

How to Perform a Non-Contrast and Sedation-Free Neonatal Feed and Wrap Cardiac MRI at 3 Tesla

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Neonatal feed and wrap cardiac MRI

Non-contrast, sedation-free neonatal feed and wrap uses natural sleep after feeding and swaddling. Centers also refer to it as feed and sleep, feed and bundle, or feed and swaddle. This technique can be used to scan babies up to the age of 3 to 5 months¹ using a free-breathing protocol. Traditionally, neonatal cardiac MRI scanning often required the administration of contrast agent to improve signal-to-noise ratio (SNR) and thereby image quality. Further limitations of cardiac MRI scanning in this group of patients include the need for general anesthesia or medical sedation due to the long scan times. However, with the advances in acceleration techniques, feed and wrap cardiac MRI can be acquired in a feasible scan time lasting 20–35 minutes. Using dedicated small body coils and a 3-Tesla MAGNETOM Prisma MRI scanner can improve SNR sufficiently so that no contrast administration is needed.

Pre-appointment preparation

Parents play an important role in the successful imaging of babies. Cardiac imaging can be stressful for parents of babies with congenital heart disease, and therefore a calm environment is important. Sending clear information out to the parents helps them prepare for the MRI scan. Our patient information leaflet tells parents how to dress the baby (metal-free clothing without poppers), to bring a feed along, and to try not to let the baby nap just prior to the scan. It also describes how the scan will be performed (including pictures of the equipment with a doll) and answers common MRI safety questions and concerns. On the

day of the scan, enough time should be allowed prior to the scan to fully explain to the parents how the scan is performed and to discuss any concerns or questions they might still have. Calm parents increase the likelihood of the baby going to sleep quickly.

Baby transfer preparation

Successful implementation of the neonatal cardiac MRI requires good preparation. A variety of options are available to perform a neonatal feed and wrap MRI scan:

- 1) Transfer the sleeping baby directly onto the scanner table from the parents' arms.
- 2) Transfer the baby in an open-top basinet or immobilizer cushion.
- 3) Transfer the baby in a closed incubator.

In our experience, option 3 has the highest success rate [1]. This could be due to the extra noise attenuation provided by the incubator housing (in addition to the hearing protection worn by the baby), as well as the option to warm the incubator.

When using an MRI-safe incubator, it is important to make sure that the incubator is fully charged prior to the scan. A feed and wrap MRI checklist can be useful for making sure that the incubator is fully prepared. This includes baby sheets, positioning devices, blankets, electrode stickers, a skin cleaning solution, spare baby leggings (metal-free clothing), MRI-compatible monitoring equipment, dedicated coils, and MRI-compatible headphones. Additional equipment needed for inpatient MRI scanning might include MRI-safe infusion pumps.

¹Siemens Healthineers disclaimer: MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures. Note: This disclaimer does not represent the opinion of the authors.

Baby preparation

Prior to feeding, the baby's length and weight should be measured. It is advisable to place the electrode stickers on the baby's chest and ask parents to prophylactically change the diaper prior to feeding the baby. At this point, it is also important to check that the baby is wearing metal-free clothes.

After the baby has been fed, the MRI cardiac monitoring box and any additional monitoring (such as a saturation monitor) are attached. The baby is then swaddled in a blanket and transferred to the MRI-safe incubator. If the baby is upset, an additional cuddle from the parents to calm the baby after swaddling is helpful before transferring to the incubator. The dedicated MRI coils are secured. Then the MRI-compatible baby headphones that provide additional noise cancellation are placed over the baby's ears. Some babies really dislike the headphones and get upset. In this instance, it is

advisable to wait to place the headphones until the baby is asleep. To keep the baby calm and cozy, the incubator can be warmed to variable temperatures and humidity. After the baby has been transferred and prepared, the feed and wrap MRI safety checklist is completed to ensure the baby is metal-free and the incubator is free of any equipment, before entering the MRI control room. Some babies benefit from being wheeled up and down the corridor in the incubator to aid sleep, while others fall asleep with gentle rocking of the incubator in a darkened room. Playing sleep music or white noise may also be helpful, and the parents can often advise how the baby normally best falls asleep.

Preparing the MRI scanner room

A dark and calm environment should be prepared. This includes dimming the lights in the MRI control room and scanner room. We also advise playing loud sleep music in the MRI scanner room – with the volume matching the scanner volume. This provides a constant noise. We have found that babies often stir and awaken from the start/stop of MRI sequences. This is greatly reduced by playing loud, calming, and continuous music.

Transferring the baby into the scanner room

In the MRI control room, another safety checklist should be completed by the assigned member of staff, and safety guidelines to be followed in the event of an emergency should be read out to make sure that everyone is aware of the MRI safety considerations. At least two team members trained in MRI safety are required to transfer the incubator onto and off the scanner table.



1 Placement of electrode stickers.



2 Neonatal incubator setup. The baby is swaddled and placed in the incubator with dedicated coils, monitoring, and noise protection.

Challenges during the MRI scan

Even though our feed and wrap MRI scan technique has a > 95% success rate, performing MRI scans in babies aiming to achieve high-quality diagnostic images can be challenging (especially in babies > 2 months) and individualized protocol adaptation is often necessary. Babies sometimes awaken or stir briefly, often because they have lost their pacifier. It helps to stop the scan and offer the baby the pacifier while the incubator stays in position, as often the baby settles and the scan can be continued. If frequent startling is observed, continuous scanning is important, with some pictures requiring repeated acquisition for optimal image quality.

General sequence and safety considerations

When scanning neonatal patients, care must be taken to avoid excessive radiofrequency (RF) or acoustic noise exposure. For the former, the patient's height and weight must be entered during registration to allow accurate specific absorption rate (SAR) modelling. For the latter, hearing protection suitable for babies' heads with appropriate noise attenuation must be used. Restricting gradient modes can help reduce acoustic noise generation. We therefore use Whisper gradient modes where possible, although we will use higher gradient modes for sequences where Whisper mode is either not available or is not consistent with other desired parameters, as long as this does not result in excessively noisy sequences.

When scanning sleeping babies, both the type and level of acoustic noise can influence the likelihood of the baby stirring and moving excessively. In our experience, sequences generating intermittent noises are more likely to wake and disturb the baby than continuous noise. We therefore consider this aspect when performing our protocols and try to keep sequences with intermittent noise generation to later in the protocol, after key sequences have been acquired. The Compressed Sensing 4D Flow MRI² research sequence is in our experience the best sequence to keep babies asleep, and we almost always manage to acquire at least these sequences.

Scanner table movement may also disturb the baby's sleep, and we avoid this during scanning. Given the small size of the patient, there is not much need for repeated table movement as the entire thoracic anatomy will be close to isocenter once positioned. We therefore acquire one localizer at the initial table position prescribed by the lasers (FIX table positioning mode with 0 mm head/foot offset), a second with a small table move (if required) to move the heart to isocenter (ISO table positioning mode), and then for all subsequent sequences, we reference all table positions to the second localizers to avoid further movement.

Due to the very small body size of these patients (and their cardiac anatomy) it is necessary to acquire images with greater spatial resolution than in adult cardiac MRI. Small fields of view can easily be used without risk of wrap due to the small patient size, and therefore the necessary resolutions can be achieved within an acceptable timeframe. However, achieving this while maintaining adequate SNR can be challenging. To aid this, we use a 3T MRI scanner with dedicated small coils which cover the baby's torso with a high density of coil elements.

Signal scaling around neonatal hearts does not suffer from the same issues as described in our previous fetal cardiac MRI article [2], whereby signals can be dominated by those from maternal tissue or amniotic fluid closer to the coil. However, for some sequences we found that some fine-tuning of receiver gain and/or Image Scaling Correction can result in better contrast resolution for the neonatal heart. Trial and improvement may be needed to find optimal values for each center's individual sequence setup. In our experience, increasing scaling values up to around 5 works well for some sequences (note that this is 2 to 3 times less than we use for some fetal sequences). This setting can be edited in retrospective reconstructions, which can allow fine-tuning without the need to repeat image acquisition.

As long as the baby remains asleep and well wrapped, large-scale motion is generally not an issue. Furthermore, as it is not possible to instruct breath-holds, imaging of each sequence (or slice) must be performed quickly to minimize respiratory motion artifacts, or averaged over longer periods of time. For many of our sequences, TE and TR are set to be automatically minimized and fast RF pulse shapes are used to minimize scan duration and (in the case of TE) maximize SNR.

²Work in progress. The application is currently under development and not for sale in the U.S. and in other countries. Its future availability cannot be ensured.

Sequences

Vasculature-triggered TurboFLASH (approx. 1 minute for 50 overlapping slices)

After acquiring standard three-plane localizers we acquire a transverse stack using 2D TurboFLASH imaging, which generates high signal from the vasculature due to inflow enhancement effects. These are acquired as 4.5 mm thick contiguous slices, but with -50% distance to provide overlapping slices with the higher SNR associated with the thicker slices.

Single-shot (per slice) triggered imaging is performed, which provides resilience to motion and allows stacks of 50 slices to be acquired in approximately 1 minute using GRAPPA acceleration factor 2. A high flip angle (for a FLASH sequence) of 30° is used to maximize saturation of stationary tissue, which yields high contrast of the flowing blood. We find that a single acquisition (no averaging) and no phase partial Fourier yields sufficient SNR with this sequence. A base resolution of 256 yields in-plane resolution of approximately $0.8 \times 0.8 \text{ mm}^2$ for a typical field of view.

Acquisition is triggered (single-phase) to acquire data every other heartbeat with a minimal trigger delay of 1 ms for systolic imaging, and repeated with a trigger delay for diastolic imaging.

This sequence may also be repeated with fewer slices to provide targeted views of specific vascular anatomy, for example aligned to show the aortic arch.

As this sequence generates a high contrast-to-noise ratio within an acceptable acquisition time, we find that use of a high receiver bandwidth (1149 Hz/pixel) maximizes image quality, and we allow use of performance gradient mode to achieve this for this sequence.



3 Planning of the transverse stack using triggered TurboFLASH.

CS 4D Flow MRI

(approx. 2 minutes for 20 slices / 5 minutes for 60 slices)

To assess blood hemodynamics over extended volumes, we use the Compressed Sensing 4D Flow MRI² research sequence, which allows volume coverage of the heart and proximal vasculature in an acceptable time for neonatal imaging. This approach allows a 3D volume to be acquired with velocity encoding in all three dimensions. It can therefore be significantly simpler and more robust than planning multiple 2D flow acquisitions, particularly in this application, as in the 2D approach, where it is critical for each view to be accurately prescribed, it is common for repeat scanning to be required when the patient moves during the time needed to accurately plan each acquisition.

Furthermore, making use of inflow enhancement, the magnitude data can also be used for anatomical assessment in 3D (as a substitute for a separate 3D whole-heart acquisition).

We acquire data with approximately 1.0 mm³ isotropic resolution, retrospectively gated into 25 cardiac phases using electrocardiographic (ECG) gating. Strong asymmetric echoes are used to allow TE and TR to be minimized, and a constant 7° is used. Different venc values are applied depending on the anatomy of interest, e.g., 150 cm/s for the aorta (oblique sagittal planning), 100 cm/s for a whole-heart acquisition (sagittal planning), and 350 cm/s for pulmonary arteries (transverse planning). Likewise, the coverage will vary from approximately 20 slices for targeted vessels (aorta/pulmonary arteries) to approximately 60 slices for whole-heart coverage. We standardized these 3 anatomical acquisitions to account for different venc requirements but also to make use of inflow enhancement for 3D assessment of the branch pulmonary arteries and aorta in the magnitude images.

It should be noted that image reconstruction can take significantly longer than acquisition for this sequence (up to around 15 minutes), and other sequences acquired subsequently will not be reconstructed until the 4D Flow MRI reconstruction completes. We reconstruct during the scan while cine stacks are running to allow for visual quality assurance of the reconstructed 4D Flow MRI acquisition.

²Work in progress. The application is currently under development and not for sale in the U.S. and in other countries. Its future availability cannot be ensured.



4 Planning of the aortic 4D Flow MRI sequence using oblique sagittal placement of the slab.



- 5 Planning of the whole-heart 4D Flow MRI sequence using sagittal placement of the slab.



- 6 Planning of the branch pulmonary arteries 4D Flow MRI sequence using transverse placement of the slab.

Cine imaging (approx. 30 seconds per slice)

For cine imaging, we also use a 2D TurboFLASH acquisition with 4 mm slice thickness and approximately $0.7 \times 0.7 \text{ mm}^2$ in-plane resolution. TE and TR are minimized, and we use a 12° flip angle. GRAPPA (acceleration factor 2) averaging (NSA = 3) gives an acceptable balance of SNR and scan time, and weak asymmetric echoes are allowed to minimize TE. Short-term averaging mode is used to minimize motion artifacts.

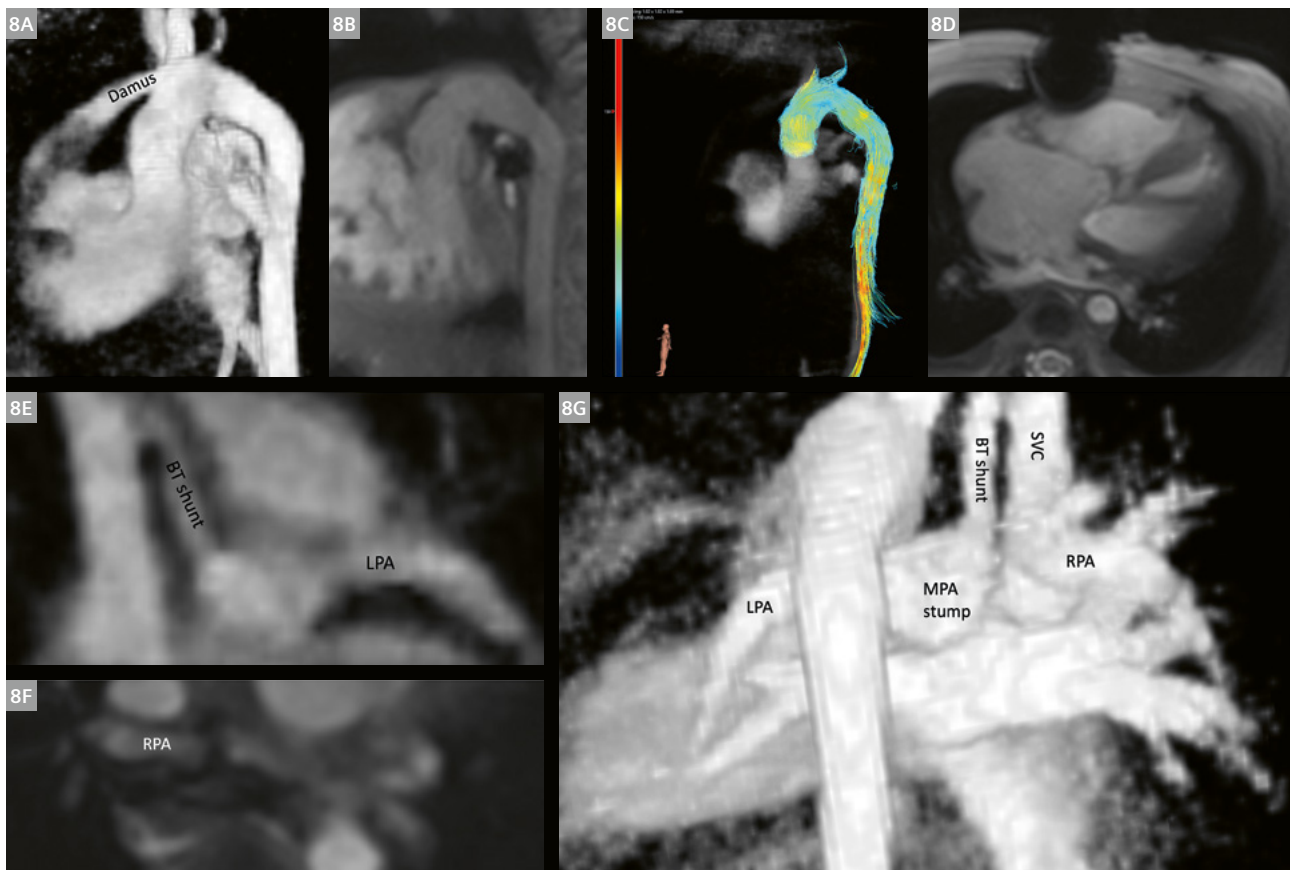
Our sequence is retrospectively gated into 25 cardiac phases using ECG. Where multiple slices are required (e.g., short-axis stack), they are acquired contiguously in sequential mode. Unlike the single-phase imaging above, we limit gradients to Whisper mode for this cine, and scan with a lower receiver bandwidth of 400 Hz/pixel.

2D flow (approx. 30 seconds per slice)

To assess hemodynamics over targeted locations, a similar 2D TurboFLASH cine sequence is used, but with velocity encoding and reduced spatial resolution. A venc (through-plane) of typically 150 cm/s is used for the aorta and 450 cm/s for the pulmonary arteries. Single slices with 4 mm thickness and in-plane resolution of $1.0 \times 1.0 \text{ mm}^2$ are acquired using 3 averages, GRAPPA (acceleration factor 3), 6/8 phase partial Fourier, and strong asymmetric echoes to minimize TE (and TR). A flip angle of 20° is used. Images are retrospectively gated into 30 phases using ECG. As for the cine imaging, Whisper mode gradients are used, with a receiver bandwidth of 454 Hz/pixel.



7 Planning of the aortic arch cine.



8 Summary of the imaging in a baby with mitral atresia, large ventricular septal defect (VSD), and transposed great arteries after Norwood operation with a Blalock-Taussig (BT) shunt. Images **(8A)**, **(8E)**, and **(8G)** are based on magnitude images from CS 4D Flow MRI images; images **(8B)**, **(8D)**, and **(8F)** are GRE cine images; image **(8C)** is CS 4D Flow MRI data.

Other sequences

For single ventricle assessment, we often also include a standard T2 SPACE sequence (for lymphatic assessment). For babies who are waking easily/frequently, we also sometimes use real-time imaging instead of the cine imaging described above.

References

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