Addressing Flow and Pulsation-Associated Artifacts in TOF-MRA in Children

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Introduction: MR angiography

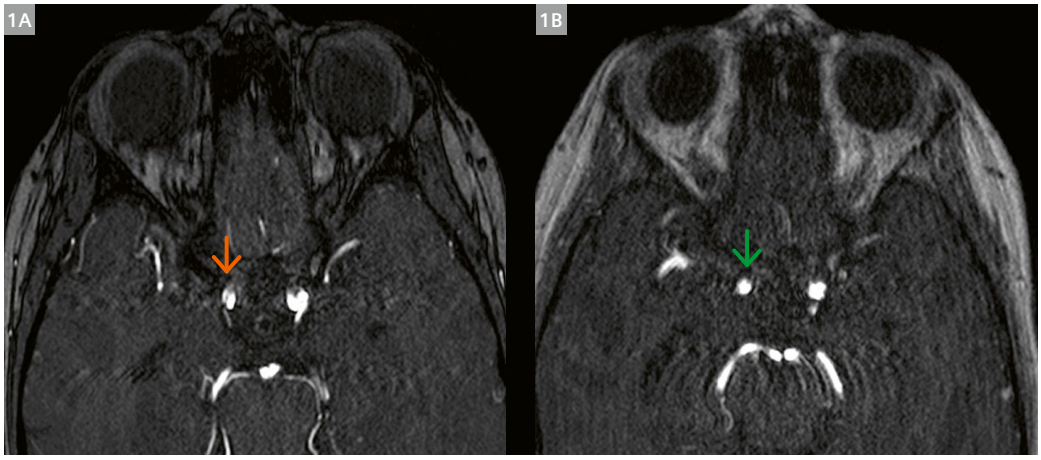
Time-of-flight [1] magnetic resonance angiography (TOF-MRA) images vascular structures without contrast [2, 3]. As its name suggests, TOF uses the phenomena of fresh blood flow into the imaging plane, which increases the signal intensity and causes blood to appear brighter than the surrounding tissue on the images [2, 3].

TOF-MRA utilizes multiple radio frequency (rf) pulses to saturate the magnetization of the spins in the imaging plane, while the moving spins in the blood vessel outside the imaging plane are not affected. Upon entering the imaging plane, these unsaturated spins result in higher signal than the stationary spins, which remain saturated. However, in-plane moving spins eventually also experience the saturation pulses and lose signal compared to the through-plane moving spins, which are always unaffected [4]. Additional in-plane spin signal loss arises from the fact that the phase of spin changes under the influence of the gradient field, although the gain and loss phases depend on the direction of the flow. In-plane flow and an area of vascular turbulence may cause signal loss [5].

To overcome the loss of signal in moving spins due to prolonged saturation RF bands, multiple thin slabs are acquired in 3D using a technique called multiple overlapping thin slab acquisition (MOTSA) [6]. This restricts the number of slices per slab and subsequently shortens saturation RF bands, which minimizes the saturation effect in the moving spin.

Using the current standard sequence in children

Standard MRA sequence: The standard TOF-MRA sequence that Siemens Healthineers provides on its scanners is optimized for adults. Some of the relevant parameters are shown in Table 1. For use with children, particularly those with sickle cell disease or those affected by radiation arthritis, the sequence will require some changes to compensate for the artifacts that may arise from turbulent flow caused by arterial stiffness or lumen narrowing [7]. Turbulent or slow flow reduced the T2 relaxation due to the spin dephasing [8]. To overcome the loss of signal caused by lower T2 relaxation, it is recom-



1 **(1A)** Orange arrow shows the pulsation artifact in the direction of phase encoding (right to left), which misregistered the vessel lumen. **(1B)** Green arrow shows the same vessel with no artifact.

mended to use shortest TE possible. To achieve that, we must also adjust other associated parameters (Table 1).

Common imaging practices: In MR imaging, choosing phase encoding (PE) direction is generally directed by the size of the region, to avoid any phase wrap. Unlike frequency encoding (FE), a higher number of data acquisitions in the PE direction costs extra time. Therefore, acquiring the PE in a shorter distance over the area of interest is common practice to keep the scan time lower. However, this strategy is not always ideal. For example, flow artifacts originating from eye movement could demand a change of PE direction to avoid propagation of the artifacts into the brain, resulting in a longer scan time. Pulsation artifacts arising from arteries is another example and could result in over- or underestimating the lumen in a segment of the vessels.

In this paper, we address turbulent flow and arterial pulsation-related artifacts in pediatric imaging and propose adaptations to improve MRA imaging quality in children.

Parameters	Standard sequence	Proposed pediatric sequence
TR	21 ms	25 ms
TE	3.42 ms	2.51 ms
Flip angle (FA)	18°	25°
Bandwidth (BW)	180 Hz/Px	448 Hz/Px

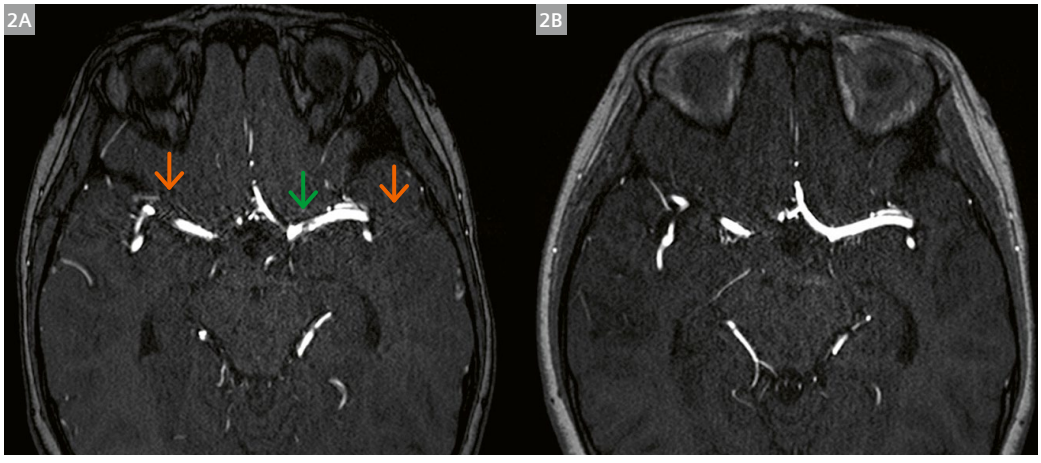
Table 1: Imaging parameters

Background

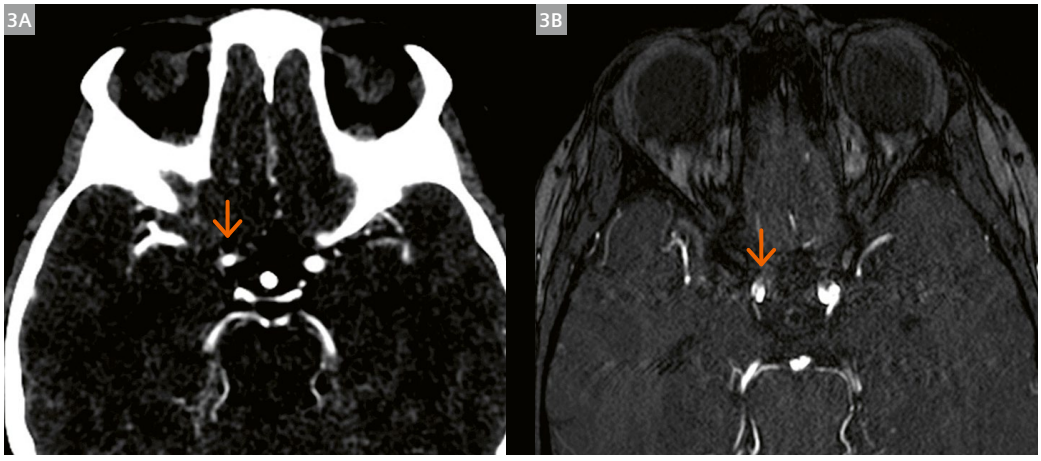
Acquiring TOF-MRA in the axial plane is common practice with right-to-left PE [9], avoiding artifacts from eye motion. However, pulsation artifacts arising from the middle cerebral artery (MCA) remain a challenge. Alongside any turbulent flow in the artery, running in-plane will create challenges in the form of signal loss that mimics vessel occlusion. In our case, we observed both phenomena in the form of occlusion in one segment of the MCA (Fig. 1A), and underestimation of the lumen at the bifurcation segments of the MCA (Fig. 2A). Occlusion-mimicking effects occurred consistently in one patient over several scans during the period, while a computed tomography angiogram (CTA) confirmed there was no occlusion, as shown in Figure 3. This finding triggered the discussion which led us to adapt the sequence to better serve pediatric patients by addressing the turbulent flow-related artifacts in sickle cell disease.

Sequence adaptation

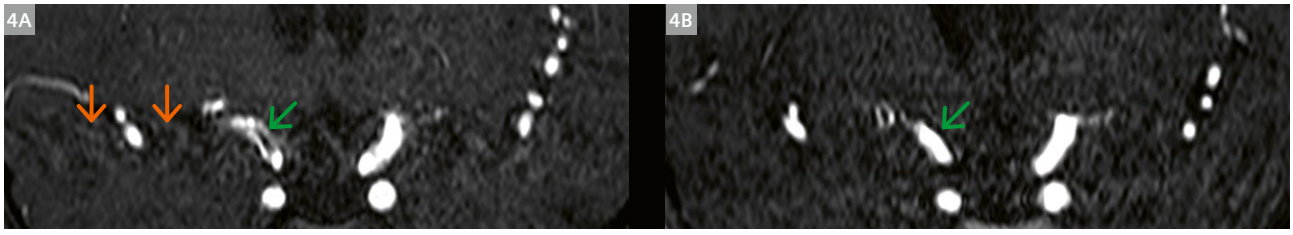
We made the following changes to the standard MRA sequence from Siemens Healthineers to minimize the phase dispersion by reducing TE and the associated parameters (Table 1): We increased the receiver bandwidth (BW) to 448 Hz/Px from 180 Hz/Px in the current sequence (thus increasing the sampling rate), which helped reduce the TE to 2.8 ms (original TE = 3.5 ms). We also changed the voxel size by reducing the resolution to 0.6 mm from 0.5 mm isotropic, which helped achieve a more suitable scan time and compensate for SNR. Increasing the TR to 25 ms helped with higher flow and therefore more signal. We increased the flip angle to 25°, which allows better background suppression.



2 **(2A)** Orange arrows show the pulsation artifact in the direction of phase encoding, and the green arrow shows the manifestation of possible turbulent flow. **(2B)** None of these artifacts are visible in the adapted sequence.



3 **(3A)** CTA shows normal flow as indicated by the arrow. **(3B)** MRA shows an occlusion-mimicking flow artifact due to a pulsation artifact.



4 Reformatted coronal images from **(4A)** the standard sequence and **(4B)** the adapted sequence. Orange arrows show the flow-related pulsation artifacts. The green arrow in (4A) shows the segment of the artery mimicking occlusion, while in image (4B) this artifact is not noticed.

Although these changes did not overcome the artifacts completely, they reduced them enough to provide much better images of the in-plane vessels. Figure 2 shows the images acquired using the standard sequence and the adapted sequence. The occlusion seen in the standard scans does not appear in the scans using the adapted sequence (Fig. 1B). Figure 4 shows coronal reformatted images from the standard and adapted sequences comparing the occlusion.

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