Assessment of asymmetric aortic distention using balanced transient field echo MR imaging

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Introduction Due to pulsatile cardiac output and aortic compliance, the aorta exhibits diameter and shape changes troughout the cardiac cycle. [1-4] Insight in these changes is important for endovascular treatment of aortic aneurysms with an endograft: it affects sizing decisions and may have consequences for endograft design. Additionally, it might improve knowledge of vascular pathology. Multi-phase ECG-triggered imaging offers insight in the dynamics of aortic shape changes and post-processing algorithms can be used to analyze the aortic morphologic changes. Previous studies have suggested that the aortic expansion is asymmetrical. [1 2 4] Knowledge of the asymmetry of the aortic expansion is important, because asymmetry will further complicate the accomplishment of a proper proximal fixation and seal of the endograft. Intravascular ultrasound (IVUS) has been previously used to study asymmetry, but, unfortunately, IVUS is highly operator dependent, which directly influences the reproducibility and accuracy of the measurements.[4] MRI is not (or just slightly) operator dependent; it is non-invasive, does not require ionizing radiation, allows image acquisition in arbitrary planes and offers excellent soft-tissue contrast, which allows studying the aortic motion and distension in relation to the surrounding anatomy. The balanced transient field echo technique (bTFE) is very well suited for retrospectively ECG-triggered imaging of dynamic changes of the aorta, since it is rather insensitive to flow artifacts and can image blood at a high signal-to-noise-ratio (SNR). Optimal images without susceptibility artifacts of the aortic lumen can be acquired using a short repetition time (TR) and a relatively high flip angle. Choosing the echo time (TE) half TR maximizes the intrinsic flow compensation of the sequence. We have implemented a scan sequence and corresponding post-processing technique that allow us to study the distension of the aorta and to quantify the asymmetry in the expansion. The purpose of the current study was to demonstrate a method to detect and quantify asymmetric aortic distension in healthy volunteers, and to investigate the accuracy by using a digital model of a pulsatile aorta at various levels of distension and asymmetric expansion.

Materials & Methods *In vivo experiments:* Fifteen healthy volunteers (7 male, median age 24 years, range 18-28) were scanned, after informed consent had been obtained. The study design and protocol were approved by the institutional medical ethics committee. A 1.5-T clinical MR scanner (Achieva, Philips Healthcare, Best, The Netherlands) was used. After initial multistack abdominal survey scans, a coronal balanced fast field echo survey scan was performed to localize the aorta and its side branches. Four cm above the aortic bifurcation, a transverse high-resolution balanced transient field echo MRI scan with retrospective ECG triggering (16 reconstructed phases over the cardiac cycle) was acquired perpendicular to the aorta, in both the coronal and sagittal plane. Relevant scan parameters were: echo time (TE) 3.1 ms, repetition time (TR) 6.1 ms and flip angle 50°, acquired and reconstructed voxel size 0.66x0.66x10mm^3, FOV 270x340mm^2. Scan duration for obtaining a data set consisting of 16 heart phases was approximately 6 minutes. For analysis of the distension, the images were supersampled by a factor 8 in the left-right *(x)* and anteroposterior *(y)* direction, using linear interpolation (Fig. 1). With dedicated in-house-developed software (Dynamix, Image Sciences Institute, Utrecht, The Netherlands), the aortic lumen in the images was semi-automatically segmented for each cardiac phase image by setting a voxel intensity threshold**.** Then, for each cardiac phase, 360 radial lines were measured from the center of mass (COM) of the lumen to the edge of the segmentation with a 1 degree increment between two lines. Changes in the radius between the diastolic (smallest diameter) and systolic (largest diameter) cardiac phase were determined along each radial line and plotted in a polar plot (see figure 2). Using Matlab computing software (Version 6.5, The Mathworks, Inc.) an ellipse was fitted over the plot with Direct Least Squares Fitting (Figure 2).[5] The radii (*Ra* and *Rb*) and angulation (θ) of the ellipse correspond to the magnitude of the radius change over the major (*Ra)* and minor axis (*Rb*), and the orientaton of the major axis (θ). The anteroposterior axis was defined as 0 degree (-90°=right, +90°=left). The distension asymmetry factor was expressed as the ratio *Ra/Rb* of the fitted ellipse.

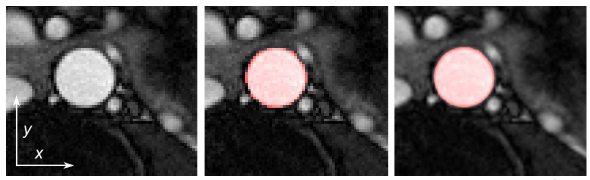

Figure 1 Axial single cardiac phase MR image. **S**upersampling (right) results in smoother segmentation (red).

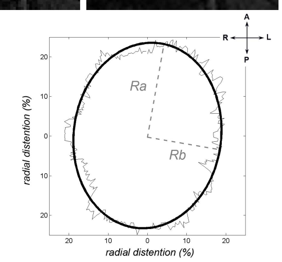

Figure 2 Polar plot of changes in radius in a volunteer. After fiting an ellipse over the plot, the radius change over the major (Ra) and minor axis (Rb) is known.

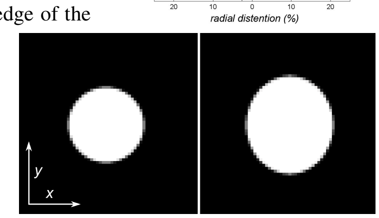

Figure 3 Digital simulation of pulsatile aorta in minimum (left) and maximum phase (right), with $\Delta R_y / R_y$ = 30% and $\Delta R_y/\Delta R_x$ = 2.00.

Computer simulations: To study the accuracy of our method a digital model of a pulsatile aorta in 16 cardiac phases was constructed. In the first cardiac phase the aorta was circularly shaped. The aortic radius (R) was set to the realistic value of 13 pixels. Multiple pulsatile aorta datasets were generated, with the distension (ΔR/R, the relative change in radius) varying over a realistic range: 5%, 10%, 20%, 30%. In subsequent cardiac phases the initially circular aorta was deformed into a pulsating ellipse with the defined relative radius change along the y-axis, and a distension in the x-direction according to different levels of asymmetry expressed in the asymmetry ratio ($\Delta R_y/\Delta R_x$)**.** Different predefined realistic asymmetry ratios were studied: 2.00, 1.50, 1.25, and 1.00. The images of the aortic computer model were post-processed using the ellipse fit method described above for the *in vivo* experiments. The measured distensions and asymmetry factors were compared to the predefined values.

Results In the volunteers, the mean distension was 1.6±0.2 mm (range 1.1-1.9, 14-24%) over the major axis, and 1.4±0.2mm (0.9-1.6, 12-20%) over the minor axis. The median asymmetry factor was 1.17 (1.09-1.34), and the mean orientation of the major axis was 0.8°±22.5 (-54.6-30.4). The table below shows the asymmetry ratio ($\Delta R_y/\Delta R_x$) and distension (ΔR_y) measured in the simulated data using the post-processing technique, at the different predefined asymmetry ratios and distension values.

	Set Distension ($\Delta R_y/R_y$) 5%		Set Distension ($\Delta R_y/R_y$) 10%		Set Distension ($\Delta R_y/R_y$) 20%		Set Distension ($\Delta R_y/R_y$) 30%	
Predefined Asymmetry factor	*Measured*		*Measured*		*Measured*		*Measured*	
$\Delta Ry/\Delta Rx$	$\Delta R_y/\Delta R_x$	ΔRy, %	$\Delta y/\Delta x$	Δy, %	$\Delta y/\Delta x$	Δy, %	$\Delta y/\Delta x$	Δy, %
2.00	1.50	4.6	1.84	10.2	1.83	19.6	1.93	30.2
1.50	1.24	4.8	1.49	9.9	1.48	19.2	1.48	29.0
1.25	1.18	4.9	1.27	10.2	1.25	19.0	1.25	28.8
1.00	1.00	4.9	1.00	10.0	1.00	19.0	1.00	28.8

Discussion & Conclusion Our method, a bTFE protocol in combination with post-processing, offers a valuable tool to study asymmetry in the aortic distension throughout the cardiac cycle. The degree of distension is accurately assed at all levels of distension. Absence of asymmetry in the expansion is accurately confirmed at all levels of distension. Measurement of the asymmetric aspect is most reliable when the aortic distension is over 5%, and in general the accuracy increases with increasing distension. In vivo experiments with the proposed technique demonstrated asymmetrical aortic expansion in the abdominal aorta of healthy volunteers.

References [1] Muhs et al. *Eur J Vasc Endovasc Surg* 2006;32:532-6. [2] van Herwaarden et al. *J Vasc Surg* 2006;44:22-8 [3] Chia et al. *J Magn Reson Imaging* 1999;10:833-40 [4] Arko et al. *J Vasc Surg* 2007;46:891-7 [5] Fitzgibbon et al. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 1999;2:476-480.