Phantom investigation on the accuracy of different pulse sequences for the determination of arterial distensibility

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Introduction
Arterial stiffness has long been recognized to play a central role in the development of cardiovascular (CV) disease. A significant relationship has been demonstrated between reduced aortic compliance and fatal and non-fatal CV events independently of classical CV risk factors [1]. Accurate measurement of aortic distensibility in vivo would constitute a powerful tool for monitoring patients at high CV risk and testing plaque-reducing pharmaceuticals and therapies.

As the cross-sectional distensibility coefficient is defined as the relative change in luminal area divided by the corresponding pressure change over the cardiac cycle \( (D = \frac{\Delta A}{\Delta P}) \), the relative area variation curve over time needs to be determined. Despite systematic and random errors have been shown to affect 2D phase-contrast (PC) images due to intravoxel phase dispersion, partial volume effects and misalignment of flow-encoding gradients and flow direction [2], a number of investigations [3-5] have used this technique to determine arterial distensibility. New approaches to the post-processing of PC images have been proposed to overcome these limitations [6-7] while other MR techniques have been explored to extract the area variation curve over the cardiac cycle [8].

The aim of this work was to assess the accuracy of different MR pulse sequences for the determination of the luminal area variation curve over time by means of in vitro experiments conducted on a human-tissue-mimicking phantom and to make direct comparisons with high resolution digital photography (HRDP) as the defined gold-standard.

Methods
A polyvinyl alcohol cryogel (PVA-C) [9] tube (inner diameter = 7.94mm, outer diameter = 11.06mm, \( T_1 = 1600ms, T_2 = 65ms \)), integrated into an existing physiological flow simulator [10] was used to model both the characteristic relaxation times and elastic modulus of human arteries. De-ionized water was used as the working fluid and a physiologically realistic aortic waveform was simulated. Images were acquired on a 1.5T whole-body system (GEHT, Milwaukee) using a 3-inch surface coil. Axial images were acquired over 50 temporal phases using a custom-developed cine black-blood (CBB) gradient echo sequence with flow suppression achieved using spatial saturation bands placed inferior and superior to the imaged slice and a standard ECG-gated cardiac echo bright-blood (CBrB) sequence. Imaging parameters for both acquisitions were: voxel size = 0.31×0.31×10mm; TE = 4.2ms; TR = 9.4ms; flip angle = 2°. Eighty millimeter saturation bands were used for the black-blood acquisition. ECG-gated 2D cine PC magnitude (PC-Mag) and phase (PC-Ph) images were also acquired with the same spatial resolution and a similar temporal resolution. The other imaging parameters for PC were: TE = 4.1ms; TR = 8.5ms; flip angle = 30°; velocity encoding = 100cm/s.

All the images were segmented using a fully automatic region-based active contour algorithm [11] implemented in Matlab that required minimal user interaction. The flow phantom setup was reproduced outside the scanner room and the pressure wave recorded immediately upstream of the compliant segment by means of a conventional pressure sensor (Sensym, Germany) was compared to the corresponding pressure measured in the scanner room to ensure the same deformation on the PVA-C tube. HRDP (Pixelink, Ottawa, Canada) videoing at 25 frames per second was used to quantify the deformation of the external diameter of the tube. As PVA-C is incompressible, the internal diameter variation over time was obtained and compared with the corresponding projected diameter extracted from MR images. The cross-sectional distensibility coefficient was computed assuming a pulse pressure \( \Delta P = 100\text{mmHg} \) on the basis of the pressure waveform recorded upstream of the flexible phantom.

Results
Cine black-blood gave the best agreement with HRDP (rms deviation = 0.011mm) while both PC magnitude and phase images were found to underestimate the projected internal diameter over the entire cardiac cycle (rms deviation = 0.087mm and 0.113mm respectively). The rms deviation of cine bright-blood from HRDP was 0.024mm. The discrepancy between the cine-black-blood and PC curves was more significant during the descending part of the cycle suggesting a possible dependence of intravoxel dephasing and partial volume effects on the local boundary layer shape (figure 1).

The mean diastolic area extracted using the cine bright-blood technique was very close to that obtained from cine black-blood while the corresponding area variation resulted overestimated by 12% with respect to cine black-blood. PC and cine black-blood showed good agreement on the area variation over the simulated cardiac cycle but both PC magnitude and phase images underestimated by 17% and 22% respectively the mean diastolic area derived from cine black-blood. As a consequence, the distensibility coefficient was overestimated by up to 26% when phase images were used to derive the area information.

Conclusions
This work demonstrates that the cross sectional distensibility coefficient can vary up to 26% depending on the pulse sequence used to derive the luminal area information over the cardiac cycle. Cine black blood has been proved to provide the best agreement with HRDP while PC was found to systematically underestimate the area variation curve. Further development includes comparison of the different pulse sequences for in vivo measurements of aortic distensibility.

References