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Is there a relationship between increased aortic stiffness and segmental left ventricular deformation in elite athletes? (Insights from the MAGYAR-Sport Study)

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Introduction: Myocardial contractility of the left ventricle (LV) is related to arterial distensibility. Sport activity is frequently associated with changes in both LV and arterial functions. This study aimed to find correlations between three-dimensional speckle-tracking echocardiography-derived segmental LV deformation parameters and echocardiographically assessed aortic stiffness index (ASI) in athletes. This study comprised 26 young elite athletes (mean age: 26.7 ± 8.4 years, nine men). *Results:* Among segmental circumferential strains (CSs), only that of apical anterior ($r = 0.40$, $p = 0.05$), septal ($r = 0.47$, $p = 0.01$), inferior ($r = 0.59$, $p = 0.001$), lateral ($r = 0.44$, $p < 0.05$), and midventricular anteroseptal ($r = 0.44$, $p < 0.05$) segments correlated with ASI, whereas LV-CS of the midventricular anterior segment showed a correlation tendency. Only longitudinal strain of basal anteroseptal ($r = -0.46$, $p < 0.05$) and inferoseptal ($r = -0.57$, $p < 0.01$) segments showed correlations with ASI, whereas that of the basal anterior segment had only a tendency to correlate. Some segmental multidirectional strains also correlated with ASI. *Conclusions:* Correlations could be demonstrated between increased aortic stiffness and circular function of the apical and midventricular LV fibers and longitudinal motion of the basal septum and LV anterior wall (part of LV outflow tract) in maintaining circulation in the elite athletes.

Keywords: aortic, echocardiography, function, left ventricle, speckle-tracking, stiffness, strain, three-dimensional

Introduction

Myocardial contractility of the left ventricle (LV) is related to arterial stiffness due to arterial–ventricular coupling (5). LV strains are quantitative features of LV deformation, which could easily be determined by three-dimensional (3D) speckle-tracking echocardiography (3DSTE) (1, 11). Echocardiographic aortic elastic properties could be assessed simultaneously with LV strain measurements allowing us to find relationship between LV and aortic functions (8, 9). Due to the fact that sport activity is frequently associated with changes in both LV and arterial functions, the correlations were aimed to be found between 3DSTE-derived

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segmental LV strains and echocardiographically assessed aortic stiffness index (ASI) in the elite athletes in this study.

Materials and Methods

Study population

To achieve goals, 26 young elite basketball and water polo players, kettlebell lifters, and runners (mean age: 26.7 ± 8.4 years, nine men) were examined. The participants have been trained for an average of 15 ± 7 years. Complete two-dimensional (2D) Doppler echocardiography with assessment of aortic elastic properties and 3DSTE have been performed in all cases. All subjects were enrolled into the Motion Analysis of the heart and Great vessels bY three-dimensionAl speckle-tRacking echocardiography in Sportsmen (MAGYAR-Sport) Study among others with the aim of evaluating (patho) physiological consequences of elite sport activity on LV deformations and vascular features and their relationship ("magyar" means "Hungarian" in Hungarian language). Written informed consent was obtained from all the participants who were enrolled in the study. The study conformed to the principles outlined in the Declaration of Helsinki and was reviewed and approved by the local institutional ethics committee (number: 71/2011, University of Szeged, Hungary).

2D echocardiography with assessment of ASI

A standard 2D Doppler echocardiographic study with ASI measurement was carried out in all subjects with a commercially available echocardiography system (Toshiba Artida™, Toshiba Medical Systems, Tokyo, Japan) using a 1–5 MHz PST-30SBP phased-array transducer. LV internal dimensions and systolic (SD) and diastolic (DD) ascending aortic diameters 3 cm above the aortic valve were measured by M-mode echocardiography in parasternal long-axis view (8, 9) (Fig. 1). LV ejection fraction was calculated by the modified Simpson's method (9). Systolic (SBP) and diastolic (DBP) blood pressures were measured in the supine position with a mercury cuff sphygmomanometer from the right arm after 10 min of rest. For calculation of ASI, the following equation was used: $\mathrm{ASI} = \ln(\mathrm{SBP}/\mathrm{DBP})/[(\mathrm{SD} - \mathrm{DD})/\mathrm{DD}]$, where ln means natural logarithm (increased ASI means more pronounced aortic stiffness).

3DSTE

3DSTE imaging was performed from an apical position using the same commercial scanner (Toshiba Artida™, Toshiba Medical Systems, Tokyo, Japan) with a 1–4 MHz matrix-array PST-25SX transducer (11). Wide-angled acquisitions were recorded, in which six wedge-shaped subvolumes were acquired within a single breath hold. 3D Wall Motion Tracking software version 2.7 (Toshiba Medical Systems) was used for LV chamber quantifications. Shortly, different views (apical two- and four-chamber views and basal, midventricular, and apical LV short-axis views) were automatically selected from the acquired 3D pyramidal "echo-cloud" at end-diastole by the software. The examiner marked the endocardium at the edges of the mitral valve and at the apex on the apical two- and four-chamber views manually. Due to the software's capability, the LV endocardial surface was tracked and automatically reconstructed through the cardiac cycle. Time–strain curves were generated by the software for segmental radial strain (RS), longitudinal strain (LS), circumferential strain (CS), 3D strain (3DS), and area-tracking/strain (AS) estimations using the 16-segment LV model (Fig. 2).

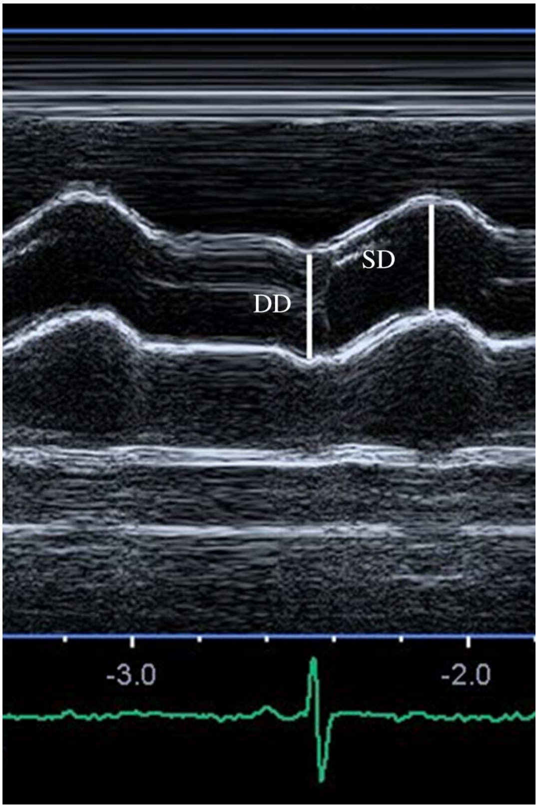


Fig. 1. Systolic and diastolic ascending aortic diameters were measured on the M-mode tracing obtained at a level of 3 cm above the aortic valve at parasternal echocardiographic long-axis view. SD: Systolic aortic diameter; DD: diastolic aortic diameter

The following definitions were used for strain parameters (1, 17):

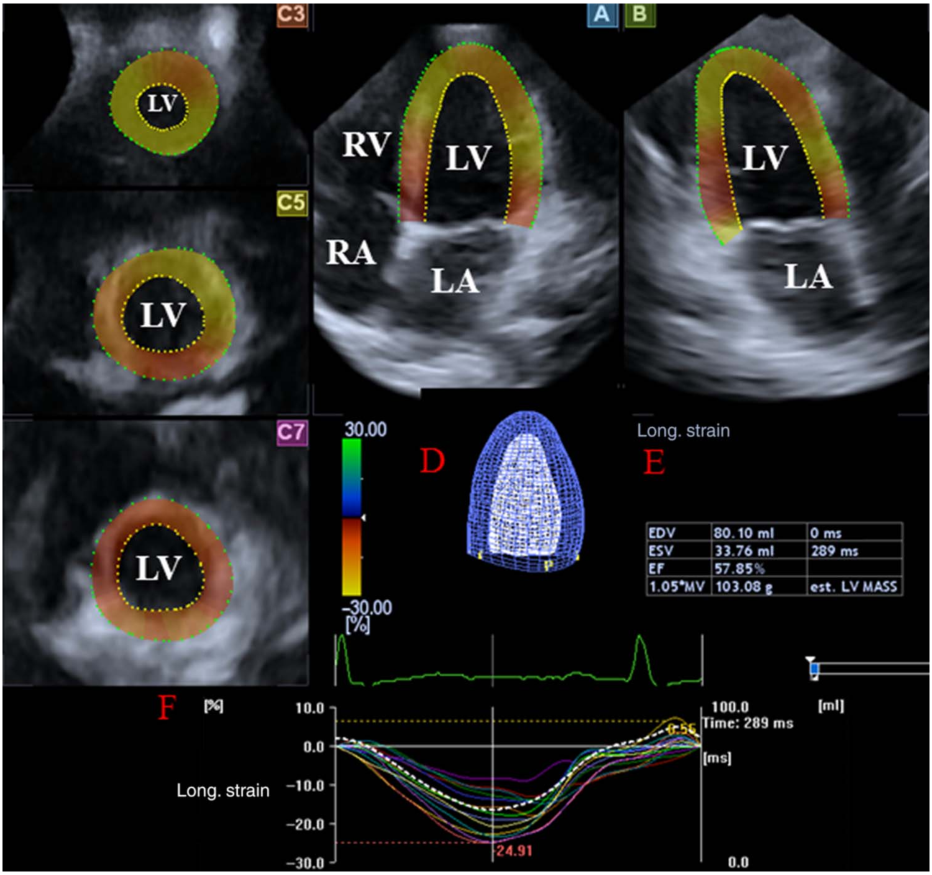
RS (%) – LV strain in the direction perpendicular to the endocardium. It is defined as changes in radial length between the endocardium and the epicardium in short-axis view.
LS (%) – LV strain in the direction parallel to the endocardial contour measuring in apical long-axis view featuring longitudinal movement.
CS (%) – LV strain in the direction circumferential to the endocardial contour. It is measured in short-axis view as the change in length along the myocardial circumference.
3DS (%) – LV strain in the wall (3D) thickening direction combining the aforementioned unidirectional strains
AS (%) – A square-shaped area is tracked and endocardial area change ratio is calculated as percentage change in area.

Statistical analysis

Data are presented as mean ± standard deviation. A value of $p < 0.05$ was considered to be statistically significant. Numerical correlations were established by Pearson's correlation. MedCalc software was used for statistical evaluations (MedCalc, Mariakerke, Belgium).

Results

Clinical, demographic, and 2D echocardiographic data of subjects are presented in Table I. 3DSTE data of subjects are presented in Table II.



EDV	80.10 ml	0 ms
ESV	33.76 ml	289 ms
EF	57.85%	
1.05*MV	103.08 g	est. LV MASS

Fig. 2. Different views of the LV extracted from the 3D echocardiographic data set are presented including apical four-chamber (A) and two-chamber views (B) and basal (C3), midventricular (C5), and apical (C7) short-axis views. A 3D LV model (D) and calculated volumetric LV parameters are also demonstrated (E) together with segmental LS curves (F) in an elite athlete. LV: left ventricle; RV: right ventricle; LA: left atrium; RA: right atrium; EDV: LV end-diastolic volume; ESV: LV end-systolic volume; EF: LV ejection fraction; est. LV MASS: estimated LV mass

Correlations

Regarding segmental LV-CSs, only that of all apical segments and midventricular anteroseptal segments correlated with ASI, whereas LV-CS of the midventricular anterior segment showed a correlation tendency (Table III). LS of basal anteroseptal and inferoseptal LV segments showed correlations, whereas that of the basal anterior segment had a correlation tendency with ASI (Table IV). None of the other segmental LV-LSs and LV-RSs showed correlations with ASI (Tables IV and V). From multidirectional strains, all apical LV-ASs (except anterior) (Table VI) and 3DS of the anterior midventricular LV segment showed correlations with ASI (Table VII).

Discussion

To the best of the authors' knowledge, this is the first study to demonstrate the segmental correlations between 3DSTE-derived uni- and multidirectional strains and echocardiographic

Table I. Clinical and demographic features and 2D echocardiographic data of sportsmen

Clinical and demographic data	
n	26
Male gender (%)	9 (35)
Mean age (years)	26.7 ± 8.4
SBP (mmHg)	116.4 ± 8.9
DBP (mmHg)	76.7 ± 6.2
Heart rate (bpm)	64.0 ± 6.8
Weight (kg)	69.1 ± 11.8
Height (cm)	173.5 ± 6.4
Body surface area (m^2)	1.88 ± 0.17
Body mass index (kg/m^2)	22.9 ± 2.9
2D echocardiography	
Left atrium (mm)	35.8 ± 4.3
LV end-diastolic diameter (mm)	47.8 ± 4.6
LV end-systolic diameter (mm)	28.2 ± 3.6
LV end-diastolic volume (ml)	108.1 ± 23.6
LV end-systolic volume (ml)	30.9 ± 9.5
Interventricular septum (mm)	8.87 ± 1.56
LV posterior wall (mm)	9.51 ± 1.89
LV ejection fraction (%)	71.9 ± 5.9
E/A	1.61 ± 0.46
LV mass (g)	154.2 ± 41.8
Systolic aortic diameter (mm)	26.5 ± 3.5
Diastolic aortic diameter (mm)	24.5 ± 3.1
ASI	8.89 ± 7.94

Table II. 3DSTE data of subjects

3DSTE	
LV end-diastolic volume (ml)	98.6 ± 21.3
LV end-systolic volume (ml)	37.7 ± 8.4
LV ejection fraction (%)	61.7 ± 2.2
LV mass (g)	141.2 ± 16.0

Table II. 3DSTE data of subjects *(Continued)*

3DSTE	
Global LV CS (%)	−31.0 ± 3.6
Mean segmental LV CS (%)	−31.7 ± 3.4
Global LV LS (%)	−16.7 ± 2.0
Mean segmental LV LS (%)	−17.6 ± 1.9
Global LV RS (%)	24.1 ± 10.2
Mean segmental LV RS (%)	25.8 ± 10.8
Global LV AS (%)	−43.5 ± 3.2
Mean segmental LV AS (%)	−44.2 ± 3.2
Global LV 3DS (%)	26.2 ± 11.0
Mean segmental LV 3DS (%)	28.8 ± 10.0

Table III. Correlations between ASI and segmental 3DSTE-derived CS parameters

	Anterior	**Anteroseptal**	**Inferoseptal**	**Inferior**	**Inferolateral**	**Anterolateral**
Basal (%)	−23.5 ± 7.5	−23.5 ± 7.5	−27.1 ± 10.6	−27.4 ± 10.0	−30.1 ± 9.4	−30.3 ± 10.2
r	0.08	0.26	0.02	−0.02	0.15	−0.22
Mid (%)	−30.9 ± 9.3	−31.7 ± 9.4	−33.9 ± 8.6	−31.5 ± 4.3	−32.5 ± 4.8	−35.8 ± 8.7
r	0.35****	0.44*	0.005	0.02	0.02	−0.08
	Anterior	**Septal**		**Inferior**	**Lateral**	
Apical (%)	−32.3 ± 11.1	−38.8 ± 10.3		−36.0 ± 10.4	−37.9 ± 10.7	
r	0.40*	0.47**		0.59***	0.44*	

*$p \le 0.05$.
**$p = 0.01$.
***$p = 0.001$.
****$p = 0.07$

features of aortic elasticity in the elite athletes. Correlations could be detected between ASI and LV apical CSs and ASs, midventricular antero (septal) CSs and 3DS and basal septal and anterior LSs of LV segments. The results of this study suggest that due to long-term physical effort, increased circulatory requirements and alterations in aortic stiffness in athletes, specific segmental LV functional adaptation could be detected. Increased aortic stiffness correlated with more pronounced circular shortening of specific apical and midventricular LV fibers and less pronounced longitudinal shortening of specific parts of the LV outflow tract (basal septum and anterior wall) in highly trained athletes.

ASI was found to be increased in the presented athlete population. However, the relationship between sport activity and aortic stiffness is controversial regarding the

Table IV. Correlations between ASI and segmental 3DSTE-derived LS parameters

	Anterior	**Anteroseptal**	**Inferoseptal**	**Inferior**	**Inferolateral**	**Anterolateral**
Basal (%)	−21.3 ± 7.1	−17.5 ± 7.9	−17.6 ± 7.0	−18.0 ± 5.8	−17.3 ± 6.6	−19.3 ± 5.6
r	−0.36***	−0.46*	−0.57**	−0.30	0.18	0.04
Mid (%)	−18.2 ± 6.5	−16.8 ± 5.3	−14.7 ± 3.8	−13.2 ± 3.9	−12.6 ± 3.7	−16.3 ± 4.2
r	−0.08	0.02	−0.10	0.005	−0.04	−0.21
	Anterior	**Septal**		**Inferior**	**Lateral**	
Apical (%)	−11.5 ± 6.6	−23.9 ± 6.2		−26.5 ± 6.2	−17.0 ± 5.1	
r	−0.009	0.24		0.22	0.009	

*$p < 0.05$.
**$p < 0.01$.
***$p = 0.07$

Table V. Correlations between ASI and segmental 3DSTE-derived RS parameters

	Anterior	**Anteroseptal**	**Inferoseptal**	**Inferior**	**Inferolateral**	**Anterolateral**
Basal (%)	25.7 ± 15.6	29.6 ± 20.0	28.7 ± 20.5	30.2 ± 24.0	27.9 ± 16.7	24.0 ± 14.8
r	0.17	0.22	0.08	−0.03	−0.27	−0.25
Mid (%)	31.3 ± 19.2	35.0 ± 16.2	31.2 ± 15.5	29.7 ± 25.5	28.3 ± 19.4	31.3 ± 13.9
r	0.30	0.26	0.18	0.21	0.15	−0.08
	Anterior	**Septal**		**Inferior**	**Lateral**	
Apical (%)	14.1 ± 7.5	14.9 ± 8.9		17.8 ± 10.8	18.2 ± 11.0	
r	−0.11	−0.21		0.003	−0.08	

Table VI. Correlations between ASI and segmental 3DSTE-derived AS parameters

	Anterior	**Anteroseptal**	**Inferoseptal**	**Inferior**	**Inferolateral**	**Anterolateral**
Basal (%)	−39.2 ± 8.3	−38.7 ± 7.8	−38.7 ± 10.3	−39.3 ± 9.6	−42.0 ± 10.6	−44.4 ± 10.5
r	−0.09	−0.19	−0.28	−0.28	0.11	−0.20
Mid (%)	−43.3 ± 11.3	−44.3 ± 10.9	−44.2 ± 8.4	−39.5 ± 6.3	−40.2 ± 5.8	−47.3 ± 8.1
r	0.20	0.27	−0.0004	−0.04	−0.10	−0.09
	Anterior	**Septal**		**Inferior**	**Lateral**	
Apical (%)	−42.1 ± 13.7	−56.7 ± 9.9		−54.5 ± 10.6	−53.1 ± 10.3	
r	0.26	0.52***		0.51***	0.47**	

**$p = 0.01$.
***$p < 0.001$

Table VII. Correlations between ASI and segmental 3DSTE-derived 3DS parameters

	Anterior	**Anteroseptal**	**Inferoseptal**	**Inferior**	**Inferolateral**	**Anterolateral**
Basal (%)	27.4 ± 16.8	32.2 ± 18.8	31.5 ± 20.8	34.9 ± 24.0	34.8 ± 16.9	26.7 ± 14.8
r	0.21	0.17	0.10	0.05	0.28	−0.21
Mid (%)	34.9 ± 19.5	35.1 ± 17.5	32.0 ± 13.3	32.6 ± 25.3	31.3 ± 20.6	32.7 ± 12.4
r	0.40*	0.29	0.23	0.20	0.12	−0.04
	Anterior	**Septal**		**Inferior**	**Lateral**	
Apical (%)	16.3 ± 7.6	15.6 ± 8.4		19.5 ± 11.0	19.3 ± 10.2	
r	−0.21	−0.19		0.04	−0.17	

*$p < 0.05$

literature. Rátgéber et al. (14) did not find significant differences in resting aortic pulse wave velocity (PWV) comparing data of young athletes and age-matched healthy volunteers. In a recent study, ASI was found to be significantly increased in strength-trained athletes (STA), but differences could not be detected between endurance-trained (ETA) and mixed-trained athletes as compared with controls (18). Similarly, aortic stiffness was significantly greater in STA, whereas aortic distensibility was higher in ETA compared with age- and sex-matched healthy controls (3). In male ultramarathon runners, Burr et al. (2) found that PWV decreased at 45 km followed by an increase toward baseline levels at the 75 km mark. This finding could indicate that exercise duration or accumulated stress may affect vascular compliance.

The effect of sport activity on LV function is also controversial. Neilan et al. (7) found that maximal intensity of short-duration exercise is associated with attenuation of LV diastolic function and augmentation of LV systolic function. Increased overall longitudinal myocardial contractility at rest was found in experienced endurance athletes compared with the published normal values in the literature, indicating a preserved and even supranormal contractility in the athletes (15). In contrast, STE analysis showed a different pattern of myocardial deformation demonstrating decreased global LS in runners and reduced GCS in bodybuilders with preserved global RS in another study (16). In a recent study, although female college athletes had mildly higher LV ejection fraction and LV global LS in absolute value, systolic strain rate and allometrically indexed stroke volume were not different between genders (4).

3DSTE is a new non-invasive imaging methodology with an ability for accurate chamber quantifications and deformation analysis (6, 11). Over LV volumetric measurements, several LV functional parameters including different uni- (RS, LS, and CS) and multidirectional (AS and 3DS) strain parameters could be calculated together with parameters of LV rotational mechanics using the same LV-3D model. At present, limited numbers of papers are available, in which relationships between 3DSTE-derived left heart deformation parameters and aortic elasticity are examined (12, 13). Correlations could be detected between echocardiographic aortic elastic properties and LV rotation and twist (10, 12) and left atrial functional features (13) in healthy subjects. This methodology could help in widening our knowledge in understanding arterial–ventricular coupling.

Limitations

There were a number of important limitations which could affect our results:

–Only a limited number of athletes were involved in the study. Moreover, sport activity showed heterogeneity (mixed population with ETA and STA athletes), which could theoretically affect the results. Moreover, gender differences in parameters were also not examined.

–It would have been interesting to compare findings with the results of age- and gender-matched non-athlete healthy controls as well.

–Low temporal and spatial resolutions of 3DSTE-derived images are known features, which could be considered as the most important technical limitation.

–Although 3DSTE is a valuable tool in assessing LV rotation and twist, this study did not aim to evaluate their relationship with ASI.

Conclusions

Correlations could be demonstrated between increased aortic stiffness and circular function of the apical and midventricular LV fibers and longitudinal motion of the basal septum and LV anterior wall (part of the LV outflow tract) in the elite athletes.

Conflict of interest

None declared.

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