Quantitative Flow Measurement of Digital Arteries at 3 Tesla

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Target audience: This abstract is written for radiologists and rheumatologists who are interested in Raynaud's disease, as well as MR physicists who are interested in flow quantification in small vessels.

Purpose: Raynaud's disease is a condition characterized by blood vessel narrowing, leading to constricted or obstructed blood flow, commonly seen in the fingers and toes. Therapeutic interventions exist, but a non-invasive, reliable, objective, and quantitative means to assess the therapeutic efficacy is still lacking. Quantitative blood flow measurement using phase-contrast (PC) MRI is an attractive approach for potentially assessing treatment efficacy for Raynaud's disease. However, accurate and reliable flow quantification in digital arteries has been challenging despite previous attempts[1,2]. The availability of 3T scanners and improved commercial RF coil performance have made it possible to achieve sub-millimeter spatial resolution with an adequate signal-to-noise ratio (SNR) for digital angiography[3, 4]. Due to the small diameters of digital arteries, it has been difficult to precisely prescribe a plane normal to the artery of interest in PC studies, resulting in flow quantification errors. Additionally, the relatively low VENC value used in PC acquisitions exacerbates eddy current problems, which contributes further to the quantification errors. In this study, we develop and evaluate a PC-based flow quantification technique for digital arteries. Our aim is to minimize the measurement errors so that the quantitative PC technique can be ultimately used to assess Raynaud's disease regression throughout therapy.

Methods: Ten healthy human subjects (age = 25-50y; 5 females) were enrolled in the study. All subjects underwent MRI scans at 3T (GE MR 750, Waukesha, Wisconsin) by placing the right hand in an 8-channel volume RF coil. To obtain accurate flow measurements, the imaging plane in a 2D PC acquisition needed to be normal to the flow direction. This was accomplished by first acquiring a volumetric image to highlight all digital arteries using an optimized 3D TOF pulse sequence with a distal saturation band and the following parameters: slice thickness=0.6mm, matrix=1024x512, FOV=22x11cm^2, TR/TE=26/3.2ms, and flip angle=20^o. From the 3D angiogram (Fig. 1a), a proper palmer digital artery of interest was identified and a plane (yellow plane in Fig. 1b) perpendicular to it was determined automatically using a commercial software package, NOVA (Non-invasive Optimal Vessel Analysis; VasSol Inc, River Forest, IL). The geometric parameters defining the plane was automatically sent to the scanner and used for slice prescription in the subsequent peripheral-gated 2D PC acquisition with the following parameters: TR/TE=10.2/5.3ms, flip angle=25°, FOV=8×8cm^2, slice thickness=4mm, VPS=16, VENC=15cm/s, matrix size=256×192, scan time=40sec. To address the adverse effect caused by eddy currents arising from the flow-encoding gradient, images from a stationary phantom with the same protocol were acquired to estimate and remove the phase errors arising from eddy currents. After this correction, flow quantification was performed using NOVA.

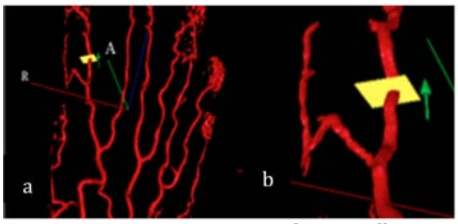

Figure 1. (a) A 3D angiogram showing all proper palmer digital arteries from a representative female volunteer. (b) A zoomed view of PPDA2 showing the automatically determined perpendicular plane for the subsequent 2D PC acquisition.

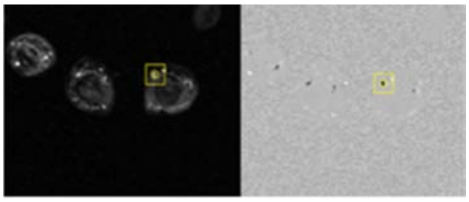

Figure 2. 2D PC images on the plane shown in Fig. 1b. (a) magnitude image; (b) phase image.

Results: With the optimized 3D TOF sequence without contrast injection, all eight proper palmar digital arteries (No. 1-8) were clearly visible at a spatial resolution of 0.2x0.2x0.6mm^3 (Fig. 1a). Figure 1b illustrates a plane normal to the second proper palmar digital artery in the right index finger (PPDA2). The 2D PC images from this artery are displayed in Fig. 2 where an adequate SNR (~270) in the magnitude image and a uniform background (i.e., minimal eddy current errors) in the phase image were observed. Figure 3 shows six velocity contours for the selected artery, each corresponding to a phase throughout a total of 12 cardiac phases within an R-R interval. The flow rate was measured within an operator-defined area (white circles in Fig. 3) and is displayed in Fig. 4. The average and peak flow for the selected artery was 13.4ml/min and 15.8ml/min, respectively. Within the same subject, the measured flow rate was consistent within 12%. For different subjects, a large variation was observed with flow rate varying between different genders and age. For example, the average flow rate for females was 4.5ml/min, while that for males was 6.3ml/min.

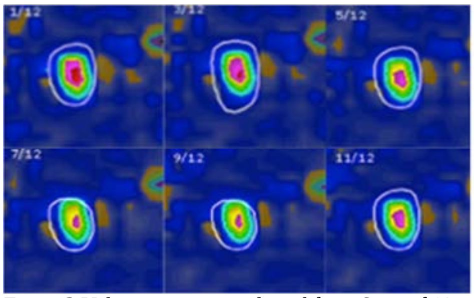

Figure 3.Velocity contours selected from 6 out of 12 cardiac phases. The white circle represents the area through which flow rate was evaluated.

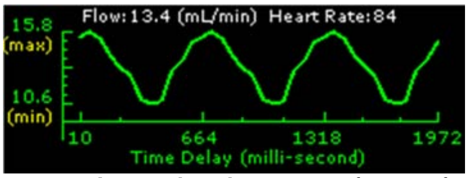

Figure 4. Flow rate through PPDA2 as a function of time throughout three cardiac cycles.

Discussion and conclusion: Through pulse sequence optimization, high resolution non-contrast-enhanced angiography was successfully obtained from proper palmer digital arteries of human subjects. By ensuring that the 2D PC plane is always normal to the arteries and by reducing residual eddy currents errors associated with relatively small VENC values, reliable flow quantification was achieved from the digital arteries. Although no patient with Raynaud's disease has been enrolled, this study has demonstrated the feasibility of using an MR-based technique for assessing the efficacy in Raynaud's disease treatments, and paves the way for an upcoming study that involves patients with Raynaud's disease.

Reference: 1. Klarhofer M et al., MRM 2001. 2. Allanore Y et al., Arthritis Rheum 2007. 3. Miyazaki M et al. Radiology 2008. 4. Li D et al. ISMRM 2010.