Cardiac reserve and exercise capacity: insights from combined cardiopulmonary and exercise echocardiography stress testing

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Aims. Combined cardiopulmonary exercise test (CPET) and exercise stress echocardiography (ESE) provides a non-invasive tool to study cardiopulmonary pathophysiology. We analyzed how cardiac functional reserve during exercise relates to peak oxygen consumption (VO2).

Methods and Results. We performed a symptom-limited graded ramp bicycle CPET-ESE in 30 healthy controls and 357 patients: 113 at risk of developing heart failure (American College of Cardiology/American Heart Association HF Stages A-B) and 244 in HF Stage C with preserved (HFpEF, n = 101) or reduced ejection fraction (HFrEF, n = 143). Peak VO2 significantly decreased from controls to Stage A-B and Stage C (Table 1). A multivariable regression model to predict peak VO2 revealed peak left ventricular systolic annulus tissue velocity (S"), peak TAPSE/PAPs (tricuspid annular plane systolic excursion/systolic pulmonary artery pressure) and low-load left atrial reservoir strain/E/e' were independent predictors, in addition to peak heart rate, stroke volume and workload (adjusted R^2=0.76, p < 0.0001). The model was successfully tested in subjects with atrial fibrillation (n = 49), and with (n = 224) and without (n = 163) beta-blockers (all p < 0.01). Peak S' showed the highest accuracy in predicting peak VO2 < 10 mL/kg/min (cut-point ≤ 7.5 cm/s; AUC = 0.92, p < 0.0001) and peak VO2 > 20 mL/kg/min (cut-point > 12.5 cm/s; AUC = 0.84, p < 0.0001) in comparison to the other cardiac variables of the model (p < 0.05).

Conclusions. A model incorporating different measures of cardiac mechanics is strongly related to peak aerobic capacity and may help in identifying different causes of effort intolerance from HF Stage A to C.

Table 1

Variable	Overall population (n = 387)	Controls (n = 30)	Stage A-B (n = 113)	Stage C-HFpEF (n = 101)	Stage c-HFrEF (n = 143)	p-value
Age, years	68.9 ± 11.1	67.1 ± 10.6	67.7 ± 10.4	70.5 ± 10.1	68.5 ± 11	0.1
Male, n (%)	247 (64)	18 (60)	70 (62)	57 (56)	102 (71)	0.1
VO2 @peak, mL/min/kg	15.7 (12.1-19.6)	23 (21.7- 29.7)	18 (15.4- 20.7)*	13.6 (11.8-16.8)*†	14.2 (10.7- 17.5)*†	<0.0001
Workload @peak, W	90 (65-120)	130 (115-195)	110 (84-130)*	70 (55-100)*†	80 (60-110)*†	<0.0001
Heart rate @peak, bpm	123 ± 22	142 ± 12	130 ± 20*	115 ± 17*†	119 ± 23*†	<0.0001
Stroke volume @peak, mL	83 (71-99)	98 (85-114)	86 (76-107)	83 (74-97)*	75 (63-95)*†	<0.0001
Average S" @peak, cm/s	11.2 ± 3.8	17.1 ± 3.9	13.3 ± 2.9*	10.6 ± 2.5*†	8.7 ± 2.7*†‡	<0.0001
TAPSE/PAPs @peak, mm/mmHg	0.75 (0.46-0.97)	1.05 (0.93- 1.16)	0.81 (0.52-0.91)*	0.52 (0.38-0.83)*†	0.58 (0.41- 0.89)*†	<0.0001
Left atrial reservoir strain/E/e" @low-load, %	2.25 (1.17-5.04)	6.23 (4.45-6.77)	4.34 (3.89-5.58)*	2.23 (1.31-2.86)*†	1.91 (1.07-2.44)*†‡	<0.0001

* $p < 0.01$ vs Controls; † $p < 0.01$ vs Stage A-B; ‡ $p < 0.01$ vs Stage C-HFpEF. **PAPs:** systolic pulmonary artery pressure; TAPSE: tricuspid annular plane systolic excursion; VO2: oxygen consumption.

Abstract Figure 1