In Vivo Quantification of Abdominal Aortic Hemodynamic Conditions at Rest and During Cycling Exercise in Healthy Subjects Aged 50-70

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Synopsis

Atherosclerosis prevalence in the human abdominal aorta increases with age and correlates with low wall shear stress (WSS) and shear oscillations. Exercise modulates these adverse conditions, observed at rest in the infrarenal aorta, in healthy subjects aged 23.6+/-2.2. Hemodynamic conditions were quantified in the abdominal aorta of 8 healthy subjects (aged 57.1+/-3.4) at rest and during exercise using an open-MRI and custom MR-compatible exercise-cycle. For the older subjects, exercise resulted in greater increases in WSS and elimination of greater shear oscillations (observed at rest) at the supraceliac and infrarenal locations as compared to the younger subjects.

Methods

Eight healthy subjects aged 50 to 70 were strapped to a seat in a 0.5T open magnet (GE Signa SP) such that they had the full range of leg motion while their abdomens were immobilized in the center of the magnet. A custom-built MR-compatible stationary cycle was positioned and the pedal resistance was adjusted to accommodate for subject size and strength. Scans were performed during seated rest and steady-state cycling exercise conditions (Figure 1), defined as 150% of resting heart rate. Cine phase-contrast MRI (cine PC-MRI) techniques were used to obtain anatomic and through-plane velocity maps [1] perpendicular to the abdominal aorta at the supraceliac and infrarenal levels at rest and during exercise [2]. The two anatomic slices were acquired in a single interleaved acquisition with a 25 msec TR, 9 msec TE, 30º flip angle, 10 mm slice thickness, 26 by 26 cm field of view, 256 by 128 matrix, and a 150 cm/sec through-plane velocity encoding gradient. Subjects breathed normally during the acquisitions and respiratory bellows were used to perform respiratory compensation [3]. The cine PC-MRI acquisitions were gated to the cardiac cycle using a plethysmograph placed on the thumb, and data was retrospectively reconstructed to 16 time points for the cardiac cycle.

We utilized a level set segmentation method to identify the aortic lumen curve, *C*, on the MR magnitude data [4]. With the segmented cross-section of the aorta, we performed blood flow rate [5] and WSS calculations [6]. WSS was computed along the curve *C* using the gradient of the measured velocity field and the dynamic viscosity of blood [6]. To compute the velocity gradient, we construct a band of 2D elements along the inside of *C* and fit 2D 3rd-order Lagrangian shape functions to represent the blood velocity profile in the vicinity of the lumen wall [6]. WSS are presented as circumferentially-averaged around the lumen. Temporal oscillations of blood flow and WSS are described by the oscillatory flow index (*OFI*) [2] and oscillatory shear index (*OSI*) [7]. Statistical comparisons of hemodynamic conditions were made between these older subjects and 11 healthy subjects aged 23.6+/-2.2 years from a previous study [2].

Results

The average age of the older subjects was 57.1+/-3.4 years. Resting heart rate of 63+/-8 bpm increased to 95+/-12 bpm during exercise for a percent increase of 51+/-3%. Quantitative comparisons of flow rate, WSS, and oscillations in flow and WSS are shown in Figure 2. While there were no statistical differences in flow and flow oscillations between the age groups, WSS was lower in the supraceliac aorta of the older subjects at rest as compared to the younger subjects (Young=3.5+/-0.8, Old=2.0+/-0.7 dynes/cm^2, $p<0.001$). The older population also had significantly higher shear oscillations (OSI) at the supraceliac (Young=0.01+/-0.01, Old=0.07+/-0.05, $p<0.001$) and infrarenal (Young=0.13+/-0.09, Old=0.25+/-0.12, $p<0.05$) levels at rest. During exercise, the older subjects experienced greater WSS in the infrarenal aorta as compared the younger subjects (Young=5.2+/-1.3, Old=16.5+/-5.1 dynes/cm^2, $p<0.05$), and also experienced elimination of all oscillations.

Discussion

The increases in flow and WSS and elimination of flow and shear oscillations in the abdominal aorta as a result of cycling exercise, as measured in this study, support the hypothesis that lower limb exercise moderates the unfavorable hemodynamic conditions that correlate with the localization of atherosclerotic disease. Even at the relatively low level of exercise corresponding to a 50% increase in heart rate, a 6-fold increase of flow into the lower extremities was observed for both young and older subject groups. Dilation of the aortic lumen with increasing age may cause the region of low mean WSS, observed only in the infrarenal region of the younger subjects, to extend superiorly in the aorta at rest for the older subjects. Although oscillations in WSS were found to be greater in the older subjects as compared to the younger subjects at the supraceliac and infrarenal levels of the aorta at rest, exercise served to eliminate these oscillations just as in the younger subjects, and the mean WSS was increased more dramatically in the older subjects. These findings support the hypothesis that even low levels of exercise are hemodynamically athero-protective for the abdominal aortas of healthy subjects aged 50 to 70, and that these benefits may be more important for older subjects than for younger subjects due to their more adverse baseline conditions at rest.

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Figure 1. 59-year-old subject pedaling a custom MR-compatible stationary cycle in the GE 0.5T open magnet

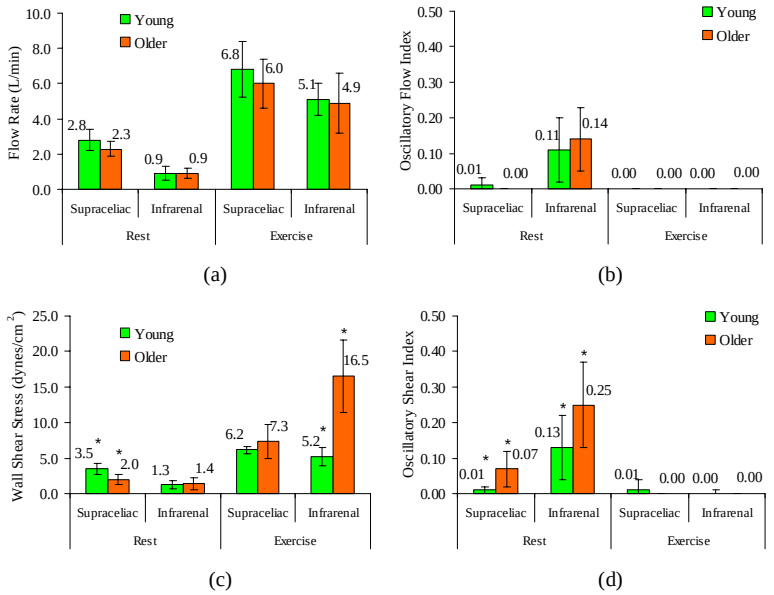

Figure 2. Population averages of rest and exercise (a) blood flow rate, (b) oscillatory flow index, (c) wall shear stress, and (d) oscillatory shear index at the supraceliac and infrarenal levels of the abdominal aorta. * Indicates statistical significance ($p < 0.05$) between young and older groups.