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SHORT COMMUNICATION

The effect of exercise training on biventricular myocardial strain in heart failure with preserved ejection fraction

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Abstract

Aims High-intensity interval training (HIIT) improves peak oxygen uptake and left ventricular diastology in patients with heart failure with preserved ejection fraction (HFpEF). However, its effects on myocardial strain in HFpEF remain unknown. We explored the effects of HIIT and moderate-intensity aerobic continuous training (MI-ACT) on left and right ventricular strain parameters in patients with HFpEF. Furthermore, we explored their relationship with peak oxygen uptake (VO_{2peak}).

Methods and results Fifteen patients with HFpEF (age = 70 ± 8.3 years) were randomized to either: (i) HIIT (4 × 4 min, 85–90% peak heart rate, interspersed with 3 min of active recovery; *n* = 9) or (ii) MI-ACT (30 min at 70% peak heart rate; *n* = 6). Patients were trained 3 days/week for 4 weeks and underwent VO_{2peak} testing and 2D echocardiography at baseline and after completion of the 12 sessions of supervised exercise training. Left ventricular (LV) and right ventricular (RV) average global peak systolic longitudinal strain (GLS) and peak systolic longitudinal strain rate (GSR) were quantified. Paired *t*-tests were used to examine within-group differences and unpaired *t*-tests used for between-group differences (α = 0.05). Right ventricular average global peak systolic longitudinal strain improved significantly in the HIIT group after training (pre = −18.4 ± 3.2%, post = −21.4 ± 1.7%; P = 0.02) while RV-GSR, LV-GLS, and LV-GSR did not ($P > 0.2$). No significant improvements were observed following MI-ACT. No significant between-group differences were observed for any strain measure. ΔLV-GLS and ΔRV-GLS were modestly correlated with ΔVO_{2peak} (r = −0.48 and r = −0.45; P = 0.1, respectively).

Conclusions In patients with HFpEF, 4 weeks of HIIT significantly improved RV-GLS.

Keywords Exercise training; Ventricular strain; High-intensity interval exercise; Heart failure with preserved ejection fraction

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Background

Heart failure is a leading cause of hospitalization among the elderly, and nearly half of the patients with a heart failure diagnosis have heart failure with preserved ejection fraction (HFpEF).[1] Heart failure with preserved ejection fraction is also associated with significant impairments in left ventricular (LV) global longitudinal strain (GLS), which in turn is associated with multiple adverse patient outcomes.[2]

We have previously demonstrated improvements in LV diastolic function following high-intensity interval training (HIIT).[3] However, recently published data with regard to acute and chronic effects of high-intensity interval exercise are mixed with some data suggesting worsening of strain characteristics in otherwise healthy individuals[4,5] and no adverse changes in individuals with heart failure and reduced ejection fraction.[6,7] Given that the effects of HIIT on ventricular strain characteristics in patients with HFpEF remain unknown, we carried out secondary analyses to explore the effects of HIIT on biventricular strain characteristics.

Aims

The primary aim of these secondary analyses was to explore the changes in right and LV-GLS and global longitudinal systolic strain rate (GSR) following 1 month of HIIT in comparison to a more traditional moderate-intensity aerobic continuous training program (MI-ACT). Secondarily, we examined the relationships between change in LV and right ventricular (RV) strain parameters and change in cardiorespiratory fitness (VO_{2peak}).

Methods

The study was approved by the Mayo Clinic and the Arizona State University institutional review boards, and all study procedures were carried out in accordance to the Declaration of Helsinki (Clinical trials registration: NCT02147613). The design and primary outcomes of this clinical trial have been described in detail by the authors previously.[3] Briefly, 19 patients with HFpEF (age = 70 ± 8.3 years; median diastolic dysfunction grade = II and median NYHA Class II) were randomized to either 4 weeks of HIIT (eight men, one woman; 4 × 4 min at 85–90% peak heart rate, with 3 min active recovery between bouts) or MI-ACT (four men, two women; 30 min at 70% peak heart rate). Subjects underwent supervised exercise training 3 days/week for 4 weeks and were on stable pharmacotherapy for >3 months (*Table 1*).

Transthoracic echocardiography was carried out 72–96 h after the last bout of exercise and utilized standard American Society of Echocardiography guidelines for views and measurements for systolic and diastolic assessment. Left ventricular and RV strain analyses using velocity vector imaging were measured at baseline and again at completion of the exercise training program for all patients.[8–10] Semi-automated signal processing software (Syngo US workstation, Siemens Medical Solutions, Mountain View, CA, USA) was used offline to track myocardial borders in order to measure the average GLS and GSR for both left ventricle and right ventricle (using the apical four-chamber view). We excluded the segments which were not adequately tracked. The indices obtained from the velocity vector imaging were averaged from three consecutive cardiac cycles.

Paired *t*-tests were used to compare pre- and post-training differences within groups, and unpaired *t*-tests were used to compare between-group differences. Data are reported as means ± standard deviation (*Tables 1* and *2*). Alpha was set at 0.05 for significance and α = 0.1 for trends. Effect sizes (Cohen's d) for within-group and between-group (d_b) differences were calculated and reported as moderate ($0.5 < d < 0.8$) or large ($d \geq 0.8$).[11] Finally, data were pooled across both exercise intervention groups, and Pearson correlation coefficients were computed to examine relationships between changes in biventricular strain and change in VO_{2peak} (change in VO_{2peak} reported in a previous publication).[3]

Table 1 Baseline characteristics

	HIIT (n = 9)	MI-ACT (n = 6)
Age (years)	69 ± 6.1	71.5 ± 11.7
HR (bpm)	62.4 ± 7.2	61.7 ± 7.8
BP (mmHg)	134 ± 14/85 ± 8	134 ± 24/78 ± 7
BNP (pg/mL)	62.4 ± 42.6	118.3 ± 90.4
ACE-I	5/9	1/6
ARB	0/9	2/6
α-ß-Blockers	6/9	4/6
Aspirin	5/9	4/6
Diuretics	4/9	4/6
Coumadin	3/9	2/6
Statins	6/9	4/6
CCBs	2/9	4/6

ACE-I, angiotensin converting enzyme inhibitor; ARB, angiotensin receptor blocker; BMI, body mass index; BP, blood pressure; CCBs, calcium channel blockers; HIIT, high-intensity aerobic interval training; HR, heart rate; MI-ACT, moderate-intensity aerobic continuous training.

Table 2 Changes in right and left ventricular parameters

	Pre	Post	P	d	Pre	Post	P	d	d_b
RV-GLS (%)	−18.4 ± 3.2	−21.4 ± 1.7	0.02	0.95	−18.4 ± 4.1	−19.5 ± 4.9	0.41	0.37	0.60
RV-GSR (s^{-1})	−1.2 ± 0.3	−1.3 ± 0.4	0.71	0.13	−1.2 ± 0.4	−1.4 ± 0.5	0.22	0.58	0.51
LV-GLS (%)	−15.8 ± 2.9	−17.9 ± 3.9	0.20	0.50	−16.0 ± 3.2	−15.8 ± 4.2	0.89	0.06	0.53
LV-GSR (s^{-1})	−0.9 ± 0.2	0.9 ± 0.3	0.48	0.26	−0.9 ± 0.2	−0.9 ±0.3	0.96	0.02	0.21
LV mass (g)	210.1 ± 61.2	180.6 ± 59.3	0.06	0.50	219.2 ± 18.3	220.0 ± 45.3	0.97	0.02	0.75
LVMI (g/m^2)	101.1 ± 22.5	87.6 ± 23.5	0.14	0.93	109.6 ± 15.7	112.0 ± 19.5	0.8	0.13	1.16
LVEF (%)	63.7 ± 6.4	62.4 ± 5.5	0.44	0.27	66.0 ± 4.7	61.6 ± 5.3	0.08	0.71	0.15
SV (cc)	93.8 ±24.8	88.2 ± 19.2	0.47	0.25	89.2 ± 16.3	97.2 ± 26.7	0.29	0.33	0.39
SVI (cc/m^2)	45.3 ± 8.4	36.9 ± 8.2	0.56	0.25	54.4 ± 8.6	50.0 ± 15.8	0.29	0.35	1.04

d, within-group effect size; d_b, between-group effect size; LV-GLS, left ventricular global longitudinal strain; LV-GSR, left ventricular global longitudinal systolic strain rate; LV mass, left ventricular mass; LVMI, left ventricular mass index; LVEF, left ventricular ejection fraction; RV-GLS, right ventricular global longitudinal strain; RV-GSR, right ventricular global longitudinal systolic strain rate; SV, left ventricular stroke volume; SVI, left ventricular stroke volume index.

Results

No baseline differences between both groups were noted with regard to age, ejection fraction, diastolic function and strain measurements as well as demographic characteristics as previously reported (*Table 1*).[3] High-intensity interval training resulted in significant improvements in RV-GLS (pre = −18.4 ± 3.2% vs. post = −21.4 ± 1.7%; P = 0.02; d = 0.95; *Table 2*). No significant between-group differences were noted for RV-GLS ($P > 0.2$) although moderate between-group effect sizes were noted (d_b = 0.60; *Table 2*). Moderate effect sizes were noted for between-group differences for improvements in RV-GSR (d_b = 0.51) and LV-GLS (d_b = 0.53). Trends for associations were noted between ΔVO_{2peak} and ΔLV-GLS (r = −0.48; P = 0.1) and ΔRV-GLS (r = −0.45, P = 0.1). Finally, ΔLV-GLS and ΔRV-GLS were strongly related (r = 0.68, P = 0.01). No significant improvements were observed in parameters regarding LV hypertrophy following either intervention although a trend for improvement of LV mass and LV mass index was noted (*Table 2*).

Conclusions

To our knowledge, this is the first study to examine the effects of HIIT on biventricular strain in HFpEF patients with impaired LV[12] and RV strain.[10] The principal novel finding of these secondary analyses was that RV-GLS improved after 4 weeks of HIIT. Importantly, none of the LV strain parameters worsened following one month of HIIT as has been previously described in healthy populations.[4,5] Alternatively, because we tested individuals 72–96 h following the last bout of exercise, it is possible that acute, adverse alterations were missed. However, it is important to note the persistence of the salutary strain phenotype beyond the acute post-exercise period. The time-course of biventricular strain-related changes during the initial 72 h after a single bout of high-intensity exercise remains unknown. The lack of improvement in LV strain parameters is consistent with what has been reported following 12 weeks of HIIT in patients with heart failure and reduced ejection fraction.[6]

Further, none of the strain parameters improved following 4 weeks of MI-ACT. Right ventricular average global peak systolic longitudinal strain is a sensitive marker of RV dysfunction and is correlated with postoperative mortality in patients with normal ejection fraction[13] as well as with pulmonary vascular resistance.[14] It is plausible that exercise-induced improvements in RV-GLS may have salutary effects on cardiovascular risk. However, long-term clinical outcomes following exercise-based interventions remain unknown. Although no significant between-group differences were noted, these are likely due to the small sample size as the study was underpowered to detect these differences. However, between-group effect sizes were in the moderate range and may provide guidance to researchers exploring changes in LV and RV strain parameters after short-term exercise training in patients with HFpEF. Changes in RV-GLS and LV-GLS were strongly correlated to each other, and both were modestly correlated with changes in VO_{2peak}, which is an established predictor of morbidity and mortality in patients with HFpEF.[15] These relationships have been previously reported in larger cross-sectional cohorts, and the magnitude of the association appears to be similar in this training study with a trend towards significance.[15]

In summation, we found significant improvements in RV global longitudinal strain following just 4 weeks of HIIT in individuals with HFpEF. Furthermore, exercise training-induced changes to LV and RV mechanics were positively correlated with improvements in VO_{2peak}. The long-term implications of these data with regard to hard clinical end-points in individuals with HFpEF remain to be explored.

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This study has Clinical Trials Registration NCT02147613.

Conflict of interest

None declared.

Author contributions

S.S.A., F.M., M.S., and G.A.G. made a substantial contribution to research design and the acquisition of data; S.S.A., M.S., and C.L.J. analysed the data; S.S.A, G.A.G., F.M., and C.L.J., drafted the paper; S.S.A., C.L.J., F.M., and G.A.G. revised it critically; and all authors have approved the submitted and final version.

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