Circumferential cyclic strain in the abdominal aorta: comparison of a phase-contrast magnetic resonance imaging vs. a FIESTA method

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Introduction. Hemodynamic conditions such as low flow and wall shear stress are known to initiate and exacerbate vascular diseases; however, little is known about the circumferential cyclic strain experienced by the normal aorta. Circumferential strain is experienced by the vessel wall in response to stress from pulsatile blood flow and its attendant pressure wave and depends on wall constituents and local disease. Previous studies have reported wall displacement using intravascular ultrasound (measurements in two planes), 3-component phase-contrast magnetic resonance imaging (PC-MRI), and in cadaveric tissue. Here we 1) report *in vivo* circumferential cyclic strain measurements in the supraceliac (SC) and infrarenal (IR) aorta of healthy subjects; and 2) compare results from a PC-MRI sequence vs. a bright-blood FIESTA (fast imaging employing steady-state acquisition) sequence, using thresholding and manual segmentation techniques.

Methods. Five healthy subjects were recruited from the community to undergo imaging. Approval from the Institutional Review Board was obtained, and all subjects gave informed consent. Inclusion criteria were age >55 years; exclusion criteria included MRI/contrast ineligibility and known vascular disease. Scans took place in a 1.5T GE magnet with an 8-channel cardiac coil. We performed 3D gadolinium-enhanced magnetic resonance angiography (MRA) of the aorta. A cardiac-gated cine PC-MRI sequence (1-component) was prescribed orthogonal to the aorta based on the MRA and a localizer scan. PC-MRI imaging parameters included flip angle 20°, FOV=24.0, NEX=2, venc=150 ms, slice thickness=5 mm, 224x192 acquisition matrix. A breath-held cardiac-gated 2D cine FIESTA sequence was performed using the same graphic prescriptions as the PC-MRI, and imaging parameters included 224x192 acquisition matrix, 8.0 mm slice thickness, TR=4.0 ms, TE=2.0 ms, 50° flip angle, and 6 views-per-segment. For each subject, twenty-four (PC-MRI) or twenty (FIESTA) timepoints were reconstructed over a cardiac cycle. Segmentation was performed with a thresholding technique supplemented with manual segmentation as needed. Through-plane aortic flow with baseline correction was calculated and plotted (Fig. 1). Equivalent diameters were calculated from the segmented vessel circumferences and were then used to find the circumferential Green-Lagrange strain (Fig. 1). To measure approximation to an idealized diastolic decay curve, an exponential curve was fitted to each strain plot from the perceived max to min, and the coefficient of determination R^2 was recorded (Fig. 2). Wall deformation was calculated as the difference between maximum and minimum diameters (Fig. 2).

Results and Discussion. For PC-MRI sequences, strain curves tended to be noisier (R^2=0.77 (SC, p=0.28); 0.64 (IR, p=0.06)). FIESTA strain curves were cleaner (R^2=0.94 (SC); 0.93 (IR)) and agreed more closely in shape with strain curves derived from invasive aortic measurements [1]. Maximum and mean cyclic strains were similar across PC-MRI and across FIESTA curves, although average PC-MRI strains were consistently higher than values from FIESTA curves (0.14±0.06 vs. 0.06±0.02 (SC, p=0.06), 0.18±0.09 vs. 0.06±0.02 (IR, p=0.02)). Aortic diameter deformation from FIESTA curves agreed with previously reported values [2], but deformations from PC-MRI segmentations were significantly higher than FIESTA values (SC: 3.0±0.6 mm (PC-MRI) vs. 1.3±0.4 mm (FIESTA), p=0.001; IR: 2.6±0.6 mm (PC-MRI) vs. 0.9±0.2 mm (FIESTA), p=0.001). For both PC-MRI and FIESTA curves, max and mean strains were similar at the SC and IR levels.

Circumferential cyclic strain depends on precise measurements of the vessel wall at all timepoints in the cardiac cycle. The Green-Lagrange strain uses as its reference point the smallest circumference, which is at the diastolic flow nadir, when the vessel edge is least reliably imaged by PC-MRI. In addition, values are squared, magnifying small diameter differences. Strain curves from the FIESTA scan were cleaner and agreed with previous work in strain levels and deformations. Therefore the FIESTA sequence, which gives excellent tissue contrast regardless of flow, should be used for measuring wall strain in preference to PC-MRI, which yields blurry vessel edges during diastole. Future work includes strain measurement in aortic locations of pathological or geometric interest, including across aneurysms and at bifurcations, as well as in populations with conditions leading to hemodynamic alteration, such as chronic spinal cord injury. A deeper understanding of the aortic strain environment will provide insight into vascular disease and refine mechanical requirements for vascular endograft design.

Green-Lagrange strain: $E_{\theta\theta}=\frac{1}{2}\left(\left(\frac{\text{diameter}_{\text{current}}}{\text{Diameter}_{\text{minimum}}}\right)^2-1\right)$

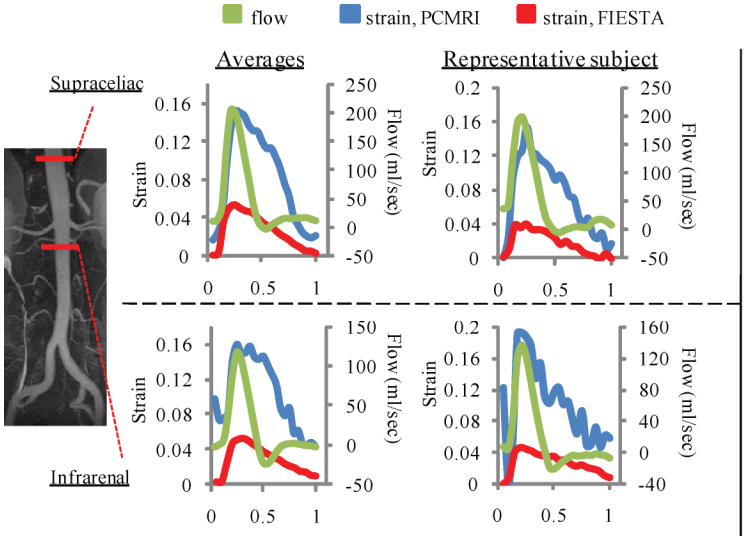

Fig. 1. Supraceliac (SC, top row) and infrarenal (IR, bottom row) flow and circumferential cyclic strain curves from PCMRI and FIESTA (x-axis=time, where 0 to 1 = one cardiac cycle). Averaged values (left column) and from a representative subject (right column) are shown.

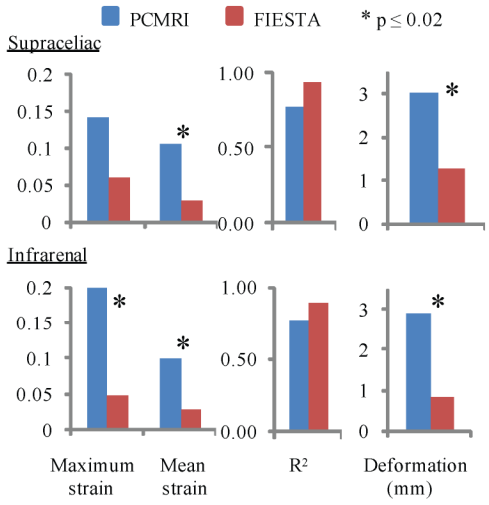

Fig. 2. The average maximum and mean strains from PCMRI or FIESTA images, coefficient of determination (R^2), and wall deformation are shown for SC (top row) and IR (bottom row) levels.

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2. Arko FR, Murphy EH, Davis CM III, Johnson ED, Smith ST, Zarins CK. Dynamic geometry and wall thickness of the aortic neck of abdominal aortic aneurysms with intravascular ultrasonography. J Vasc Surg. 2007;46(5):891-6.