A Complete Vascular Description of a Human Brain using TOF-MRA for application in Thermal Modeling

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Introduction

In this paper, we present a new magnetic resonance angiography (MRA) post-processing methodology that increases the vascular detail seen in a human brain. While small vascular detail is often not critical in diagnostic radiology, it is essential in applications, such as high intensity focused ultrasound (HIFU), that require accurate *in vivo* heat transfer modeling. It has been shown that accurate thermal modeling requires the inclusion of all thermally significant blood vessels, (i.e. those with a diameter of greater than 0.1 mm) [1, 2]. While the current MR technology available to us does not allow for such fine vascular resolution, the post-processing methodology presented here will help increase the vascular detail obtained, providing a more complete description of the vessel network.

Methods

The methodology of this process is described in the following steps:

1**) Image Acquistion:** High resolution images showing small vessel detail over the entire brain were obtained using a multiple slab 3D TOF-MRA (white blood) sequence without contrast enhancement and a rapid whole brain single slab 3D spoil gradient echo sequence with contrast enhancement on a Siemens 3T Magnetom Trio scanner (Siemens Medical Solutions, Erlangen, Germany) with Sonata gradients.

2) Intensity correction: Due to transmit and receiver coil sensitivity variations over the large field of view, the intensity of the reconstructed source image is modulated by a spatially variable function. Hence, intensity inhomogeneity correction is necessary before any quantitative analysis can be done. In this study, we have applied a correction technique where regions of a single tissue type (brain matter) is identified over the entire brain by simple thresholding and then corrected using a similar technique as found in [3].

3) Vessel segmentation: Once the intensity is corrected, a segmentation algorithm using the maximum intensity projection (MIP) Z-buffer, as seen in [4], was used to segment and display the blood vessels.

4) Dura mater segmentation: As is common in contrast enhanced imaging, the dura mater and midline structures were enhanced as well as the blood vessels, obstructing the vascular detail seen in the segmentation process. An algorithm has been developed that isolates and removes the identified dura mater, through identification of the outermost voxels in the segmented vascular image. While many of these points are dura mater, some points are vessels. Through performing a convexity test, the identified dura mater voxels are isolated from vessels and removed. The resulting segmented vasculature after intensity correction and dura mater removal are seen in Figure 1.

5) Vessel centerline and diameter extraction: The vessel network will be described by centerlines and diameters. The method described in [5] is applied to obtain the centerline coordinates. The diameters are calculated by identifying the tangent direction along several points of the vessel centerline, and finding the number of voxels in the plane perpendicular to those tangents.

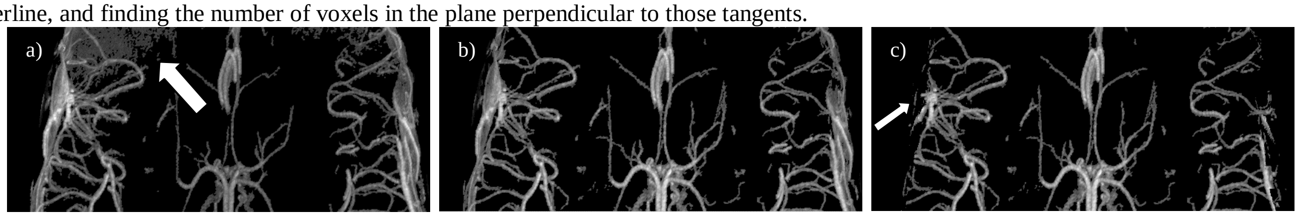

Figure 1: Segmented images a) before intensity correction and dura mater removal, b) after intensity correction, c) after dura mater removal. The wide arrow indicates a region affected by intensity inhomogeneity, the narrow arrow indicates region of removed dura mater.

Discussion

This presented new methodology provides a more complete description of the blood vessel network in a human brain. This improved method will allow us to build finite difference heat transfer models with a patient-specific vascular network. These networks will allow for more precise comparisons between various model descriptions, such as the Pennes' bio-heat transfer equation [6], the developmental thermal convective energy based equation [7], and a conjugate convective energy-heat conduction equation. Patient-specific vessel networks and verified models will allow for future optimization of patient treatment planning, resulting in more efficient HIFU, and other thermal therapies.

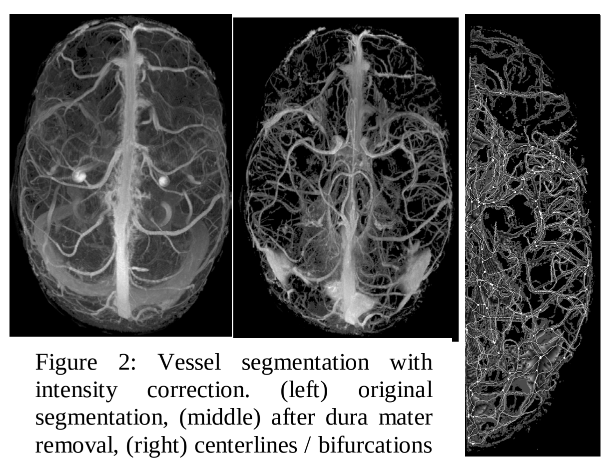

Figure 2: Vessel segmentation with intensity correction. (left) original segmentation, (middle) after dura mater removal, (right) centerlines / bifurcations on some vessel segments

Acknowledgments

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