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Assessing the hemodynamic response to exercise - a novel MR approach

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Introduction

Exercise is a powerful stimulator of the cardiovascular system. Therefore, it can be used to unmask subtle vascular changes in early hypertensive disease. Routinely only blood pressure and heart rate response to exercise are measured. However measuring cardiac output (CO), systemic vascular resistance (SVR) and arterial compliance would increase the sensitivity of exercise testing. MRI is a proven method of measuring CO and deriving SVR and compliance at rest. Unfortunately the lack of appropriate sequences has made it difficult to perform MRI during exercise.

Purpose

We hypothesize that measuring the hemodynamic response to exercise is feasible using a novel high temporal resolution, real-time, spiral MRI flow sequence.

Methods

Twenty healthy volunteers (21.9-49.2 years) underwent aortic flow quantification using real-time spiral PC-MR (8 interleaves, 4-fold SENSE acceleration, 40 ms temporal resolution). Aortic flow quantification was carried out at rest and during supine exercise (at 4 W and 8 W). The novel sequence was validated against a standard gated flow sequence at rest and against a real-time sequence to measure left ventricular volume during exercise. The real-time flow data was combined with simultaneous oscillometric blood pressures to calculate systemic vascular resistance (SVR) and arterial compliance.

Results

A good agreement of the flow volumes calculated from our real-time flow sequence was found against the standard flow sequence and also against the left ventricular volumes calculated Table 1.

The real-time flow volumes calculated were combined with simultaneous blood pressure measurements to calculate SVR and compliance.

At 4 W, heart rate, cardiac output, and systolic and mean blood pressure significantly increased, whilst SVR and compliance decreased, as expected (Table 2). Apart from heart rate and cardiac output, there was no significant change in these parameters between 4 W and 8 W. There was no change in diastolic blood pressure during either stage of exercise.

Conclusion

We have demonstrated the feasibility of measuring the hemodynamic response to exercise using a novel real-time flow MRI sequence. The high temporal resolution of this sequence ensures accuracy at the high heart rates present during exercise. This technique is relatively simple to perform and could be made available in a large number of centers. This raises the possibility of assessing exercise response in large populations and linking it to cardiovascular risk. Understanding this link should improve identification of at-risk groups and increase understanding of the early development of vascular disease.

Table 1: Validation of real-time flow sequence at rest and during exercise

Validation	Bland Altman Assessment			Correlation coefficient
	Bias (ml/cycle)	Limits of agreement (ml/cycle)		
Standard flow sequence Vs. Real-time flow sequence, at rest	-0.58	-0.58	-4.71	0.994 ($p < 0.005$)
Real-time ventricular volume Vs. Real-time flow volume, at rest	-2.04	-8.29	4.21	0.988 ($p < 0.005$)
Real-time ventricular volume Vs. Real-time flow volume, at 8 W	0.83	-4.18	5.84	0.984 ($p < 0.005$)

Table 2: Hemodynamic response to exercise

	Rest+	4 W+	8 W+	*P** (0 W-4 W)	*P** (4 W-8 W)	*P** (0 W-8 W)
Heart rate (bpm)	68.2 (12.5)	99.2 (15.8)	108.6 (21.2)	<.001	< .001	< .001
Cardiac output ($L.min^{-1}$)	5.8 (1.4)	8.3 (1.6)	9.1 (1.7)	< .001	0.002	< .001
Systolic BP (mmHg)	112.5 (10.4)	137.2 (15.2)	134.6 (21.0)	< .001	.50	< .001
Diastolic BP (mmHg)	64.8 (6.0)	66.3 (12.3)	64.3 (13.1)	.54	.46	.85
Mean BP (mmHg)	83.9 (6.8)	95.5 (9.4)	95.3 (8.9)	< .001	.91	< .001
Vascular resistance (WU)	15.2 (2.9)	11.8 (2.5)	10.7 (1.7)	< .001	.007	< .001
Arterial compliance ($mL.mmHg^{-1}$)	1.00 (0.23)	0.62 (0.23)	0.63 (0.21)	< .001	.80	< .001

+ Mean from all volunteers (std) * Paired t-test