Hemodynamic Response to Exercise in Small Abdominal Aortic Aneurysms

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Introduction

Abdominal Aortic Aneurysms (AAA) greater than 5 cm in diameter are repaired with open or endovascular surgical treatments [1]. However, there are currently no treatment strategies to slow or halt the progression of small AAA (defined as 3.0 to 5.0 cm). Exercise has been shown to alter the dynamics of blood flow in the abdominal aorta, including eliminating retrograde and stagnant flow while increasing wall shear stress, which may promote vascular health [2]. The aims of this study are to characterize baseline flow conditions in small AAA, measure changes in blood flow during lower limb exercise, and compare these hemodynamic conditions with those of healthy volunteers.

Methods

Six male patients (age: mean ± standard deviation = 73.0 ± 10.8 years) with small AAA (defined as 3.0 to 5.0 cm) were recruited for the study. All patients gave written informed consent and were screened for other pre-existing medical conditions. These patients were compared to eight younger healthy control subjects (57.1 ± 3.4 years, $p < 0.05$) with no known cardiovascular disease. Data was collected for both seated resting conditions and during upright lower limb exercise conditions for subjects with a 0.5T scanner (GE Signa SP, GE Medical Systems, Milwaukee, WI). Lower limb exercise was performed on a custom-built MR-compatible exercise cycle composed of plastic and wood (Figure 1) [3]. The cine PC-MRI acquisitions measured blood velocities in the abdominal aorta for three anatomical positions: 2-3 cm superior to the celiac artery (SC), immediately infrarenal (IR), and mid-aneurysm (MA). The cine PC-MRI data was gated to the cardiac cycle, respiratory compensated, and reconstructed to 24 time points within the cardiac cycle. Scan parameters included: 25 ms TR, 9 ms TE, 30^{o} flip angle, 10-mm slice thickness, 26 X 26 cm square field of view, 256 X 256 image matrix, and a 150 cm/s through-plane velocity encoding gradient. Patients were instructed to perform a workload up to 150% of resting heart rate with resistance and pedaling speed adjusted to accomplish the desired workload. The aortic lumen was segmented manually on the magnitude data, and cross-sectional area and blood flow rate were calculated. To minimize phase error, second-order baseline corrections were applied to each time frame.

Figure 1: MR Compatible Bicycle

Results

Average blood flow conditions were not statistically different between AAA patients and controls for both rest and exercise conditions at the SC and IR levels (Figure 2). During exercise, AAA patients increased their heart rate by 30.0 ± 15.3% which was less than controls (51.4 ± 3.0%, $p < 0.05$). Both populations had significantly lower oscillatory flow index (OFI) at the IR position during exercise as compared to rest, and AAA patients had higher OFI at the SC position than controls during rest (Table 1). OFI is a measure of oscillatory blood flow with a value of zero corresponding to positive flow throughout the cardiac cycle, and a value of 0.5 corresponding to zero mean flow. AAA patients had larger cross-sectional area than controls at the SC (5.2 ± 1.1 to 3.9 ± 0.7, $p < 0.05$) and IR (4.1 ± 0.9 to 2.5 ± 0.5, $p < 0.01$) positions as measured at rest. In addition, AAA patients had a significant decrease in visceral blood flow (SC-IR difference) from rest to exercise (1.7 ± 0.7 to 0.9 ± 0.3, $p< 0.01$), a finding not observed in controls.

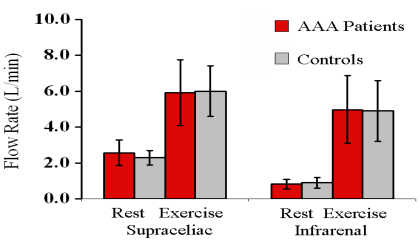

Figure 2. Average mean flow values for AAA patients and controls. Blood flow rates were similar between groups during rest and exercise.

Discussion

The average blood flow rate values at rest and exercise were similar between the populations, even though the AAA patients were older than controls, had macrovascular disease, and were not able to increase their heart rate as much as the controls during exercise. These findings might be explained by the significant decrease in visceral blood flow for AAA patients with exercise, meaning less blood flow was shunted by renal and splanchnic vasculature as compared to the controls during lower limb exercise. The SC and IR cross-sectional areas were greater in the AAA patients than controls, a result consistent with age-related aortic dilation [4] and the presence of AAA disease. Observed differences during rest conditions in OFI at the SC locations indicate more complex flow patterns that may contribute to AAA pathogenesis. Reduction in OFI at the SC, IR, and MA position during exercise for AAA patients reduces hemodynamic conditions that are hypothesized to promote atherosclerosis [5]. Taken together, these findings suggest that mild exercise may mediate the adverse hemodynamic conditions in small AAA. Future work is recommended in determining optimal exercise prescriptions to achieve desired outcomes, and effects of long-term exercise therapy on rate of disease progression.

	AAA Patients (N=6)			**Controls (N=8)**			**Group Difference**	
Flow (L/min)	Rest	Exercise	Statistical Significance	Rest	Exercise	Statistical Significance	Rest	Exercise
Supraceliac	2.6±0.7	5.9±1.8	p<0.01	2.3±0.4	6.0±1.4	p<0.001	--	--
Infrarenal	0.8±0.3	5.0±1.9	p<0.01	0.9±0.3	4.9±1.7	p<0.001	--	--
Mid-Aneurysm	0.8±0.5	4.6±2.0	p<0.01	--	--	--	--	--
OFI								
Supraceliac	0.02±0.01	0.00±0.00	p<0.05	0.00±0.00	0.00±0.00	--	p<0.05	--
Infrarenal	0.18±0.12	0.01±0.01	p<0.05	0.14±0.09	0.00±0.00	p<0.01	--	--
Mid-Aneurysm	0.20±0.12	0.02±0.05	p<0.01	--	--	--	--	--

Table 1. Flow characteristics of AAA patients and control subjects. Group averages during exercise and rest were calculated for average blood flow rate and oscillatory flow index (OFI) at the supraceliac (SC), infrarenal (IR), and mid-aneurysm (MA) positions (for AAA patients). For both populations, the average flow rate at the SC and IR locations increased significantly from rest to exercise. In addition, AAA patients had greater OFI during rest compared to exercise at the SC, IR, and MA positions. Control patients showed a reduction in OFI at the IR position during exercise. AAA patients had significantly higher OFI than controls at the SC position during rest.

Acknowledgments

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References

1. Zarins CK, et al. J Vasc Surg, 2006. **44**(5): 920-29; discussion 929-31.
2. Cheng CP, et al. Atherosclerosis, 2003. **168**(2): p. 323-31.
3. Taylor CA, et al. Ann Biomed Eng 2002. **30**(3): 402-8.
4. Lazarus M, et al. Am J Cardiol 1988. **62**(7): 439-43.
5. Zarins CK, et al. Circ Res, 1983. **53**(4): 502-14.