High resolution 7T MRI scanning of human cerebral vascular casts

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Introduction: One of the challenges in blood flow modelling is determining boundary conditions such as peripheral resistance. More detailed knowledge regarding the morphology of the cerebral arterial tree could help in setting correct boundary conditions. This could ease modelling for diseases such as vascular dementia and help in planning of cerebral bypass surgery. A historical way of gaining insight in the cerebral arterial morphology is through the production of plastic casts of the cerebral arterial vasculature.[1] These casts could potentially give extensive knowledge of the dimensions of the cerebral vasculature. Measurement by hand, however, is difficult and extremely time consuming. Therefore, to speed up these measurements and make them better reproducible, a computerized analysis is preferred. Current magnetic resonance imaging (MRI) techniques utilizing higher magnetic field strengths make scanning at ultrahigh resolution possible. Scanning a cast using MRI could give great morphological description of the cerebral vasculature. Therefore, in this study a novel approach of scanning cerebral arterial casts with 7 tesla MRI was explored for gaining more detailed insight in the morphological features of the cerebral arterial network.

Figure 1: Cerebral cast. Different colors for six major cerebral arteries.

Methods: From the anatomy department one Araldite F cast of the cerebral arterial vasculature of a human cadaver brain was obtained (Figure 1). The cast was produced according to the method previously described by van der Zwan et al.[1] In summary, production of these casts is done by post-mortem injection of Araldite-F plastic in the six major cerebral arteries at 93mmHg. Brain tissue is removed after solidification of the plastic with potassium hydroxide and thorough rinsing in water, leaving only the casts. Before scanning, the cast was embedded in a tight fitting PVC container with a solution of a gadolinium-containing contrast agent (2.8*10^-3 mL contrast agent / mL water; Gadobutrol, Gadovist 1.0mmol/mL, Bayer Schering Pharma, Newbury, UK) and gelatin (14%) in water. The container was left overnight at 5 degrees Celsius to solidify the gelatin. Imaging was performed on a 7T whole body system (Philips Healthcare) with a custom-made 16-channel surface coil (MR Coils BV) and a volume transmit/receive coil for transmission (Nova Medical). For image acquisition a T1w sequence was used with the following scan parameters: Field-of-view (FOV) 150x150x30mm^3, acquired resolution 0.1x0.1x0.1mm^3, TR/TE 35/15ms, flip angle 60 degrees, bandwidth 106.1 Hz/pixel, TFE factor 1004 (= number of excitations in each shot), scan duration approximately 3h46min. To mitigate potential artifacts caused by scanner frequency drift, the scanner resonance frequency was measured and adjusted between each shot. After scanning the cast was cleaned from gelatin by rinsing with warm water. At 50 locations artery diameters where measured in the cast by hand using a digital caliper (Mitutoyo Corporation, Takatsu-ku, Japan. Accuracy ± 0.001 mm) under a microscope (Zeiss, Oberkochen, Germany) at 24x magnification. At the same locations, diameters were measured in the MRI data. For each location 150 measurements were performed using a full-width at half maximum (FWHM) method where the border of a vessel was defined as 50% of the maximum contrast between the vessel and its surroundings. For each measurement, 50 profiles perpendicular to the centerline of the vessels were obtained by rotating the profile around the centerline. Linear interpolation was used to get intensity values in-between voxels and linear trends in the background signal were removed. Interpolation in the Fourier domain was used to increase resolution of acquired profiles for improved peak detection. Next, using a FWHM algorithm, the borders of the vessel where determined. Finally, all calculated widths where combined resulting in an average width for every single vessel. All calculations were performed using Matlab® (R2014a, Mathworks Inc., Massachusetts, USA). The diameters measured directly by hand and calculated from the MR images were compared. A Shapiro-Wilk test was used to test for normality. Statistical differences where determined using a Related-Samples Wilcoxon Signed Rank Test where no normality could be proven. Bivariate linear regression analysis was performed between vessel cast diameter as measured by caliper (independent variable) and diameter from MRI data. All statistical analysis where performed using IBM® SPSS® Statistics (version: 20.0.0, IBM Corp., Armonk, USA)

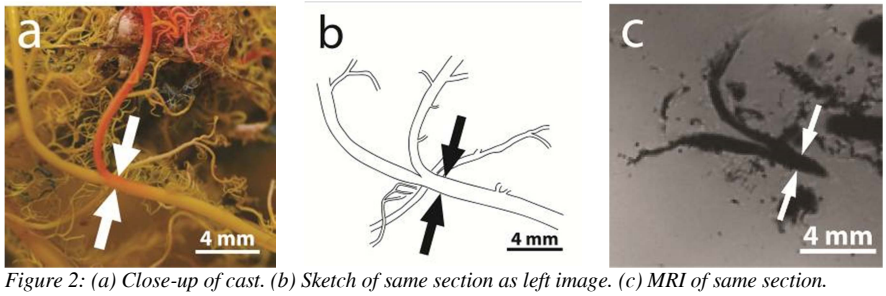

Figure 2: (a) Close-up of cast. (b) Sketch of same section as left image. (c) MRI of same section.

Results: Figure 2 shows an illustrative case with the same location of cast and MRI. Arrows mark the corresponding locations where measurements were performed. Figure 3 shows a scatter plot with a linear regression analysis of the diameter as measured on MRI versus the actual diameter measured by hand. The Wilcoxon singed-rank test showed that there was a statistical difference ($Z = -4.58$, $p < 0.001$) between the measured diameters on the cast (mean: 0.59, SD: 0.41, range 0.06-1.69 mm) compared to the measurements on the MRI (mean: 0.68, SD:0.42, range 0.14-1.64 mm), indicating a slight overestimation of the diameter by MRI. The diameter of the vessel on MRI closely followed the actual diameter of the cast as shown by Figure 3 and the high goodness of fit ($R^2 = 0.81$).

Discussion and conclusion: The current results show that ultrahigh-resolution MRI enables accurate measurement of the Araldite F casts. To our knowledge no previous studies have used the presented method of "negative" scanning, where first a polymer cast (that doesn't yield MR signal) is produced, followed by ultrahigh resolution MRI. A major advantage of this technique is that the use of gadolinium-containing contrast agent solution around the casts yields a very high contrast-to-noise ratio compared to normal in-vivo measurements. Besides high contrast-to-noise ratios, high resolution and long scanning times can be utilized as no life subject is present in the MRI scanner. Furthermore, the sizes of the vessels in the cast closely corresponds the average in-vivo situation, since Araldite F is known to have minimal shrinkage in size (3.90±0.05%) and since a static pressure corresponding to the mean arterial pressure is used during production.[1] In the future, we want to apply this technique for accurate modeling of the cerebral arterial vasculature. This could potentially help in better understanding of different cerebrovascular diseases, and in simulating the effect of surgical procedures like bypasses.

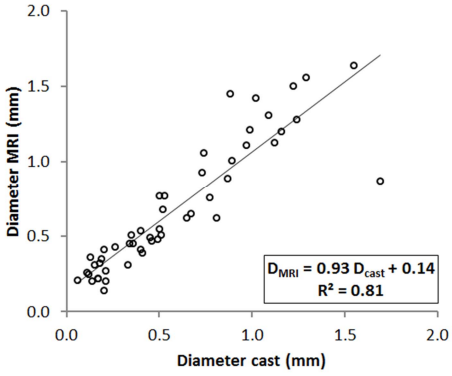

Figure 3: Scatterplot of diameter as measured on the actual cast versus the diameter as measured on MRI.

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References: 1. Van der Zwan A, Hillen B. Anat. Rec. 1990;228(2):230-236