The pressure–strain work indices in response to isometric handgrip exercise

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Introduction Noninvasive estimation of myocardial work (MW) via left ventricular (LV) pressure–strain relations describes cardiac function.[1] Invasively measured LV pressure-volume loops are applied to estimate the LV function. Pressure--volume work area correlates closely with oxygen consumption and MW, relating cardiac energy metabolism with mechanical performance. Invasive nature of this procedure limits its routine clinical implementation. Recently, Russel et al[2] introduced a noninvasive pressure–strain analysis which combined both myocardial strain and LV pressure estimation. The area within the pressure-strain loop represents MW. However, this approach should be regarded as an indirect index of MW and not its direct measurement.

The pressure–strain relation and cardiac work are less afterload-dependent than LV systolic descriptors such as myocardial strain and ejection fraction (EF).[1-3] Thus, an increase in afterload may impair markers such as longitudinal myocardial strain and/or EF, despite normal contractility mirrored by an unchanged MW. To test this hypothesis, we investigated the interaction between the indices of global MW and LV systolic function in response to an acute and transient increase in arterial load during an isometric handgrip exercise (IHG).

Methods A total of 15 healthy male volunteers who gave their informed and written consent for participation were recruited to this study. The local Ethics Committee approved the study protocol.

Echocardiography with a 3.5-MHz transducer (Vivid E95; GE Healthcare, Horten, Norway) was performed at rest and during peak IHG. All echocardiographic tracings were obtained with the subjects placed in a left lateral recumbent position. Digital images were transferred to a computer workstation (EchoPAC, GE Healthcare) for offline analysis. Standard measurements were made according to the recommendations of the European Association of Echocardiography and the American Society of Echocardiography.

Echocardiographic electrocardiography-guided cine loops, optimized for speckle-tracking analysis (global longitudinal peak systolic strain [GLPSS]), were acquired at standard apical views. Strain data and brachial cuff blood pressure recordings quantified global MW efficiency by a novel, noninvasive technique.[1,4-7] Automated Function Imaging software (GE Healthcare) was used to analyze speckle-tracking and calculate MW and the related indices (Supplementary material, *Figure S1*). Global constructive work (GCW) represents the contribution of all normally contracting segments to work related to blood ejection from the LV to the aorta. In contrast, global wasted work (GWW) quantifies the amount of work not contributing to blood ejection. GCW divided by the sum of both constructive and wasted work measures the global work efficiency (GWE), while the LV pressure-strain loop area depicts the global work index (GWI).

Measurement of maximal handgrip strength was performed in a sitting position via a hand dynamometer (Sammons Preston Rolyan, Bolingbrook, Illinois, United States). Next, the subjects performed an IHG by compressing the dynamometer while lying in a left lateral recumbent position for 3.5 minutes and maintaining 30% of their maximal handgrip strength. Stress echocardiography was performed between 2.45 and 3.15 minutes of the IHG.[4,8]

Statistical analysis All analyses were made using GraphPad Prism, version 5 (GraphPad Software, San Diego, California, United States). Continuous

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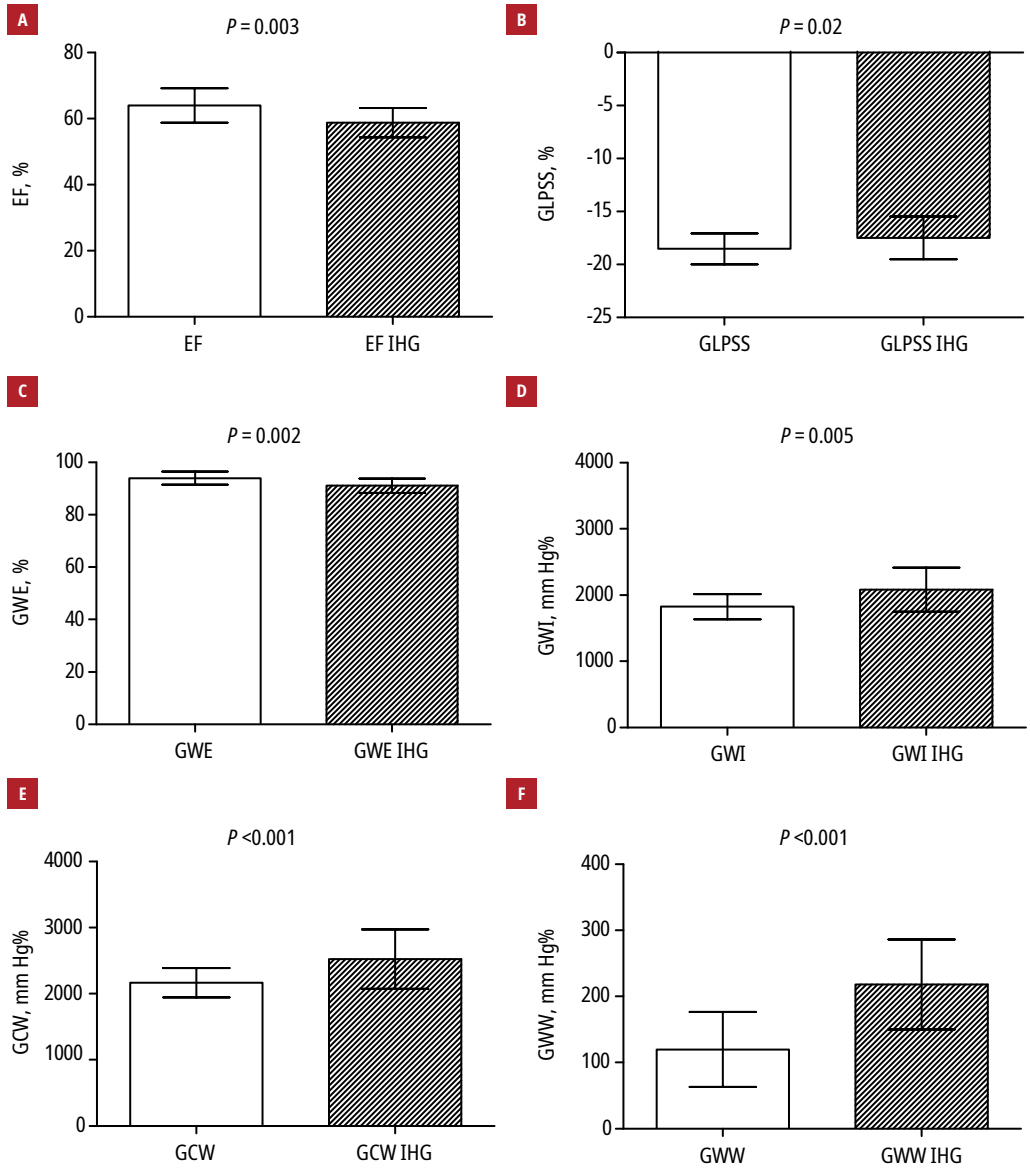

FIGURE 1 Differences in cardiac work markers estimated before and after isometric handgrip exercise (IHG); mean (SD) values for **A** – ejection fraction (EF); **B** – global longitudinal peak systolic strain (GLPSS); **C** – global work efficiency (GWE); **D** – global work index (GWI); **E** – global constructive work (GCW); **F** – global wasted work (GWW)

data are reported as mean (SD). The differences between means were estimated with the use of paired *t* tests with a significance threshold set at *P* value of less than 0.05. Normal distribution was estimated with the Kolmogorov–Smirnov test.

Results and discussion

The clinical characteristics of the study participants are presented in Supplementary material, *Table S1*.

Hemodynamic response to handgrip maneuver

The mean values of hemodynamic indices at rest and during IHG are presented in Supplementary material, *Table S2*. At the peak of IHG, systolic and diastolic blood pressure as well as heart rate increased significantly. Similarly, there was a significant increase in systemic vascular resistance and cardiac output, accompanied by a decreased stroke volume. The ratio of early mitral inflow velocity to mitral annular early diastolic velocity (E/e') remained unchanged.

Changes in left ventricular systolic descriptors and myocardial work indices during peak handgrip

The descriptors of LV systolic function at rest and during IHG are presented in FIGURE 1. At the peak IHG, a decrease was noted in EF (mean [SD], 63.9% [4.5%] vs 58.8% [4.5%]), GLPSS (mean [SD], –18.5% [1.5%] vs –17.5% [2%]), and GWE (mean [SD], 94% [2.5%] vs 91% [2.8%]) (FIGURE 1A–1C). In contrast, on average, the GWI increased by 258 mm Hg%, GCW by 357 mm Hg%, and GWW by 98 mm Hg% (FIGURE 1D–1F).

This study shows that an acute increase of arterial load in individuals with normal LV systolic function leads to diminished myocardial

performance (estimated by EF) and longitudinal systolic strain, and an increased MW (evaluated by the pressure–strain relation).

The interaction between the heart and the arterial system is multifactorial. Arterial load represents an opposition that must be overcome by the LV during ejection. Such arterial resistance to LV ejection in the absence of aortic valve disease is the primary determinant of LV afterload. A comprehensive evaluation of LV function must consider the dynamic nature of arterial–ventricular interaction. Therefore, we evaluated the heart's response to changes in the loading conditions obtained through the IHG to capture the full spectrum of the hemodynamic load imposed on the LV.

Our study confirms previous reports demonstrating that IHG causes a significant increase in heart rate, blood pressure, and systemic vascular resistance. This dynamic change in loading conditions, that is, an increase in afterload surge, led to a significant decrease in EF and GLPSS. Furthermore, it appears that the obtained results mirror a transient impairment of LV systolic function.

The novel technique of LV function estimation may help to dissect these complex issues further. The pressure-strain loop area corresponds to oxygen consumption and mechanical performance (intrinsic myocardial contractility). Therefore, by providing an insight into myocardial energetics, pressure–strain analysis allows an understanding of the relation between LV performance and loading conditions.

Recently, Chan et al[6] used this approach to estimate MW in hypertensive individuals and patients with dilated cardiomyopathy. Both EF and GLPSS were preserved in the hypertensive group, similarly to healthy controls. Moreover, the GWI was significantly higher in patients with hypertension as a compensatory mechanism to maintain contractility against increased arterial load.

Assessment of MW during dynamic exercise has been previously reported, but comparable data on the effect of isometric exercise are lacking. Clemmensen et al[9] demonstrated diminished work efficiency during exercise in patients with cardiac amyloidosis. Exercise test after spironolactone treatment in individuals with heart failure and preserved EF demonstrated improved GCW but not GLPSS.[10] In the present study, a dynamic change in loading conditions, that is, an increase in afterload surge, led to a significant decrease in EF and GLPSS, which might suggest a transient impairment of LV systolic function. It is noteworthy that increased afterload resulted in enhanced wasted work and reduced work efficiency, thereby illustrating that the estimation of only EF and GLPSS might be misleading, since an impairment of both markers in response to change in afterload was not a result of diminished contractility. Such analysis is useful in people with mildly impaired systolic function, for example, young, highly trained athletes. The presence of resting systolic dysfunction (described as EF <52%) is a relatively frequent finding in high-performance athletes. A lower resting EF is attributed to heart remodeling in response to intensive exercise. The evaluation of myocardial work based on pressure–strain analysis in various phases of training might provide additional information to understand the pathophysiology of "athlete's heart." Moreover, MW estimation might be useful in serial assessments of cardiotoxicity during oncotherapy or cardiac effects of pharmacotherapy.

In summary, an acute increase in arterial load exerts a contrasting effect on the descriptors of LV systolic function and markers derived from pressure–strain analysis.

SUPPLEMENTARY MATERIAL

Supplementary material is available at www.mp.pl/kardiologiapolska.

ARTICLE INFORMATION

CONFLICT OF INTEREST None declared.

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