Measurement of Common Carotid Artery Lumen Dynamics during Cardiac Cycle Using TrueFISP Cine MR Imaging

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Introduction

MRI has been extensively used in vascular imaging to provide detailed anatomical information of blood vessels, yielding lumen size and wall thickness measurements. Diseases like carotid atherosclerosis have been characterized in T1, T2 and intermediate-weighted MR images [1]. However, these studies often specify the morphology and composition of vessel walls without examining the dynamic pulsatile properties of these vessels. Arterial dynamics can better describe physiological behaviour correlated with other vascular parameters, therefore has potential clinical importance in differentiating abnormalities. Such dynamics could not be revealed adequately in images typically obtained at mid-to-late diastole and just before systole in most of the current studies [2,3]. In this study, the vascular dynamics of the right and left common carotid arteries throughout the whole cardiac cycle was investigated using TrueFISP cine cardiac imaging.

Methods

Study population: Four normal male volunteers (21-24 years old, mean age = 22, mean body weight = 150 lbs) were recruited in this study.

Imaging protocol: All MRI experiments were performed on a Philips 3T Achieva scanner (Philips Medical System, Best, Netherlands) with maximum gradient amplitude of 80 mT/m and a switching rate of 200 T/m/s. A 16 channel SENSE neuro-vascular coil was used to image the carotid arteries. A 3D time-of-flight (TOF) MRA with maximum intensity projection (MIP) images was used to determine the location of carotid bifurcation. True Fast Imaging with Steady-State Precession (TrueFISP) cine sequence with cardiac gating was then used to acquire images of the arteries. (TR = 5.3 ms, TE = 2.7 ms, FA = 45º, FOV = 170×170 mm, slice thickness = 3 mm, no. of slices = 4, slice gap = 0 mm, acquisition matrix = 256×256, voxel size = 0.66×0.66×3 mm^3, no. of frames per cycle = 20, NEX = 2, TFE factor = 13, SENSE factor = 1.2, total scan time = ~2 min) Slices were chosen 1cm below the carotid bifurcation with the imaging plane perpendicular to the targeted vessel.

Data analysis: Images were analyzed using Segment v1.662 software. The lumen boundary was automatically segmented with refinements on ROI delineation made under the same visual contrast. The lumen area at each cardiac frame was computed. Distension was calculated as $(A_{max} - A_{min}) / A_{min} * 100\%$, where A_{min} is the minimum lumen area, and A_{max} is the maximum lumen area.

Results

Figure 1 shows one set of images of the left common carotid artery at the first slice 1cm below the bifurcation. It consists of 20 cardiac frames with ROI delineation, depicting the change of lumen size throughout the cycle. Distension values of the lumen are tabulated in Table 1, which agree well with the literature values on subjects of similar age [4]. Note that slightly higher distension was detected in the right carotid artery than the left one, which can be ascribed to their asymmetric branching from the aorta [5]. Figure 2(a) shows the dynamic area waveform of the artery from the same subject through the whole cardiac cycle with the corresponding triggering ECG. Waveform patterns in all subjects show nearly identical features with a diacrotic notch shortly occurring after T-wave position, indicating the closure of the aortic valve. This pattern correlates with the pressure waveform of the carotid artery in terms of its shape [6]. Figure 2(b) shows the signal intensities of the ROIs drawn on the arteries as a function of time. Signal intensities are nearly constant except for 2-3 time points during early systole, probably due to blood flow with high velocity leading to dark flow artifacts [7]. Note that such constant intensity prevents the lumen segmentation from partial volume interference.

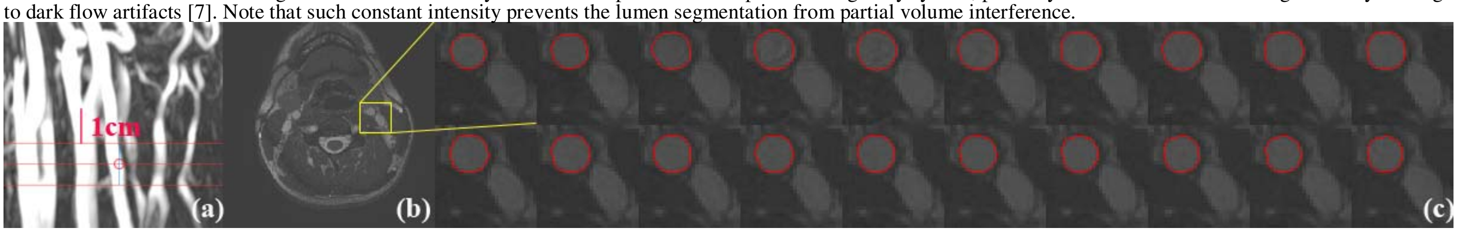

Figure 1 (a) A maximum intensity projection (MIP) image of the MRA data, indicating slice selection 1cm below the bifurcation. (b) A TrueFISP Cine MR image of the left common carotid artery from a young male subject with (c) 20 cardiac frames throughout the whole cardiac cycle. (from left to right, up to down)

Table 1 Lumen areas and distension values (percentage change of lumen area) of the common carotid arteries from the four young male subjects in mean ± SD.

Side	Maximum Area (mm^2)	Diastolic Area (mm^2)	Area Change (mm^2)	Distension (%)
Left	41.97 ± 3.26	32.93 ± 2.81	9.04 ± 0.59	27.62 ± 1.55
Right	43.56 ± 2.84	33.74 ± 1.77	9.82 ± 1.20	29.24 ± 2.75

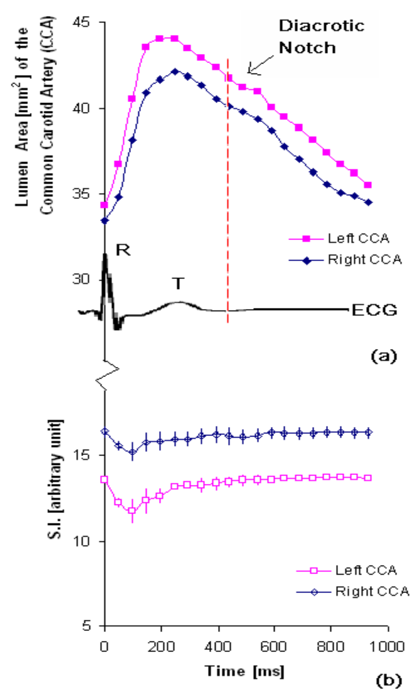

Figure 2 (a) Area waveforms with ECG illustrated and (b) average signal intensities (S.I.) vs. time of the common carotid arteries (CCA) of the same subject as Figure 1.

Discussion

By employing the TrueFISP cine cardiac imaging technique, dynamic pulsations of the common carotid arteries throughout the whole cardiac cycle can be imaged. Distension values can be obtained and the arterial motion be reliably traced from the area waveform. Consistent results and patterns were seen among the four normal subjects. Pattern deviation from the normal one can be related to diseases or abnormalities. Therefore, cine imaging of the carotid arteries has potential application to evaluate different diseases and disorders, for example, plaque deposition. If coupled with pressure waveform measurements, more quantitative information can be derived about the vascular response to hemodynamics. This provides valuable information about the physiological condition of the vasculature, assuming linear elasticity of vessels.

The TrueFISP cine imaging technique provides good contrast images of the artery with lumen boundary easily distinguished and this makes it a better choice than Fast Field Echo (FFE) cine imaging. Blood signal intensity in FFE images is highly velocity-dependent due to in-flow effect, thus intensity changes with different blood flow which may lead to error in ROI delineation. When compared with ultrasound (US), cine imaging visualizes true cross sections of carotid arteries with the surrounding anatomical structures. Due to the nature of US, high discrepancies on arterial areas may occur as the artery is assumed circular which may not be true at the focal lesions of atherosclerosis [8]. Therefore, TrueFISP cine MR imaging which provides the whole cross-sectional area for measurements allows higher accuracy in waveform tracing and calculation of distensibility and compliance. More quantitative assessment of a larger sample size consisting of different age groups and patients is under progress.

References

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