognosis and monitoring of congenital heart diseases in adults and children [1, 2]. Image acquisition methods available in adults have improved and become faster, providing higher spatial and temporal resolution, so that both contractility of the heart muscle and the volume of blood ejected by the heart can be reliably assessed [3–8].

The imaging of infant hearts imposes higher demands for spatial and temporal resolution because of smaller cardiac dimensions and higher resting heart rates [2, 9]. This entails more stringent requirements on hardware and pulse sequences, which has effectively impeded the use of CMRI in neonates. Currently available hardware designed for CMRI in adults includes multichannel phased-array dedicated cardiac coils that are generally unsuitable for CMRI of infants. In our experience, the existent cardiac coils can be used for adults and children with bodyweight > 10 kg. For neonates, however, these cardiac coils are oversized; their weight is too high unless positioned on special supports and the large coil dimensions are not optimal for small field-of-view imaging. Free breathing of the neonate necessitates the utilization of conventional small-sized and low-weight surface coils. These coils have only a limited number of elements so that field of view and signal-to-noise ratio (SNR) is greatly reduced. This has led others to utilize MRI head coils for morphological investigations of the pulmonary circulation in neonates [2, 10, 11].

To meet the special demands of high-field CMRI in neonates, an eight-element knee coil (Philips Healthcare, Best, The Netherlands) was tested for its feasibility for improved cardiac imaging at 3 Tesla, illustrating the idea that existing MRI hardware can be adapted for improved cardiac imaging in neonates.

Materials and methods

The study was approved by the local institutional review board, and for each volunteer informed parental consent was obtained before participation. An eight-element knee coil was used in two neonates for CMRI at a 3-Tesla MRI scanner (Achieva; Philips Healthcare, Best, The Netherlands). One child had previously undergone surgery for supracardiac total anomalous pulmonary venous return. Postoperative echocardiography was not able to assess the anastomosis between the common pulmonary vein and the left atrium.

The second child had a transposition of the great arteries and underwent an arterial switch operation. CMRI was requested to assess biventricular function and to rule out a pericardial hematoma. Sedation was used in both neonates, but they were not intubated for the examination. Heart rate and oxygen saturation were monitored continuously during the examination with an MRI compatible monitor (Invivo Precess 3160; Invivo, Orlando, FL, USA). The cylindrically shaped coil's inner bore diameter is 130 mm and its length 160 mm. The top of the coil can be removed for optimal positioning.

We performed standard ECG-triggered scout images of the heart in three orthogonal planes, followed by axial cine imaging to investigate the cardiac anatomy. The scout images were acquired with a turbo field echo sequence (TFE) in multishot mode (turbo factor, 40), with voxel size, 1.0 × 2.2 × 5.0 mm and TR/TE, 9.5/2.4 ms. Scan parameters for the axial cine imaging sequence were: TFE mode, voxel size, 1.9x2.0x6.0 mm, TR/TE, 4.3/2.5 ms, flip angle, 15°, 17 slices. A four-chamber and a short-axis stack of slices were used for assessing cardiac function and measuring the ventricular volumes to cover the heart from the base to the apex. Scan parameters were as follows: TFE mode, voxel size, 1.9 × 1.9 × 5.0 mm, TR/TE, 4.4/2.5 ms, flip angle, 15°, three slices for the four-chamber and eight for the short-axis stacks.

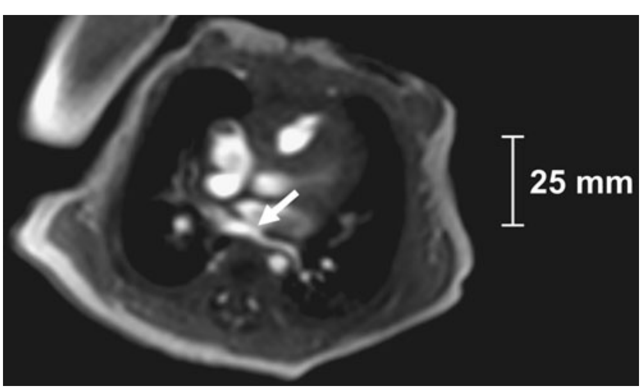

Fig. 1 Image from an axial cine sequence. The anastomosis between the left atrium and the pulmonary veins (*arrow*) is clearly visualized

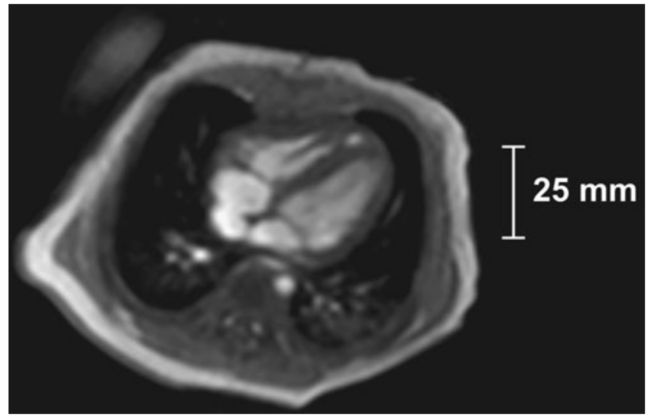

Fig. 2 Four-chamber view of the same patient as in Fig. 1

Results

The eight-element knee coil was successfully used in both neonates. All images were of high diagnostic quality following optimization of voxel size, TR/TE and flip angle. Example images are shown in Figs. 1, 2, 3. The anastomosis between the common pulmonary vein and the left atrium allowing unobstructed pulmonary blood flow could be clearly visualized in the first infant (Fig. 1). In the second, biventricular function was successfully assessed, and pericardial hematoma could be ruled out. Both examinations took less than 5 min to complete. The excellent signal-to-noise ratio (mean SNR for cine MRI:

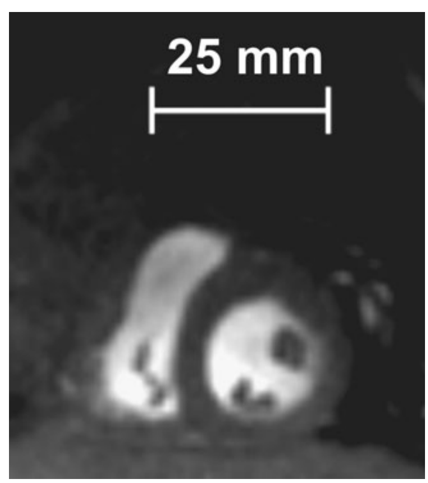

Fig. 3 Short-axis view of the same patient as in Figs. 1 and 2

26.4) allowed all cine studies to be acquired with only three averages.

Discussion

The two case examples demonstrate that CMRI of neonates at 3 Tesla can be successfully performed with an eight-element radiofrequency resonator that surrounds the torso. CMRI at 3 Tesla still remains challenging because of technical constraints, such as susceptibility artifacts, that are inherent to higher field strengths. In particular for CMRI at 3 Tesla, assuring signal stability during respiration can be challenging. This is partly because surface coil motion during breathing can cause changes in electromagnetic coupling between the coil and surrounding structures, and partly due to fluctuations of the coil impedance. Magnetic susceptibility effects, which cause image artifacts due to signal loss, increase linearly with magnetic field strength. With increasing field strength, the susceptibility effects become relatively large in relation to the size of the neonatal heart. Susceptibility effects occur at air, bone or soft tissue interfaces and may cause regions of significant signal loss, inhomogeneous fat saturation and geometric distortion, all of which may impede the routine clinical use of high-field CMRI. Since neonates are very small compared with adults and tend to have higher lung water content and smaller air spaces, susceptibility effects may be somewhat reduced. This makes neonates good candidates for CMRI at 3 Tesla [11]. To obtain the best possible imaging results, it is essential to employ optimized and adapted hardware.

The eight circularly arranged elements of the coil have optimal sensitivity profiles for parallel imaging, and allow accurate delineation of the small cardiovascular structures. This is essential for diagnosis, surgical planning and follow-up in various congenital cardiac abnormalities. We found that high spatial resolution of the phased array even enabled accurate assessment of very small structures such as anastomosis of the left atrium and the pulmonary veins. Our results seem promising also for perfusion imaging, diagnosis of anomalous coronary anatomy, assessment of aorto-pulmonary collaterals and systemic-to-pulmonary artery shunts. However, further clinical investigation by comparing the results from CMRI at 3 Tesla with conventional methods like cardiac CT or catheter studies is needed to evaluate the results and clarify the usefulness of this application.

The advantageous coil design improves safety in neonatal CMRI. Neonates require sedation or general anesthesia for successful scanning, which involves some inherent risk and need for specialized staff. Since the head of the infant is not covered by any part of the knee coil, continuous visual observation and additional monitoring is feasible and delivery of oxygen is easy. Further, in case of an emergency, the coil's upper part can quickly be removed to allow access to the child. It is also noteworthy that the coil does not rest on or come into contact with the neonate's chest, including the ECG leads on the chest. Close contact and coupling of the ECG leads and the radiofrequency coil elements would cause interference on the ECG trace and consequently impaired monitoring and less reliable ECG gating. There have been reports of very close contact of coil elements with the ECG electrodes causing undue increases of skin temperature beneath the ECG-electrode patches.

However, the use of this particular knee coil is limited to neonates weighing less than approximately 4.5 kg. For example, the inner coil surface is arched in the lower half, which requires additional pillow pads to create a flat and comfortable layer for the infant. Furthermore, the coil becomes narrower towards its center so that it is difficult to keep the arms of a neonate inside the coil. Nevertheless, our study suggests that similar coil designs that correct minor aspects of the current physical design might provide optimal conditions for CMRI in neonates.

Conclusion

Our data show that an eight-element knee coil array can be successfully used for high-field CMRI in neonates. The improved coil technique has the potential to provide important additional anatomical and functional information in infants with congenital heart disease, who would otherwise require invasive imaging. For an optimal utilization for CMRI in infants, however, vendors need to be encouraged to improve the physical coil design.

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