# An automated post-processing pipeline for the separation of intracranial and extracranial vessels in 7T TOF-MRA

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## Purpose

Image quality of TOF-MRA is excellent at ultra-high magnetic fields because of the higher SNR (Signal-to-Noise Ratio) and longer T1 relaxation time [1]. However, the network of intracranial vessels is usually contaminated by scalp vessels in the MIP (Maximum Intensity Projection) images. Intracranial and scalp vessels will overlay each other if manual scalp stripping is not taken (see Fig. 1a). Vice versa, a pure scalp vessels image is not possible when it is needed for extra-intracranial bypass surgery. For these two reasons, it is of significance to separate intracranial and scalp vessels in TOF-MRA.

Conventional scalp stripping is achieved by manually drawing an ROI to define intracranial and scalp areas in MIP images. One reason is that vessels such as the carotid arteries at the skull base are at the border of brain parenchyma, and have a great chance to be cropped if the threshold in the skull-stripping tool was set for separating eyes from brain (see Fig. 2). Another reason is that a conventional skull-stripping tool usually operates on T1w (T1-weighted) structural images, which are not always accessible when only TOF-MRA is acquired. In this work, an automated post-processing pipeline is designed to define intracranial and scalp areas based on TOF images, thus, two MIP images are created for intracranial and scalp vessels, respectively.

## Methods

Firstly, a template of TOF-MRA on 7T MRI was established. 40 whole-brain TOF images were acquired from volunteers (20 males and 20 females, aged 19-30 years). The experiments were performed on a 7T whole-body scanner (Siemens, Erlangen, Germany), with a homemade 8-channel phased-array Tx/Rx head coil for a good coverage of the skull base. Parameters of TOF sequence: FA=18degrees, TR=20ms, Resolution=0.42mm isotropic. All images were aligned to one reference selected from them using FSL FLIRT [3]. All aligned images were averaged to generate the template. An ROI containing intracranial signal was drawn on the template and defined as intracranial ROI, while the remaining voxels were defined as extracranial ROI. An automated intracranial and scalp vessels separation method is created based on two ROIs and the template. When any TOF images were acquired, the template was nonlinearly registrated to the TOF images by FSL FNIRT to get the transformation coefficients. Then two ROIs in the template were transformed to the TOF images with these coefficients, so that intracranial and extracranial areas were found for individual TOF images.

Secondly, 10 TOF images from another 10 volunteers were acquired with the same parameters to validate the automated separation method. Intracranial and extracranial TOF images were extracted and MIPs are calculated.

## Results

An axial slice of the template from 40 TOF images is shown in Fig. 3, in which the red line is the boundary between intracranial ROI and extracranial ROI. In Fig. 3, brain parenchyma can be differentiated from scalp and eyes. Carotid and vertebral arteries show high-intensity flow signal and are distinguishable from surroundings.

Fig. 4 demonstrates one of the individual TOF images used in the examination, overlapped by an intracranial ROI transformed from the template space. It is shown that the signal of the carotid arteries and other vessels are fully included in the ROI, while scalp and eyes are excluded. Near the carotid artery is the connection between eyes and brain tissues, where it is hard to set a reasonable boundary using traditional skull-strip tools (see Fig. 2). The MIP images of its intracranial and extracranial parts are respectively shown in Fig. 1(b)(c). Fig. 1(b) reveals more details of intracranial blood flow after removing extracranial contaminations, while scalp vessels (especially Superficial Temporal Artery) are clear in Fig. 1(c) after removing intracranial signal. Examinations on the other 9 subjects also get satisfactory results.

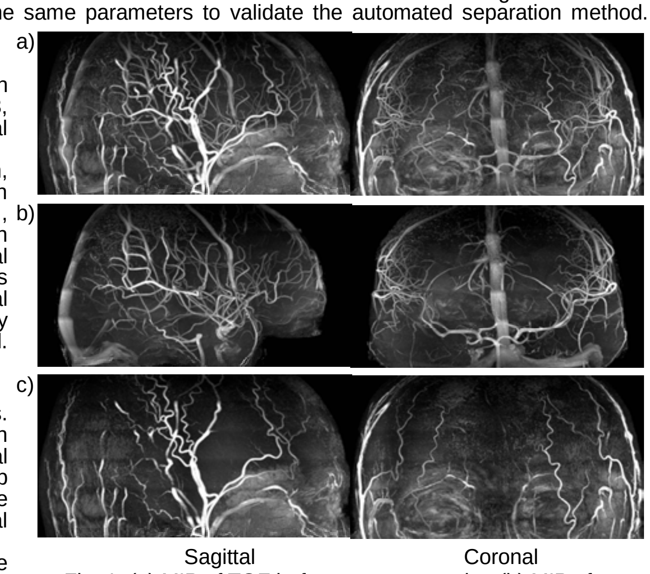


Fig. 1. (a) MIP of TOF before post-processing (b) MIP of intracranial TOF signal (c) MIP of extracranial TOF signal

## Discussion

The TOF template cannot depict all the vessels because of individual variances. However, the outline of brain and carotid arteries can be clearly shown, which guarantees intra- and extra-cranial ROIs to be reasonable. The intracranial sagittal MIP achieves outstanding improvement because of removing high-intensity scalp vessels. In intracranial coronal MIP, the exclusion of eye signal greatly enhances the contrast between the Circle of Willis and background. The isolation of extracranial vessels provides useful reference for extra-intracranial bypass surgery.

Potential improvements of the post-processing pipeline are: fine tuning the parameters of nonlinear registration to fix the warp error at top and bottom slices, enlarging the age range of the TOF template to improve its generalization, etc.

**Conclusion:** In this work, an automated post-processing pipeline of TOF-MRA is proposed to separate intracranial and extracranial vessels, without the aid of T1w structural images. The post-processing uses nonlinear registration to produce ROIs in individual space. The pipeline was verified to provide clear MIP images of intracranial and extracranial vessels, respectively, which is useful in extra-intracranial bypass surgery.

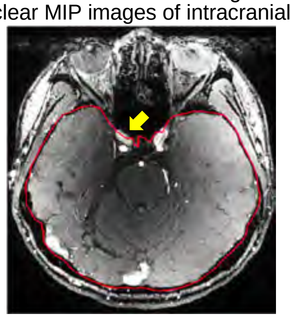

Fig. 2. Intracranial ROI border by FSL BET. The arrow points to the incomplete carotid artery.

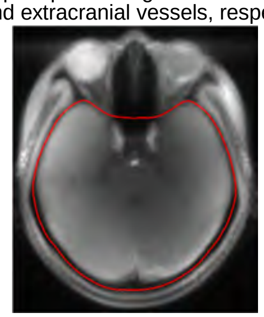

Fig. 3. An axial slice of the template. The red line is the border of the intracranial ROI.

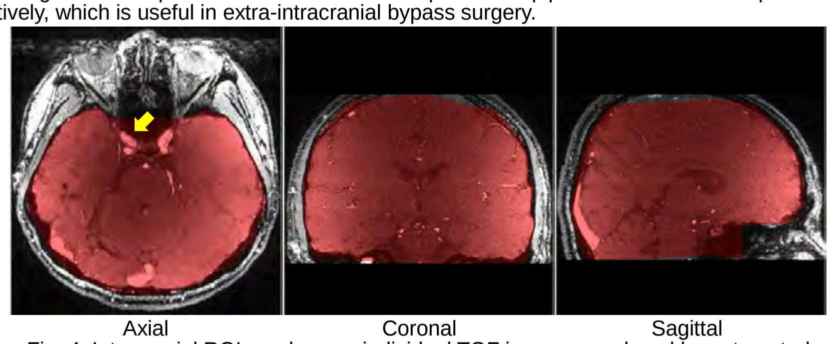


Fig. 4. Intracranial ROI overlays on individual TOF images, produced by automated post-processing pipeline. The carotid artery is well preserved, noted by the arrow.

**References:** [1] Stanisz GJ et al., Magn Reson Med. 2005 Sep;54(3):507-12. [2] Homann H, SAR Prediction and SAR Management for Parallel Transmit MRI, 2012. [3] M. Jenkinson, C.F. Beckmann, T.E. Behrens, M.W. Woolrich, S.M. Smith. FSL. NeuroImage, 62:782-90, 2012.

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