

# 2-DIMENSIONAL STRAIN ANALYSIS OF REGIONAL CHANGE IN RIGHT VENTRICULAR FUNCTION AFTER TREADMILL EXERCISE

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**BACKGROUND:** Function of right ventricle (RV) influences on symptoms and prognosis in various diseases. However the regional RV function analyzed with 2-dimensional (2D) strain echocardiography before and just after treadmill test has not been evaluated. The aim of this study was to show the change of regional RV function just after treadmill exercise with strain analysis.

**METHODS:** A total of thirty eight patients who visited hospital for hypertension, chest pain or dyspnea between January 2007 and December 2010 were retrospectively analyzed (men, 47.4%; mean age, 54.9 ± 7.2 years). Treadmill exercise test and pre and post echocardiography were performed. 2D strain echocardiography was analyzed off line in RV free wall and septum.

**RESULTS:** Mean exercise duration was 737 ± 132 sec. Tissue velocity in lateral tricuspid annulus is significantly increased in post exercise (initial, 10.5 ± 2.4 cm/sec vs. post exercise, 12.2 ± 1.8 cm/sec,  $p = 0.006$ ). Systolic strain of RV free wall apex and mid portion were significantly changed in post exercise stage (free wall apex, -18.2 ± 7.6% vs. -22.3 ± 5.8%,  $p = 0.010$ ; free wall mid, -14.1 ± 6.7% vs. -22.6 ± 6.8%,  $p = 0.022$ ).

**CONCLUSION:** 2D strain imaging provides a precise tool to quantify regional RV function and reveals a characteristic regional pattern of RV after treadmill exercise.

**KEY WORDS:** Exercise test · Right ventricular function · 2-dimensional strain echocardiography.

## INTRODUCTION

Right ventricular (RV) function is an important determinant of clinical status and prognosis of patients with various conditions, including pulmonary hypertension.<sup>1-3)</sup> There are many studies showing the functional analysis of RV and some of them revealed regional analysis of RV using strain analysis in patients undergoing long term exercise.<sup>4-6)</sup> However, little study is known to analyze RV function with 2-dimensional (2D) strain echocardiography before and just after treadmill test. Treadmill exercise is very similar with usual and non-specific activity most people can easily experience and we tried to evaluate importance of an acute cardiovascular adjustment of RV function to meet these needs which requires an integrated neural and hormonal responses that increase heart rate and stroke volume of RV. Some researches showed the change of echocardiography just after exercise.<sup>7,8)</sup> The aim of this study is

to show the change of regional RV function just after treadmill exercise with strain analysis.

## METHODS

### PATIENTS POPULATION

Data from 38 consecutive patients who visited hospital for hypertension, chest pain or dyspnea between January 2007 and December 2010 were retrospectively analyzed. Patients with heart failure, coronary artery occlusive disease, pulmonary thromboembolism, pulmonary hypertension of any cause, renal disorder or liver disease were excluded.

### TREADMILL EXERCISE TEST

Symptom-limited graded treadmill exercise testing was performed with a standard Bruce protocol in a fasting state, and a

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post-treatment treadmill exercise test was repeated at the same time of day as the baseline test.<sup>9)</sup> A 12-lead electrocardiogram was recorded at rest and 1-minute intervals until onset of limiting chest pain, leg fatigue or  $\geq 0.2$ -mV ST-segment depression. Blood pressure was measured with a sphygmomanometer during each minute of exercise and recovery. Time to 0.1-mV ST-segment depression was defined as the elapsed time from initiation of exercise to the occurrence of horizontal or down-sloping 0.1-mV ST-segment depression measured at 80 ms after the J point. In this study, heart rate and systolic blood pressure at onset of 0.1-mV ST-segment depression were measured to determine the ischemic threshold. All exercise tests and ST-segment evaluations were performed by investigators blinded to results of coronary angiograms and treatment status.

**ECHOCARDIOGRAPHIC DATA**

Transthoracic echocardiography was performed at baseline and just after exercise test (within 2–3 minutes). With the subject in the left lateral position, transthoracic examinations were conducted according to current guidelines.<sup>10-12)</sup> Echocardiographic studies were performed in all subjects and all recordings were stored digitally and analyzed offline. Measurements of left ventricular (LV) function included: LV outflow tract velocity time integral, LV end diastolic dimension, LV volume (diastolic and systolic), ejection fraction. Measurements of diastolic function, tricuspid regurgitation (TR), RV outflow tract velocity time integral (RVOT VTI), tissue Doppler peak systolic velocity of tissue Doppler imaging at the tricuspid annulus (S') velocity were performed.

Pulmonary vascular resistance (PVR) was calculated as per Abbas et al.<sup>13)</sup>

$$PVR \text{ (wood units)} = 10 \times (\text{TR velocity} / \text{RVOT VTI})$$

To estimate systolic function of RV, RV tissue Doppler imaging (S') was measured in RV free wall. The 6 × 6 mm sample volume was placed directly underneath the mitral or tricuspid annulus in the basal myocardium in an apical four-chamber view.

**TWO-DIMENSIONAL SPECKLE-TRACKING ECHOCARDIOGRAPHY**

Dynamic 2D ultrasound images of three cardiac cycles from apical two-, three-, and four chamber views were acquired using conventional ultrasound, with a frame rate of 57 to 72 frames per second. To measure strain and strain rate, the image analysis was performed offline using customized software within the EchoPAC work station (EchoPAC, GE Vingmed Ultrasound, Milwaukee, WI, USA). The endocardial boundary of the LV was delineated manually, after which the software automatically drew the epicardial boundary. The widths of the regions of interest were adjusted manually to match the actual endocardial and epicardial boundaries. Automatic frame by frame tracking of speckle patterns during the cardiac cycle yielded a measure of strain and strain rate at any part of the

myocardium. On 2D global longitudinal strain analysis, echocardiographic machine with a 3.5-MHz transducer and high frame rate (50 or more Hz) was used to image the RV in apical views. 2D global longitudinal strain of whole RV (6 segments) and RV free wall only not including inter-ventricular septum (3 segments), were calculated using the EchoPAC. The longitudinal strain and strain rate of the basal, middle, and apical portions of RV free wall and septum were obtained in apical four-chamber view. By averaging these segmental values, RV peak systolic longitudinal velocity, strain and strain rate were calculated. The peak systolic longitudinal strain and strain rate represent ventricular longitudinal systolic function.

**Table 1.** Baseline characteristics of echocardiographic data

Baseline characteristics	Mean ± SD (n = 38)
Age (years)	54.9 ± 7.2
Sex (male)	18 (47.4%)
Hypertension	18 (47.4%)
Diabetes mellitus	9 (23.7%)
Weight (kg)	69.4 ± 16.5
Height (cm)	163.5 ± 12.1
BSA (m <sup>2</sup> )	1.7 ± 0.2
Mean exercise duration (sec)	737.0 ± 132.2
SBP (mm Hg)	126.8 ± 23.6
DBP (mm Hg)	64.3 ± 11.9
HR (/min)	74.8 ± 19.7
LVEDD (mm)	51.3 ± 6.8
LVESD (mm)	32.3 ± 6.4
EF (%)	65.0 ± 8.0
LAVI (mL/m <sup>2</sup> )	32.0 ± 12.9
LVOT VTI (cm)	22.1 ± 5.6
SV (mL)	75.1 ± 28.9
CO (L/min)	4.8 ± 2.1
TR peak velocity (m/sec)	2.6 ± 0.5
IVC diameter (mm)	1.5 ± 0.5
S' (cm/sec)	6.7 ± 4.9
E (m/sec)	0.7 ± 0.2
A (m/sec)	0.6 ± 0.2
e' (m/sec)	0.07 ± 0.35
a' (m/sec)	0.08 ± 0.14
E/e'	11.4 ± 4.4
RVOT VTI (cm)	17.3 ± 3.8
PVR (wood unit)	1.7 ± 0.7

Data are presented as mean ± SD or number of patients (%). BSA: body surface area, SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, LVEDD: left ventricular end diastolic dimension, LVESD: left ventricular end systolic dimension, EF: ejection fraction, LAVI: left atrial volume index, LVOT VTI: left ventricular outflow tract velocity time integrals, SV: stroke volume, CO: cardiac output, TR: tricuspid regurgitation, IVC: inferior vena cava, S': peak systolic velocity of tissue Doppler imaging at the tricuspid annulus, E: early diastolic flow velocity, A: late diastolic flow velocity, e': early diastolic annular velocity, a': late diastolic annular velocity, RVOT: right ventricular outflow tract, PVR: pulmonary vascular resistance

## STATISTICAL ANALYSIS

Categorical variables were expressed as numbers and percentages. Continuous variables were analyzed using one sample *t* tests and are expressed as mean  $\pm$  SD. Paired *t* test was used to compare between strain echocardiographic data of pre- and post exercise. All analyses were performed using SPSS version 20.0 (IBM, Armonk, NY, USA). *p* values < 0.05 were considered statistically significant, and all *p* values are two sided.

**Table 2.** General echocardiographic change after exercise

Index	Baseline mean $\pm$ SD	After exercise mean $\pm$ SD	<i>p</i> -value
SBP (mm Hg)	120.3 $\pm$ 21.7	149.9 $\pm$ 82.1	0.921
DBP (mm Hg)	65.7 $\pm$ 11.5	78.3 $\pm$ 9.2	0.655
HR (/min)	72.1 $\pm$ 16.8	92.7 $\pm$ 32.4	0.198
LVEDD (mm)	51.5 $\pm$ 6.6	50.8 $\pm$ 11.2	0.622
LVESD (mm)	33.3 $\pm$ 7.4	31.1 $\pm$ 7.2	0.391
EF (%)	65.0 $\pm$ 7.9	72.1 $\pm$ 12.5	0.284
LAVI (mL/m <sup>2</sup> )	32.5 $\pm$ 12.2	29.1 $\pm$ 6.6	0.795
LVOT VTI (cm)	22.9 $\pm$ 3.3	21.4 $\pm$ 11.2	0.615
SV (mL)	76.1 $\pm$ 24.2	73.4 $\pm$ 33.1	0.477
CO (L/min)	4.8 $\pm$ 1.7	4.5 $\pm$ 1.9	0.185
TR peak velocity (m/sec)	2.3 $\pm$ 1.1	2.9 $\pm$ 1.4	0.081
S' (cm/sec)	7.5 $\pm$ 2.4	12.2 $\pm$ 1.8	0.006*
E (m/sec)	0.7 $\pm$ 0.1	0.6 $\pm$ 0.1	0.647
A (m/sec)	0.5 $\pm$ 0.1	0.6 $\pm$ 0.3	0.800
e' (m/sec)	0.06 $\pm$ 0.41	0.04 $\pm$ 0.24	0.195
a' (m/sec)	0.07 $\pm$ 0.22	0.08 $\pm$ 0.19	0.058
E/e'	10.8 $\pm$ 1.2	13.4 $\pm$ 5.1	0.102
RVOT VTI (cm)	14.3 $\pm$ 2.4	12.1 $\pm$ 9.8	0.252
PVR (wood unit)	1.6 $\pm$ 0.9	1.8 $\pm$ 0.6	0.786

Data are presented as mean  $\pm$  SD or number of patients (%). \**p* < 0.05. SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, LVEDD: left ventricular end diastolic dimension, LVESD: left ventricular end systolic dimension, EF: ejection fraction, LAVI: left atrial volume index, LVOT VTI: left ventricular outflow tract velocity time integrals, SV: stroke volume, CO: cardiac output, TR: tricuspid regurgitation, S': peak systolic velocity of tissue Doppler imaging at the tricuspid annulus, E: early diastolic flow velocity, A: late diastolic flow velocity, e': early diastolic annular velocity, a': late diastolic annular velocity, RVOT: right ventricular outflow tract, PVR: pulmonary vascular resistance

**Table 3.** Baseline systolic strain data of right ventricle (n = 38)

Index	Base	Mid	Apex
Regional velocity (cm/sec)			
Septum	5.6 $\pm$ 1.4	4.1 $\pm$ 1.1	2.3 $\pm$ 0.8
Free wall	7.5 $\pm$ 2.9	5.5 $\pm$ 1.5	3.4 $\pm$ 1.4
Regional strain (%)			
Septum	-21.1 $\pm$ 5.9	-21.0 $\pm$ 5.8	-17.9 $\pm$ 6.8
Free wall	-24.9 $\pm$ 9.2	-22.2 $\pm$ 9.9	-18.2 $\pm$ 7.6
Regional strain rate (1/s)			
Septum	-1.4 $\pm$ 0.5	-1.4 $\pm$ 0.4	-1.4 $\pm$ 0.5
Free wall	-2.2 $\pm$ 0.7	-1.6 $\pm$ 0.6	-1.5 $\pm$ 0.5

Data are presented as mean  $\pm$  SD

## RESULTS

### BASELINE DEMOGRAPHIC AND ECHOCARDIOGRAPHIC DATA

A total of 38 patients were studied. Mean age was 54.9  $\pm$  7.2 years and male was 18 (47.4%). Patients showed good exercise tolerance (exercise duration, 737.0  $\pm$  132.2 sec) and preserved systolic ejection fraction (65.0  $\pm$  8.0%). Systolic blood pressure was 126.8  $\pm$  23.6 mm Hg and diastolic blood pressure was 64.3  $\pm$  11.9 mm Hg with mean heart rate was 74.8  $\pm$  19.7/min. Left atrial volume index was 32.0  $\pm$  12.9 mL/m<sup>2</sup> and TR peak velocity was 2.6  $\pm$  0.5 m/sec. early diastolic flow velocity/early diastolic annular velocity was 11.4  $\pm$  4.4 and S' velocity was 6.7  $\pm$  4.9 cm/sec (Table 1).

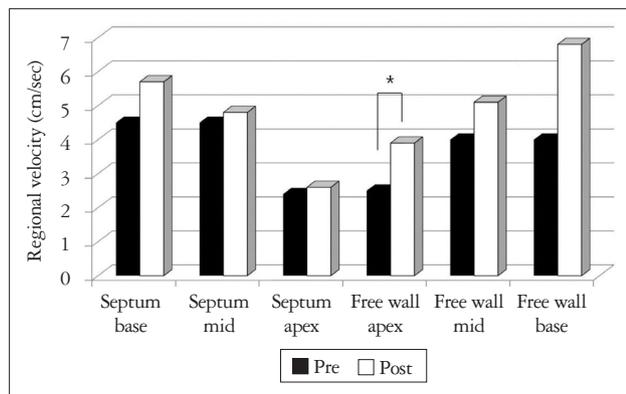
### CHANGE OF ECHOCARDIOGRAPHIC INDEX AND STRAIN DATA OF PRE AND POST EXERCISE (N = 38)

There was no significant change of ejection fraction or chamber size except for RV tissue Doppler imaging (S'). S' velocity of tricuspid annulus was significantly increased after exercise (pre vs. post, 7.5  $\pm$  2.4 cm/sec vs. 12.2  $\pm$  1.8 cm/sec, *p* = 0.006) (Ta-

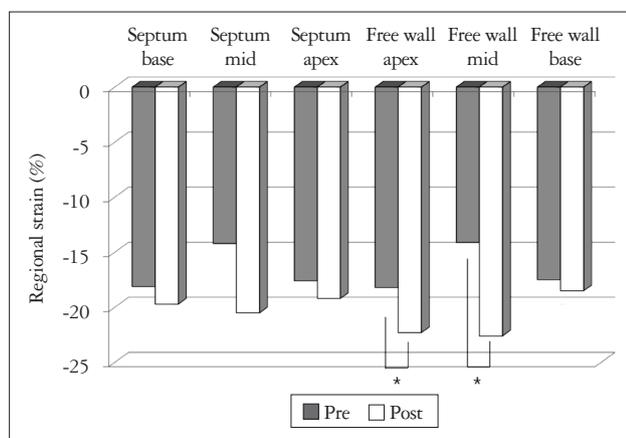
**Table 4.** Echocardiographic change of systolic right ventricular strain data after exercise

	Baseline	Follow-up	<i>p</i> -value
Regional velocity (cm/sec)			
Septum			
Base	4.5 $\pm$ 1.2	5.7 $\pm$ 2.0	0.312
Mid	4.5 $\pm$ 1.2	4.8 $\pm$ 1.8	0.637
Apex	2.4 $\pm$ 1.1	2.6 $\pm$ 0.8	0.818
Lateral			
Base	4.0 $\pm$ 2.0	6.8 $\pm$ 1.8	0.058
Mid	4.0 $\pm$ 1.2	5.1 $\pm$ 2.5	0.307
Apex	2.5 $\pm$ 0.9	3.9 $\pm$ 1.4	0.038*
Regional strain (%)			
Septum			
Base	-18.1 $\pm$ 3.1	-19.7 $\pm$ 5.9	0.976
Mid	-14.2 $\pm$ 3.7	-20.5 $\pm$ 7.8	0.321
Apex	-17.6 $\pm$ 4.8	-19.2 $\pm$ 9.0	0.688
Lateral			
Base	-17.5 $\pm$ 5.5	-18.5 $\pm$ 7.6	0.795
Mid	-14.1 $\pm$ 6.7	-22.6 $\pm$ 6.8	0.022*
Apex	-18.2 $\pm$ 7.6	-22.3 $\pm$ 5.8	0.010*
Regional strain rate (1/s)			
Septum			
Base	-1.3 $\pm$ 0.5	-1.6 $\pm$ 0.6	0.154
Mid	-1.1 $\pm$ 0.4	-1.2 $\pm$ 0.6	0.699
Apex	-1.1 $\pm$ 0.4	-1.2 $\pm$ 0.6	0.778
Lateral			
Base	-2.0 $\pm$ 0.7	-2.6 $\pm$ 0.5	0.095
Mid	-1.3 $\pm$ 0.5	-1.4 $\pm$ 0.4	0.782
Apex	-1.2 $\pm$ 0.8	-1.7 $\pm$ 0.5	0.290

Data are presented as mean  $\pm$  SD. \**p* < 0.05



**Fig. 1.** Systolic regional velocity of right ventricle after exercise. There is significant change of systolic velocity at right ventricular free wall apex after exercise. \* $p < 0.05$ .

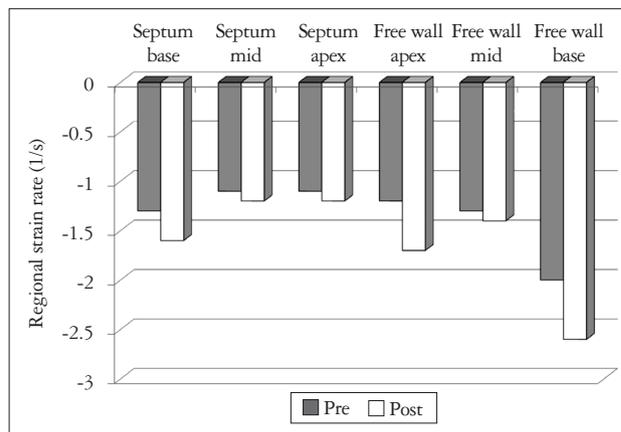


**Fig. 2.** Systolic regional strain of right ventricular after exercise. There is significant change of systolic strain at right ventricular free wall apex and mid portion after exercise. \* $p < 0.05$ .

ble 2). There was increasing tendency of absolute values in systolic velocity, strain and strain rate of RV base level (Table 3). In follow-up data, there was significant change of systolic velocity at lateral apex of RV after exercise (pre vs. post,  $2.5 \pm 0.9$  cm/sec vs.  $3.9 \pm 1.4$  cm/sec,  $p = 0.038$ ) and significant change of systolic strain at mid portion of lateral wall (pre vs. post,  $-14.1 \pm 6.7\%$  vs.  $-22.6 \pm 6.8\%$ ,  $p = 0.022$ ) and lateral apex (pre vs. post,  $-18.2 \pm 7.6\%$  vs.  $-22.3 \pm 5.8\%$ ,  $p = 0.010$ ) after exercise. There was no significant change of systolic regional strain rate of RV after exercise (Table 4, Fig. 1, 2, and 3).

## DISCUSSION

The anatomy and complex geometry of the RV confer significant limitations to 2D echocardiography.<sup>14,15</sup> Current studies use many novel technique including 3-dimensional or strain to analyze RV systolic function.<sup>16-19</sup> Speckle tracking echocardiography is a highly sensitive technique used to detect subtle myocardial dysfunction of systolic abnormalities.<sup>20-22</sup> Many studies revealed regional analysis of RV using strain analysis in patients undergoing long term exercise.<sup>4-6,23</sup> Anjak et al.<sup>23</sup> demonstrated that tricuspid annular plane systolic excursion (TAPSE) and tricuspid annular systolic velocity are reliable



**Fig. 3.** Systolic regional strain rate of right ventricle after exercise. There is no significant change of systolic strain rate of right ventricle after exercise.

and accurate measures of the RV response to exercise during a supine bicycle stress echocardiography protocol. In that study, authors showed activated RV contraction during exercise through significantly increased TAPSE, tissue Doppler image velocity and peak RV strain compared with baseline ( $-34 \pm 5\%$  vs.  $-40 \pm 5\%$ , baseline vs. 75 W). However, there is little study to show the regional analysis of RV with strain imaging before and just after treadmill exercise. Here we analyzed the systolic RV function with strain both pre and post exercise in non-coronary artery disease population. In this study, there was significant change of systolic velocity and strain at lateral apex and mid portion of RV after treadmill exercise. More significant activation was noted in RV free wall apex and mid portion via strain analysis. S' velocity of tricuspid annulus was significantly increased after exercise.

The dynamic movement of RV has some different characteristics from LV. Compared with free wall, septal movement of RV is extremely dependent on LV movement, so septal wall motion is much more limited than the free wall of RV. The change of strain data at basal level of free wall between pre and post exercise is not significant. The absolute value of velocity and strain data of basal free wall is already larger even before exercise rather than mid or apex. For this reason, the difference between pre and post exercise may be relatively small.

Lord et al.<sup>24</sup> revealed a similar study for RV function analysis within 30 minutes after ultra-endurance exercise, but it was performed to see the impact of ultra-marathon running on RV structure and function in highly trained runners. The subjects and type of exercise was difference from those of current study. In addition, it used mean global strain data other than regional analysis. La Gerche et al.<sup>3</sup> showed a similar data for strain analysis immediate after endurance race (3-11 hours duration), the subjects were not a normal group but endurance athletes and the data was mean global strain data. In another report,<sup>25</sup> improvement of RV strain was noted after chronic exercise training of 8 weeks, however we tried to evaluate regional RV function just after treadmill exercise.

The present study had some limitations. First, the number of patients enrolled was small, and our results should be confirmed in a larger population. Second, we excluded patients in whom suitable views could not be obtained even by shifting or moving the echo probe from the standard 4 chamber view position. Furthermore, the feasibility of 2D strain analysis software applied to RV has remained unclear, although this software has been applied to RV in several clinical studies. Finally, the present study does not include long-term follow-up data.

## CONCLUSION

2D strain imaging provides a precise tool to quantify regional RV function and reveals a characteristic regional pattern of RV after treadmill exercise. Our study demonstrates for the first time the regional change of RV just after treadmill exercise.

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