The effect of incremental endurance exercise training on left ventricular mechanics: a prospective observational deformation imaging study

Artan dayanıklılık egzersiz eğitiminin sol ventrikül mekanikleri üzerine etkisi: İleriye-dönük gözlemsel bir deformasyon görüntüleme çalışması

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Abstract

Objective: Exercise training has been known to cause structural and functional alterations in the heart called athletes heart. We aimed to investigate the effects of incremental endurance exercise training (IEET) on the left ventricular (LV) mechanics in healthy subjects.

Methods: This prospective observational study included 34 healthy young men who participated in competitive sports. The participants were subjected to a six-month IEET program. The LV mechanics measured using two-dimensional speckle tracking echocardiography was recorded while the participants were in an inactive state before and at the end of the six months. To compare continuous variables before and after IEET, Wilcoxon or paired-t test were used.

Results: Baseline and post training echocardiographic measurements showed that there was no significant change in LV ejection fraction (%) (p=0.64) and there were an increase in end-systolic and end-diastolic diameters, posterior and septal wall thickness, relative wall thickness and LV mass index (p<0.05, for all). LV mechanical parameters such as global strain (S) (19.8±1.33% vs. 20.4±1.26%, p=0.001), apical four -chamber S (19.4±1.96% vs. 20.1±1.86%, p=0.01), apical two- chamber S (19.9±1.75% vs. 20.7±1.75%, p=0.003), apical (23.0±3.1% vs. 23.6±3.2%, p=0.03), and basal circumferential S (21.1±2.2 % vs. 21.6±2.5%, p=0.03), and apical rotation (degree) (7.9±0.95 vs. 8.4±0.74, p=0.001) values were significantly increased by IEET.

Conclusion: We demonstrated that IEET has led to exercise related cardiac structural and functional changes such as LV dilatation and LV hypertrophy, accompanied by a significant increase in LV systolic S and LV twist measurements. *(Anadolu Kardiyol Derg 2013; 13: 432-8)*

Key words: Athletes heart, exercise training, left ventricular mechanics

Özet

Amaç: Egzersiz eğitiminin kalpte atlet kalbi olarakta bilinen yapısal ve fonksiyonel değişikliklere neden olduğu bilinmektedir. Biz bu çalışmada, sağlıklı bireylerde artan dayanıklılık egzersiz eğitiminin (ADEE) sol ventrikül (SV) mekanikleri üzerine olan etkisini araştırmayı amaçladık.

Yöntemler: İleriye-dönük gözlemsel bu çalışmaya spor yarışmalarına katılan 34 sağlıklı genç erkek alındı. Katılımcılar altı ay boyunca ADEE programına alındı. SV mekanikleri, iki boyutlu benek izleme ekokardiyografisi kullanılarak katılımcıların yarışma öncesi inaktif durumda ve altıncı ay kayıtlarından ölçüldü. Sayısal değişkenlerin ADEE öncesi ve sonrası ölçümlerinin karşılaştırılmasında Wilcoxon testi veya eşleştirilmiş t-testi kullanıldı.

Bulgular: Egzersiz öncesi ve sonrası ekokardiyografik ölçümler SV ejeksiyon fraksiyonunda (%) anlamlı bir değişiklik olmadığını (p=0,64), sistol sonu ve diyastol sonu çaplarda, septal ve posteriyor duvar kalınlıklarında, nispi duvar kalınlığı ve SV kitle indeksinde artış olduğunu gösterdi (p<0.05, hepsi için). SV mekanik belirteçlerinden global strain (S) (%19,8±1,33 ve %20,4±1,26, p=0,001), apikal dört boşluk S (%19,4±1,96 ve %20,1±1,86, p=0,01), apikal iki boşluk S (%19,9±1,75 ve %20,7±1,75, p=0,003), apikal (%23,0±3,1 ve %23,6±3,2, p=0,03) ve bazal sirkumferansiyel S (%21,1±2,2 ve %21,6±2,5, p=0,03) ve apikal rotasyon (derece) (7,9±0,95 ve 8,4±0,74, p=0,001) değerleri ADEE ile anlamlı olarak arttı.

The summary of this study was presented at the "7th International Congress of Update in Cardiology and Cardiovascular Surgery (UCCVS)" in association with "Transcatheter Cardiovascular Therapeutics (TCT) Mediterranean" in March 24-27, 2011, Antalya-Turkey.

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Sonuç: Biz bu çalışmada ADEE'nin SV dilatasyonu ve hipertrofisi gibi egzersiz ile ilişkili kardiyak yapısal ve fonksiyonel değişiklikler ile birlikte SV sistolik S ve SV burulma ölçümlerinde belirgin artışa neden olduğunu gösterdik. *(Anadolu Kardiyol Derg 2013; 13: 432-8)*
Anahtar kelimeler: Atlet kalbi, egzersiz eğitimi, sol ventrikül mekanikleri

Introduction

Long-term exercise training has been known to cause structural and functional alterations in the heart (1, 2). This condition is described as athlete's heart or exercise related myocardial remodeling, and it is characterized by increases in the chamber size, wall thickness and left ventricular (LV) mass. Few studies have been conducted on how this structural alteration occurring in athletes affects LV mechanics (3-6). In addition, most of the studies related to the effects of endurance training on cardiovascular functions in athletes are cross-sectional and only a few longitudinal studies involving the exercise related structural and functional alterations in the heart have been conducted (4, 5).

Systolic strain (S) is defined as the change of the myocardial fiber length during the cardiac cycle (7, 8). Strain echocardiography has been used in the quantitative assessment of LV contractile function in many cardiovascular diseases (9-12). Initially myocardial deformation was assessed by tissue Doppler imaging derived S. But the most important limitation of this technique is angle-dependent and deformation can only be assessed longitudinally (8, 13-15). Non-Doppler two-dimensional (2D) strain imaging derived from speckle tracking is a newer echocardiographic technic for obtaining strain and strain rate measurements. Speckle tracking derived 2D strain measurements have the advantage of angle independency but are sensitive to image quality (16-17).

For the early detection of myocardial dysfunction, 2D speckle tracking derived myocardial deformation imaging is recommended as a non-invasive diagnostic method for extensive clinical use. 2D strain echocardiographic assessment also appear to be useful in sports medicine for the quantification of LV systolic function in athletes involved in sports requiring endurance or strength and the differentiation of physiologic hypertrophy in athletes' hearts from asymptomatic nonobstructive hypertrophic cardiomyopathy, which is the major cause of sudden cardiac death in young competitive athletes (18). Besides, 2D strain imaging may help in the understanding of the structural changes related to the athletes' heart. A study by De Luca et al. (19) revealed that LV apical twist improved in young athletes after exercise training. However, Chan-Dewar et al. (20) found LV twist comparable.

Discordance results are common in the literature regarding this subject and these results may be explained by several factors, including study population, study design, athletic experience and strain measurements that might be affected by loading conditions.

Therefore, we aimed to investigate the effects of cardiac remodeling related to the incremental endurance exercise training (IEET) on the LV mechanics in healthy subjects. To accomplish this aim, we evaluated LV mechanics before and after IEET in healthy subjects by using 2D speckle tracking echocardiography, a novel method.

Methods

Study design

This study was designed as a prospective observational study.

Study protocol

The study population consisted of thirty-four healthy young men (ranging in age from 19 to 26 years) without any history of prior exercise exposure (exercise- naïve person). Each of the young men was affiliated with the department of athletics. All the participants completed a baseline clinical examination before the training, and the results of the physical examination, laboratory findings, electrocardiograms and chest X-rays were normal.

Written informed consent was obtained from all participants. The study protocol was approved by the institutional review board.

Exercise training

Exercise training in our study was defined as long distance running. The participants were subjected to a six-month IEET program. During the first month, the volume of the training was low; during the second month, the volume of the training was moderate, and during the last four months the volume of the training was high. Low- volume training consisted of 1 hour; moderate- volume training consisted of 2 hours, and high -volume training consisted of 4 hours of training in a day. Exercise intensity was assessed by using Borg`s RPE (rating of perceived exertion) scale. Accordingly, exercise intensity categories were identified as moderate (category scale 11-13), vigorous (category scale 14-16) and high (category scale ≥17). Exercise volume and intensities for all the participants were targeted to be matched and had been achieved during IEET. All participants completed the training period.

Echocardiography

The LV mechanics measured using speckle tracking echocardiography was recorded while the participants were in an inactive state before and at the end of the six months. All participants underwent a complete transthoracic echocardiography according to American Society of Echocardiography guidelines. Transthoracic echocardiographic studies were performed, with the patient in the left lateral position, using GE-Vivid 7 system (GE-Vingmed Ultrasound AS, Horten, Norway). Echocardiography was performed by cardiologists with high clinical expertise in echocardiography and unaware on the clinical data. All data was transferred to a workstation for further offline analysis (EchoPAC 6.1; GE Vingmed Ultrasound AS, Horten, Norway). After a standard comprehensive M-mode, 2D echocardiogram, and echocardiographic Doppler study were performed. The routine standard echocardiographic examination included measurements of thickness of the ventricular septum and posterior wall, and end-systolic and end-diastolic LV diameters from M-mode or 2D imaging. Ejection fraction (EF) was calculated by biplane Simpson's method from apical 4- and 2-chamber views. Left atrial volume measurement and standard pulsed-wave Doppler evaluation of diastolic function were carried out as previously described (21). Both LV mass and left atrial volume were indexed to body surface area. Mitral inflow was obtained by pulsed-wave Doppler echocardiography with the sample volume between mitral leaflet tips during diastole, and mitral annulus velocities were obtained from the septal and lateral annulus by tissue Doppler imaging. Average mitral annulus velocities were calculated by averaging of septal and lateral mitral annulus velocities. All measurements were performed from three cardiac cycles and then averaged.

Left ventricular mechanics by speckle tracking echocardiography

For deformation imaging analysis, standard grayscale 2D images were acquired in the four -chamber (4C), apical long axis (LAX), two -chamber (2C), parasternal short- axis at mitral basal and apical level views. From parasternal short -axis view, just proximal to the level with end-systolic LV apical luminal obliteration, LV apical short- axis view was visualized by angulation of the transducer. From this position, the position of the transducer was changed to one and two intercostal spaces more caudal with subsequent similar transducer adaptations and apical short- axis view was obtained. All of the images were recorded with a frame rate of between 50-90 frames/sec to allow for reliable operation of the software. A region of interest was traced on the endocardial cavity interface by a point-and-click approach from an end-systolic single frame. After that an automated tracking algorithm followed the endocardium from this single frame throughout the cardiac cycle. Further adjustment of the region of interest was performed to ensure that all of the myocardial regions were included. Next speckles, equally distributed in the region of interest, could be followed throughout the entire cardiac cycle. The time interval between the onset of the QRS on the electrocardiogram and the aortic valve opening and closure, and the time from the QRS wave to the mitral valve opening and closure were measured using pulsed-wave Doppler from the LV outflow and inflow, respectively. Strain measurements were reported as the peak longitudinal strain (LS) for 4C, LAX, 2C views and global longitudinal strain (GS) was calculated by averaging of three apical views. Peak longitudinal, radial and circumferential strains were measured in the parasternal short and long axis views. The averaged LV rotation and rotational velocity from 6 segments of each short-axis view were used for the calculation of LV twist (LVtw). Data points depicting the basal and apical LV rotation and rotational velocities were exported to a spreadsheet program (Excel, Microsoft Corp, Redmond, Washington, USA) to calculate LVtw. After procurements of LV rotation at the 2 short-axis levels, LVtw was calculated as the net difference between LV rotation angles obtained from basal (clockwise) and apical (counterclockwise) short axis planes at the same time point, that is, LVtw (degree)=(apical LV rotation-basal LV rotation). Counterclockwise rotation was expressed in a positive value and clockwise rotation in a negative value. All measurements and analysis were performed as previously described (22).

Measurement variability

The intra-observer and inter-observer variability for LV deformation parameters were assessed in all participants on recorded data. For intra-observer assessment the measurements were re-analyzed after two weeks. Intraclass correlation coefficients (ICC) for each measurement were used to quantify variability (An ICC <0.40 was rated as poor agreement and values >0.75 as excellent agreement). The degree of inter-observer and intra-observer agreement for LVtw, and LV strain measurements were perfect (All ICC values >0.75).

Statistical analysis

Statistical analyses were performed using SPSS (SPSS Inc. Chicago, IL, USA), version 15.0 for Windows. Variables are presented as mean±SD. The Kolmogorov-Smirnov test was used for normality test of continuous variables. To compare continuous variables, the paired t-test or the Wilcoxon matched pair test were used. A p value of <0.05 was considered significant.

Results

The mean age of the participants was 21.6±2.0 years and their baseline clinical and echocardiographic characteristics are summarized in Table 1. After IEET, the heart rate was significantly lower, whereas there was no significant difference in blood pressure. Baseline and post training measures of 2D and M mode echocardiographic parameters showed that while there was no significant change in EF (%) (p=0.64) and, there was an increase in end-systolic diameter, end-diastolic diameter, posterior and inter-ventricular septal wall thickness, relative wall thickness and LV-mass index (p<0.05, for all).

Left ventricular strain and twist parameters are summarized in Table 2. LV strain parameters such as GS (%), apical 4C (%) and 2C LS (%) were significantly increased by IEET (p<0.05, for all); however there was a statistically non-significant increase in LAX LS measurements (%) (p=0.16). Apical (%) and basal circumferential strains (%) were significantly increased after IEET (p=0.03, for both), however apical (%) and basal radial strains (%) were comparable before and after IEET (p=0.11 and p=0.31)

Table 1. Clinical and echocardiographic characteristics before and after incremental endurance exercise training

Variables	Before IEET	After IEET	*p
Age, years	21.6±2.0	N/A	-
Body surface area, m^2	1.91±0.14	1.88±0.13	<0.001
Body mass index, kg/m^2	24.7±2.3	24.1±2.1	<0.001
Heart rate, beat/min	68.4±9.1	64.1±8.7	0.001
Systolic blood pressure, mmHg	112±15	115±14	0.24
Diastolic blood pressure, mmHg	69±11	70±10	0.49
LV ejection fraction, %	66.9±4.0	67.2±3.6	0.64
LV end-diastolic diameter, cm	4.69±0.29	4.78±0.33	0.02
LV end-systolic diameter, cm	2.82±0.36	2.94±0.34	0.02
LV posterior wall thickness, cm	0.9 (0.8-1.0)	1.0 (0.9-1.0)	0.001
LV septal wall thickness, cm	0.92±0.11	1.0±0.10	0.001
LV relative wall thickness	0.39±0.04	0.41±0.03	0.002
LV mass index, g/m^2	77.3±16.6	89.1±15.8	0.001
Mitral annular Sm –average, cm/s	0.09 (0.08-0.11)	0.12 (0.11-0.14)	0.14

Data are shown as mean±standard deviation or median (interquartile range) and numbers/percentages
*Wilcoxon or paired t-test
IEET - incremental endurance exercise training, LV - left ventricle, N/A - not applicable, Sm - tissue Doppler imaging mitral annular systolic velocity

Table 2. Left ventricular strain and twist measurements before and after incremental endurance exercise training

Variables	Before IEET	After IEET	*p
Apical rotation, degree	7.9±0.95	8.4±0.74	0.001
Basal rotation, degree	4.3±1.34	4.4±2.0	0.74
LV twist, degree	12.3±1.65	12.8±1.47	0.039
Apical 4-chamber-LS, %	19.4±1.96	20.1±1.86	0.01
Apical long-axis-LS, %	20.2±1.30	20.5±1.17	0.16
Apical 2-chamber-LS, %	19.9±1.75	20.7±1.75	0.003
LV-global strain,%	19.8±1.33	20.4±1.26	0.001
Apical circumferential strain, %	23.0±3.1	23.6±3.2	0.03
Apical radial strain, %	40.0±7.1	41.5±7.6	0.11
Basal circumferential strain, %	21.1±2.2	21.6±2.5	0.03
Basal radial strain, %	40.8±6.2	39.7±7.6	0.31

Results are shown as mean±standard deviation and numbers/percentages
*Wilcoxon or paired t-test
IEET - incremental endurance exercise training, LS - longitudinal strain, LV - left ventricle

(Fig. 1). After the IEET study period, there was a significant increase in apical rotation (degree) ($p=0.001$); however there was no significant change in basal rotation (degree) ($p=0.74$). This translated into a significant increase in LVtw (degree) after IEET ($p=0.039$) (Fig. 2).

Discussion

Our longitudinal and prospective observational study results indicate that assessment of LV mechanics by speckle tracking echocardiography offers new insight into exercise related myocardial remodeling. This study showed that, despite the relatively well preserved EF, there were significant increases in the LV systolic strains and torsional mechanics during the exercise training period.

Left ventricular systolic functions and left ventricular strain

Several studies have evaluated the effect of endurance exercise training on LV systolic functions. In a meta-analysis that contains these studies, the data showed that there were no significant differences between sedentary controls and athletes with regard to LV-EF (23). However, in almost all of these studies LV systolic functions generally were assessed with ejection phase indexes such as the extent and velocity of fiber shortening, EF, and velocity of circumferential fiber shortening. These indexes are known to have some limitations in the assessment of LV systolic functions. For example, it was shown that intrinsic myocardial performance was impaired in hypertensive subjects, whose normal pump function was assessed by EF, because ejection phase indexes reflect chamber mechanics not myocardial mechanics (24). It is well known that EF is well preserved in athletes; however to conduct an assessment of intrinsic myocardial performance on the athlete's heart using invasive measures is not practical considering the risk it would pose for the athlete.

It has been shown in numerous studies that strain measurements by speckle tracking echocardiography is useful in subclinical detection of cardiac involvement in many systemic diseases (22, 24, 25). Recently, Baggish et al. (6) demonstrated, in a longitudinal study, that a 90 day period of endurance exercise training increased the LV strain without changing the LV-EF. The study by Mantziari et al. (3) also demonstrated similar results. Our findings are consistent with these studies showing that long term IEET increases the LV strain without changing the EF. In a case-control study, De Luca et al. (19) reported, using layer specific analysis, that epicardial strain was higher and endocardial strain was comparable in young cyclists in comparison with the control group. In contrast to this study, the present study, which featured longitudinal follow-up, did not include layer specific analysis. However, in some studies, the athletes' LV strain measurements were found to be similar to control groups (5, 26). The seemingly discordant results may be explained by several factors, including study population (subject number), study design (longitudinal or case-control), athletic experience and strain measurements that might be affected by loading conditions.

How endurance exercise training enhances the LV strain is not exactly known. Systolic strain is defined as the change of the myocardial fiber length during the cardiac cycle, and it is affected by after-load, pre-load and intrinsic contractility (27). The relationship between heart rate and strain is biphasic. Parallel

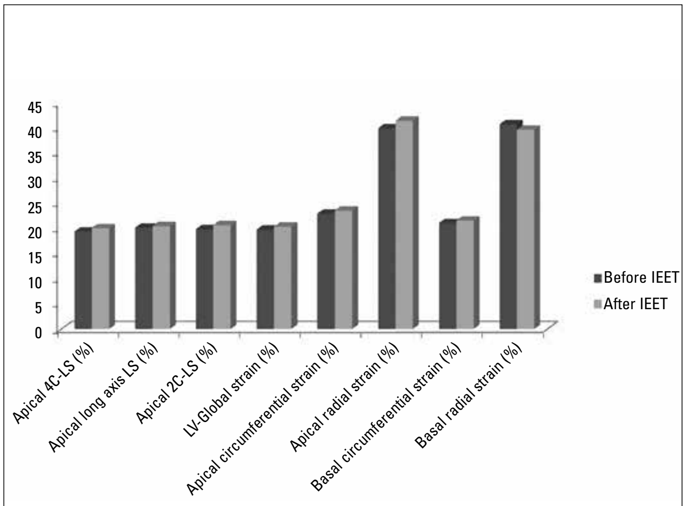

Figure 1. Left ventricular strain measurements before and after incremental endurance exercise training

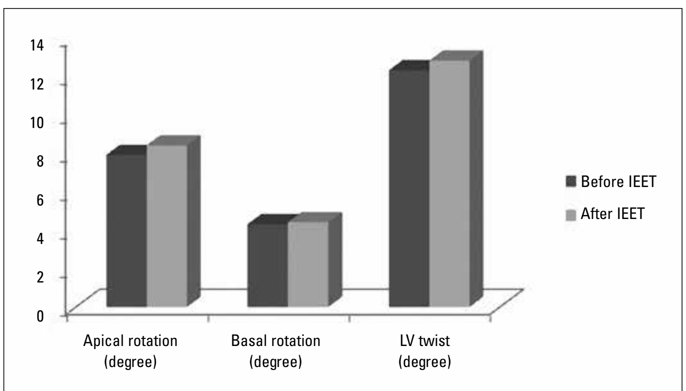

Figure 2. Left ventricular twist measurements before and after incremental endurance exercise training

increases in heart rate and strain are seen up to a certain value, but after the threshold, despite the increase in heart rate, the strain decreases (28). However, heart rates of the participants in our study were decreased therefore the possibility of a heart rate decrease induced by IEET for an increase of the LV strain is very low. There were no significant differences in systolic blood pressures between the baseline and post-training period. This lack of difference decreases the probability of after-load in the increase of the LV strain. The increased end-diastolic volume, and thereafter, the ventricular preload, augments LV systolic functions through the Frank-Starling mechanism. Increased contractility might be responsible for the increase in the strain; however this was not able to be shown by carrying out noninvasive procedures on the athletes' hearts. As a result, we hypothesized that the increased preload, as it related to the increased end-diastolic volume and contractility, was responsible for the increase in the LV systolic strain.

Left ventricular twisting

During LVtw, the base rotates in an overall clockwise direction and the apex rotates in a counterclockwise direction when viewed from apex to base. LV torsion is followed by rapid untwisting, which contributes to ventricular filling. Since LVtw is directly related to fiber orientation, it might indicate subclinical abnormalities in heart function (29).

In healthy subjects, short term exercise enhances the LV torsion increased heart rate, myocardial contractility and relaxation (30, 31). However, the effect of long term exercise on LV torsional mechanics is not exactly known. Case control studies showed that professional soccer players (32) and cyclist (5) have significantly lower LVtw compared to sedentary controls. Chan-Dewar et al. (20) reported no significant change in LV torsion in amateur male runners after they completed a marathon, whereas Nottin et al. (5) observed that LV torsion were decreased and delayed after completion of an "Ironman" distance triathlon. Weiner et al. (4) reported an increase in LV torsion after a 90 day period of exercise training when compared to before the training period. Similarly, we observed increases in LV torsion before and after a six months period of IEET. Our results showed that an increase in LVtw might represent an important component of the myocardial remodeling related to IEET.

In our study, the discovery that IEET leads to an increase in LVtw might appear to contradict some prior studies (5, 32). The lack of an athletic background of our study participants and the longitudinal study design might explain these results. Another important reason for the differences might be explained by the apical imaging position (33). The apical imaging position has not been defined exactly and that may predispose measurement variability.

Although the mechanism responsible for our findings is not known exactly, factors including LV geometry and loading condition deserve mention. Firstly, the increase in end-diastolic volume related to the myocardial remodeling enhances LV torsion (34). Secondly, IEET results in significant blood expansion (35) and it is well known that LV torsion is preload dependent (34). As a result, the increased end-diastolic volume and vascular volume might contribute to the enhanced LV torsion that accompanied IEET.

The present study shows a new horizon in cardiac remodeling related to the incremental endurance exercise training. Important differences in our study as compared to other studies include its non -case–control design, its longitudinal follow-up period, its homogenous participants (long-distance runners), its LV longitudinal and rotational parameters, its inclusion of participants who initially had no experience in exercise training and its relatively long follow-up periods. This study demonstrated that conventional systolic indexes, such as EF, are not changed in athletes through the use of exercise training. LV deformation was, however, significantly changed subclinically.

Study limitations

The study population consisted of young, healthy male subjects and as a consequence this might prevent the generalization of the results. In addition, the lack of objective data quantifying participants exercise capacity before and after the training prevents us from reaching a conclusion about the relationship between exercise capacity and LVtw and systolic strains. However, we used Borg's RPE scale to assess the exercise intensity which has been shown to be a valid measure of exercise intensity. As known more objective methods such as VO_{2max}, METs and HR_{max} are also present.

Conclusion

In conclusion, we demonstrated that incremental endurance exercise training has led to exercise related cardiac structural and functional changes such as LV dilatation and LV hypertrophy, accompanied by a significant increase in LV systolic strain and LV twist measurements. This might help us in understanding the physiology of athletes' hearts.

Conflict of interest: None declared.

Peer-review: External peer-review.

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