Measurement of Global Myocardial Work with Exercise Testing

The assessment of change of global longitudinal strain (GLS) with exercise may be a means of quantifying systolic functional reserve. However, like left ventricular (LV) ejection fraction (EF), GLS is afterload dependent, which leads to these measurements being influenced by changes in blood pressure.[1] Myocardial work (MW) may now be assessed noninvasively by integrating myocardial strain and afterload, and these data account for different loading conditions.[1,2] The assessment of myocardial deformation responses to exercise might represent one situation where MW may be of value, and there are currently limited data on the use of MW during exercise stress echocardiography (ExE). As functional capacity (FC) is an important predictor of mortality in healthy subjects,[3,4] the association of LV measurements with FC has been used to understand the relative prognostic importance of the different measures. For example, there is a stronger association of diastolic markers than EF with FC,[5] and this mimics the strong prognostic signal from diastolic dysfunction. We sought to determine the feasibility of MW during ExE and its association with FC, relative to other potential markers of myocardial reserve.

Of all subjects between January 2017 to April 2019 who underwent an ExE, 115 healthy subjects were identified to have a low pretest probability (<10%) for coronary artery disease and no documented heart disease. A standard Bruce treadmill protocol was performed in 96%, with the remaining undergoing an upright bicycle protocol. A comprehensive echocardiogram (Vivid 95, GE Medical Systems, Milwaukee, WI) was performed pre- and postexercise using the same image setting with a minimum temporal resolution of 45 frames/sec, which included diastolic and systolic assessment. Offline measurement of myocardial deformation was performed using EchoPAC (GE Medical Systems, Milwaukee, WI; ver. 202) with a minimum 16-segment requirement for GLS evaluation. Measurement of MW (mm Hg %) was performed by the software after calculation of LV GLS, and peak noninvasive systolic blood pressure was entered. Pressure-strain loops were timed to the aortic and mitral valve opening and closing times. Global work index (GWI; mm Hg%) represented the area within the pressure-strain loop. Global constructive work (GCW; mm Hg%) represented the LV work during shortening of the myocardium during systole and lengthening with isovolumetric relaxation. Global wasted work (GWW; mm Hg%) was the amount of wasted energy with LV lengthening during systole and shortening during isovolumetric relaxation.

From the initial data set, 19 subjects were excluded due to unsatisfactory image quality and problems related to ECG triggering postexercise, leaving 96 subjects (83%) who were suitable for the study. The mean age of the cohort was 53 ± 17 years, 64% were male, and 93% achieved their target metabolic equivalent of task for age. At rest, GLS was within the normal range (−21% ± 3%). Myocardial work parameters showed substantial variation at rest and exercise but nonetheless increased with exercise (Table 1). Functional capacity (Figure 1) showed a weak correlation with peak GWI ($r = -0.32$, $P = .002$), a modest correlation with peak e′ ($r = 0.53$, $P < .001$), but no correlation with GLS ($r = 0.15$, $P = .144$). Correlation between FC and delta (Δ) GWI, e′, and GLS (calculated as peak − rest) was weaker and not statistically significant (ΔGWI $r = -0.19$, $P = .068$; Δe′ $r = 0.20$, $P = .057$; ΔGLS $r = 0.01$, $P = .92$). After adjustment for age and gender, regression analysis showed FC was somewhat associated with both peak GWI and e′. Peak e′ showed a modest association with FC, but with borderline significance ($\beta = 0.24$ [95% CI, −0.001 to 0.5], $P = .051$). There was a weak association seen with peak GWI ($\beta = -0.001$ [95% CI, −0.002 to −0.0001], $P = .034$).

During systole, LV performance is influenced by three components: preload, contractility, and afterload.[6] By incorporating afterload into its analysis, MW provides an assessment on LV work and oxygen consumption.[2] This is important as during exercise significant changes in blood pressure can affect cardiac performance. Nonetheless, this report should be considered as a preliminary communication about this parameter. Acquiring good echocardiographic images during an exercise protocol can be difficult and may have led to selection bias. Furthermore, high dropout rates due to issues with ECG tracking postexercise may have also contributed to a selection bias and may represent an issue with utilizing MW with exercise testing. Undersampling during tachycardia may have led to underestimation of MW estimates pre- and postexercise. Nonetheless, our results illustrate the feasibility and utility of MW with ExE and highlights its potential role in sequential studies where afterload is variable. The interpatient variability of MW is large, and using each patient as his or her own control may control interpatient variability. Use of MW in ExE may be a useful adjunct to GLS in the measurement of myocardial reserve.

Table 1 Resting and peak two-dimensional echocardiogram parameters in 96 patients

Echo parameters	Rest	Peak	Individual increment	*P* value
Systolic blood pressure, mm Hg	138 [18]	191 [28]	53 ± 22	<.001
EF, %	65 [8]	74 [8]	10 ± 7	<.001
GLS, %	−21 ± 3	−23 ± 4	-3 ± 3	<.001
Average E/e’	6.3 [3]	6.9 [3]	0.5 [2]	.021
Average E, cm/sec	66 ± 17	96 ± 24	30 ± 19	<.001
Average e’, cm/sec	9.8 [6]	13 [6]	3.5 [3]	<.001
GWI, mm Hg%	2,176 ± 445	2,834 ± 823	658 ± 663	<.001
GCW, mm Hg%	2,482 [680]	3,546 [1,235]	986 ± 768	<.001
GWW, mm Hg%	67 [51]	158 [162]	90 [129]	<.001

Data are expressed as mean ± SD for normally distributed and median [interquartile range] for nonnormally distributed variables.

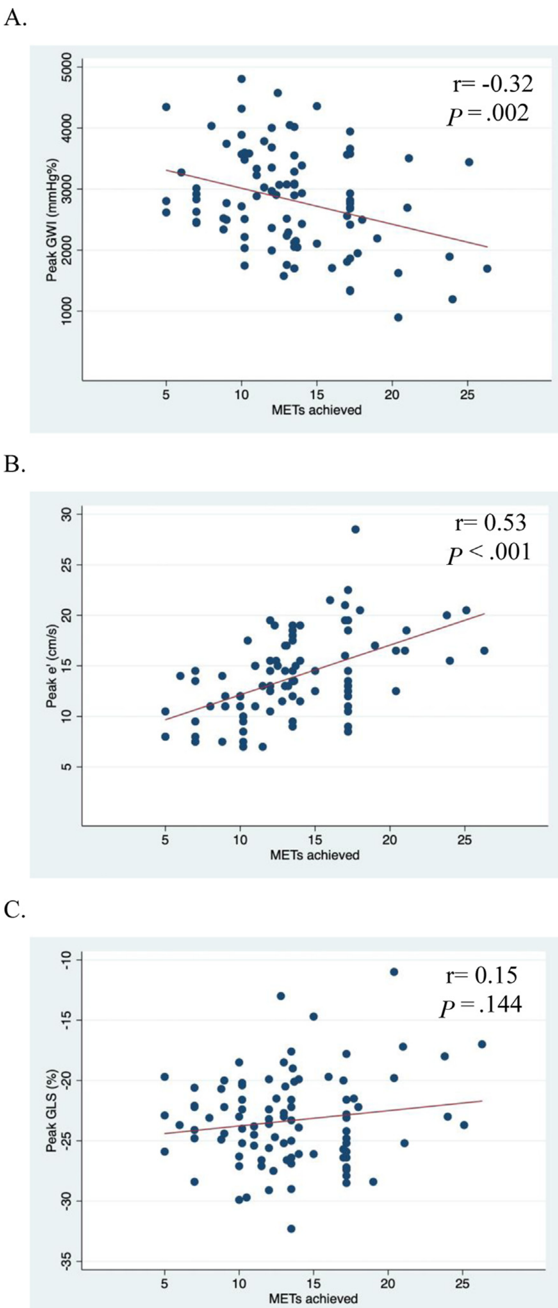

Figure 1 Association among **(A)** peak global work index, **(B)** peak e', and **(C)** peak GLS and FC. *METs*, Metabolic equivalents of task; *GWI*, global work index; *GLS*, global longitudinal strain.

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Deep Learning for Assessment of Left Ventricular Ejection Fraction from Echocardiographic Images

For automated measurements of left ventricular ejection fraction (LVEF), obtaining accurate border detection is a difficult task due to the complicated temporal deformation of the left ventricle (LV). Recently, deep learning (DL) has been developed as a state-of-the-art method for the classification of cardiovascular diseases.[1,2] Our study aim was to evaluate whether a three-dimensional convolutional neural network (3DCNN) could estimate and differentiate preserved ejection fraction (EF) or reduced EF independently of volumes using echocardiographic images.

The 3DCNN model was trained on a selected data set of 340 heart failure (HF) patients with homogeneously distributed EF range (185 patients had LVEF < 50%, and 155 patients had LVEF ≥ 50%). We selected cases with good or adequate acoustic detail to test the DL algorithm on images obtained from two vendors' machines. To test for generalizability, we gathered a separate validation group of 189 consecutive patients who were referred to our laboratory using six vendors with various image qualities (68 patients had LVEF < 50%, and 121 patients had LVEF ≥ 50%). The Institutional Review Board approved the study protocol.

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