Original Article

Left ventricular deformation in athletes playing sports with high dynamics—insights from the three-dimensional speckle-tracking echocardiographic MAGYAR-Sport Study

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Background: Earlier results suggest the role of speckle-tracking echocardiography (STE)-derived left ventricular (LV) strains in screening and could help better understanding of adaptation to exercise. The present retrospective cohort study aimed to investigate three-dimensional STE-derived LV strains representing its deformation in athletes playing sports with high dynamics with different grades of static components of their training.

Methods. The study consisted of 67 athletes (mean age: 23.6±6.4 years, 39 males). This group of athletes was further divided into the following groups: Group C.I. (high dynamic/low static) (n=12), Group C.II. (high dynamic/moderate static) (n=22) and Group C.III. (high dynamic/high static) (n=33). The control group comprised 83 age- and gender-matched non-athletic healthy volunteers (mean age: 23.6±3.2 years, 50 males).

Results: Global LV longitudinal strain (LS) representing LV lengthening or shortening (−18.5%±3.0% *vs.* −16.3%±2.3%, P<0.05), LV circumferential strain (CS) representing LV widening or narrowing (−29.9%±5.2% *vs.* −28.1%±4.8%, P<0.05) and LV area strain (AS; combination of LS and CS; −43.7%±5.4% *vs.* −40.9%±4.8%, P<0.05) were increased in elite athletes as compared to those of non-athlete controls. All apical LV strains proved to be increased in all athletes with enhanced basal radial strain (RS, representing LV thickening and thinning) and LS and midventricular LS, AS and 3D strain (3DS, combination of RS, LS and CS).

Conclusions: Increased LV-LS, LV-CS and LV-AS represents enhanced LV deformation in longitudinal and circumferential directions in athletes playing sports with high dynamics. This enhancement is not related to the grade of the static component of training. Some regional differences in LV strains could be detected.

Keywords: Echocardiography; left ventricle; speckle-tracking; sport; strain; three-dimensional

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Introduction

Physiologic remodeling due to repetitive overload induced by exercise training is a known feature in the athletes' heart including significant changes in left ventricular (LV) deformation mechanics (1-3). Although meta-analyses showed no differences in LV strain and twist mechanics between athletes and controls, detailed analyses revealed some changes in different directions in elite athletes with different type and level of training (3). Although two-dimensional (2D) speckle-tracking echocardiographic (STE) assessment of LV strains is an accepted and widely used echocardiographic method of evaluation of LV strains and is able to detect subclinical abnormalities (4), three-dimensional (3D) STE allows more detailed and realistic evaluation within a short time including volumetric, strain and rotational LV assessment at the same time (5-8). Results suggest the role of LV strains in screening and could help better understanding of adaptation to exercise, therefore the present study aimed to investigate 3DSTE-derived LV strains in elite athletes playing high dynamic sports with different grades of static components. We present the following article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-417/rc).

Methods

Classification of participants

The present retrospective cohort study was organized and data were collected at the 2nd Department of Medicine and Cardiology Center, University of Szeged since 2014. It is a part of the Motion Analysis of the heart and Great vessels bY three-dimensionAl speckle-tRacking echocardiography in Sportsmen (MAGYAR-Sport) Study, which purposed to investigate elite sport activity-related changes in myocardial mechanics by 3DSTE ('magyar' means 'Hungarian' in Hungarian language). The study conformed to the provisions of the Declaration of Helsinki (as revised in 2013) (9). The Institutional and Regional Human Biomedical Research Committee of University of Szeged (Hungary) approved the study (NO. 71/2011, prolonged 25/1/2021). Informed consent was given by all subjects. The athlete group comprised 67 participants, who were engaged in a spectrum of 11 different disciplines according to the modified Mitchell's classification of the American College of Cardiology considering dynamic and static components of their training (10,11). All athletes were registered member of a sports club and regularly participated in a medical control. Athletes with cardiovascular risk factors, know disorders or pathological states have been excluded from the study. None of them received any drugs. Electrocardiography (ECG) and laboratory findings proved to be normal in all cases. Athletes spent 9±4 years on training before inclusion. All athletes were involved into the study who was willing to participate. According to the above mentioned classification, the following groups of elite athletes were created:

- ❖ Group 1 (C.I., high dynamic/low static) consisted of 12 participants: 11 football players and 1 orienteer (mean age: 23.1±4.0 years),
- ❖ Group 2 (C.II., high dynamic/moderate static) consisted of 22 sportsmen, including 3 handball players, 12 runners, 5 basketball players and 2 swimmers (mean age: 24.8±7.8 years),
- ❖ Group 3 (C.III., high dynamic/high static) consisted of 34 athletes, including 2 kayakers, 6 canoers, 6 rowers, 13 triathletes and 7 boxers (mean age: 23.0±6.1 years).

Clinical data are detailed in *Table 1*. The results of the control group were selected from a pool of non-athletic healthy volunteers (n=83, mean age of 23.6±3.2 years, 50 men) with a caution to be age- and gender-matched. All subjects were selected from the pool who met the criterion.

Control subjects were physically active, but were not elite athletes or sportsmen. All athletes and non-athletes underwent a physical examination, an ECG assessment and a complete 2D Doppler echocardiography with 3DSTE were completed at the same time with the same device (12). Athletes and matched controls were all Caucasian Hungarians.

2D Doppler echocardiography

A Toshiba Artida® echocardiographic machine (Toshiba Medical Systems, Tokyo, Japan, now Canon Medical Systems) using a PST-30BT (1–5 MHz) phased-array transducer was used for echocardiographic examinations. Routine assessments included measurement of heart chamber dimensions and functional parameters [for instance LV ejection fraction (EF)] according to the guidelines, quantification of valvular regurgitations and stenosis (if present by Doppler) and measurement of transmitral early (E) and late (A) diastolic flow velocities and their ratio to characterize LV diastolic function (13). All echocardiographic examinations (including 3DSTE) were performed by the same expert (ÁK) and all analyses were performed 3 times, and mean values were provided into the study.

3D speckle-tracking echocardiography

3DSTE was performed by the same echocardiographic

Table 1 Clinical and two-dimensional Doppler echocardiographic data

Data	Controls (n=83)	All athletes (n=67)	Group 1 (n=12) (high dynamic/low static)	Group 2 (n=22) (high dynamic/ moderate static)	Group 3 (n=33) (high dynamic/high static)
Demographic data					
Age (years)	23.6±3.2	23.6±6.4	23.1±4.0	24.8±7.8	23.0±6.1
Male gender (%)	50 (60)	39 (58)	11 (92)*	10 (45)	18 (55)
Height (cm)	175.1±10.7	177.2±8.4	181.0±8.3	176.2±10	176.6±7.3
Mean hours per week (hours)	0	9.4±4.33	7.6±3.7	7.1±3.4	11.7±4.0
Weight (kg)	72.2±16.8	72.4±11.9	72.2±9.0	70.6±13.5	73.7±11.7
Body mass index (kg/m^2)	23.2±3.9	23.0±3.1	22.0±2.8	22.6±2.7	23.6±3.5
Resting heart rate (rps)	73±3	58±3*	60±5*	58±3*	57±5*
Two-dimensional echocardiography					
LA-D (mm)	36.2±4.8	36.6±3.2	35.4±3.1	36.4±2.4	37.6±3.4*
LA-D-indexed (mm/m^2)	19.4±2.1	19.6±1.5	18.9±1.5	19.5±1.1	20.1±1.6*
LV-ED-D (mm)	48.3±3.7	49.9±3.6*	50.5±3.7	48.7±2.9	50.7±3.1*
LV-ED-D-indexed (mm/m^2)	25.8±1.7	26.7±1.6*	27.0±1.6	26.0±1.4	27.1±1.4*
LV-ED-V (mL)	107.8±21.5	118.5±21.3*	121.7±21.4	113.7±16.9	121.3±24.3*
LV-ED-V-indexed (mL/m^2)	57.6±10.4	63.4±10.6*	65.1±10.8	60.8±8.2	64.9±12.1*
LV-ES-D (mm)	31.9±3.7	30.5±2.6*	31.7±2.9‡	29.3±2.0*	31.1±2.7*
LV-ES-D-indexed (mm/m^2)	17.1±1.8	16.3±1.2*	17.0±1.4‡	15.7±1.1	16.6±1.4
LV-ES-V (mL)	35.5±9.8	37.5±8.5	41.6±10.0‡	34.3±6.4	38.6±8.7
LV-ES-V-indexed (mL/m^2)	19.0±4.9	20.1±4.2	22.2±4.8‡	18.3±3.1	20.6±4.3
IVS (mm)	8.7±1.6	9.4±1.2*	9.2±1.4	9.1±1.1	9.8±1.2*
LV-PW (mm)	8.8±1.6	9.3±1.2*	9.0± 1.3	9.1±1.2	9.7±1.2*
E (cm/s)	86.1±15.6	89.8±19.4	58.9±12.3*‡	93.5±15.1	95.4±15.4*†
A (cm/s)	65.4±22.6	65.1±14.1	82.4±14.1*‡	60.1±7.1	61.9±12.7†
E/A	1.6±0.26	1.44±0.39	0.75±0.25*‡	1.56±0.24	1.57±0.25†
LV-EF (%)	67.0±5.8	68.3±3.78	66.0±3.7‡	70.0±3.7*	67.9±3.5

*, P<0.05 *vs.* Controls; †, P<0.05 *vs.* Group 1; ‡, P<0.05 *vs.* Group 2. A, late transmitral flow velocity; D, diameter; E, early transmitral flow velocity; ED, end-diastolic; EF, ejection fraction; ES, end-systolic; IVS, interventricular septum; LA, left atrium; LV, left ventricular; PW, posterior wall; V, volume.

machine after changing the transducer into a special matrix phased-array 2.5 MHz PST-25SX transducer (Toshiba Medical Systems, Tokyo, Japan, now Canon Medical Systems). Firstly, transducer was positioned in the apical window, then to optimize image quality, the participants were asked to hold their breath. Six wedge-shaped R-wave-triggered sub-volumes were acquired, from which pyramid-shaped full-volume 3D echocardiographic datasets were automatically performed. When datasets were stored on the workstation, their analysis started with the use of 3D Wall Motion Tracking software (Toshiba Medical Systems, Tokyo, Japan). Apical two- (AP2CH) and four-chamber (AP4CH) views and three short-axis views at different LV levels at end-diastole were created, then non-foreshortened views were optimized, and markers were set on long-axis views. Finally, automatic reconstruction of the LV endocardial surface was

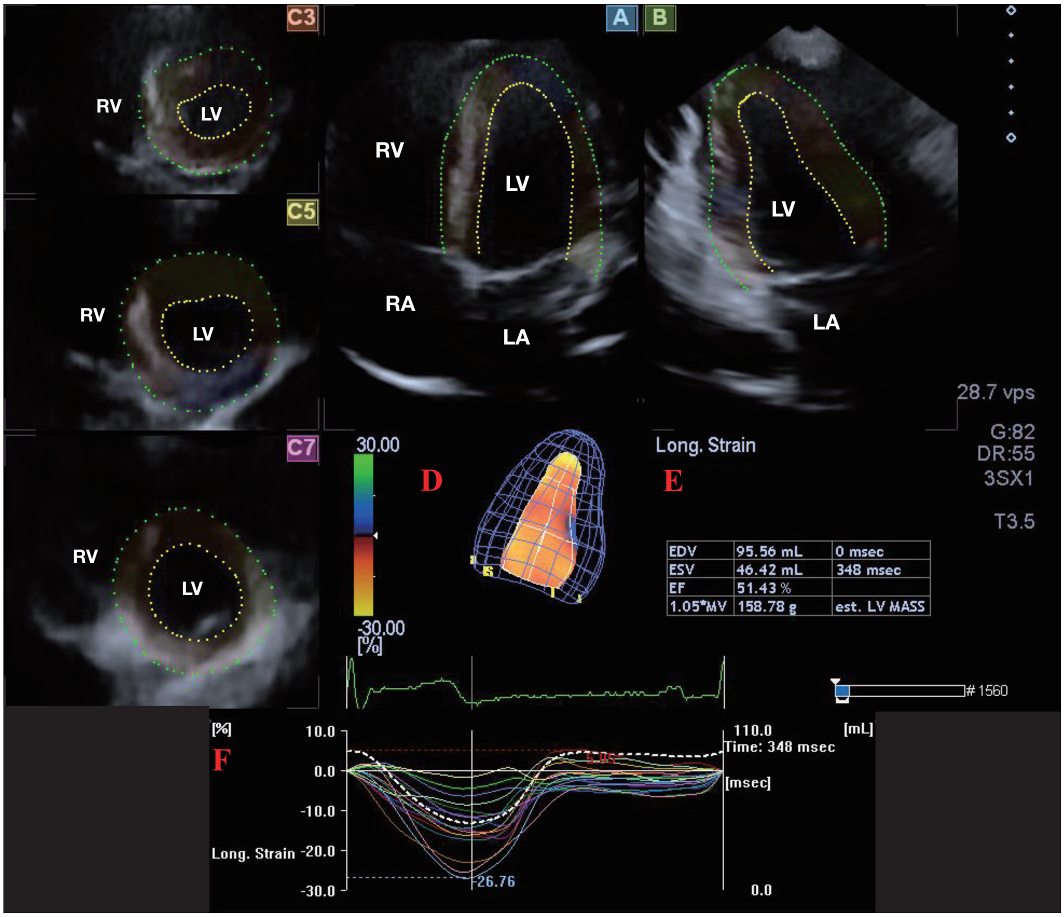

Figure 1 LV analysis was performed by 3D speckle-tracking echocardiography. From the acquired 3D echocardiographic dataset, several views were automatically created by the software including apical four-chamber (A) and two-chamber longitudinal (B) views and LV apical, mid-ventricular and basal (C3, C5, C7) short-axis views. A 3D virtual LV cast could be created with these auxiliary views (red D). Analysis included not only detailed exact measurement of LV volumes respecting the heart cycle (red E), but LV segmental and global strain assessments, as well (red F). LA, left atrium; LV, left ventricular; RA, right atrium; RV, right ventricle; EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction; long strain, longitudinal strain; 3D, three-dimensional.

made in the 3D space which was tracked during the heart cycle to create 3D cast of the LV (*Figure 1*).

Using this virtual 3D model of the LV, in addition to LV end-diastolic (ED-V) and end-systolic (ES-V) volumes and EF, global (representing the whole LV) unidirectional longitudinal (LS; representing LV lengthening or shortening), circumferential (CS; representing LV widening or narrowing), radial (RS; representing LV thickening or thinning) and complex/multidirectional area (AS; combination of LS and CS) and 3D strains (3DS; combination of RS, LS and CS) were assessed. According to the international guidelines, recommended 16-segment LV model was used for segmental analysis, from which mean segmental and apical, midventricular and basal regional LV strains were calculated (5-8). LV twist was also calculated (5-8,14).

Statistical analysis

Mean ± standard deviation format was used for continuous variables and frequencies and percentages format was used for categorical variables. Student *t* test with Welch correction and one-way analysis of variance (ANOVA) test with Bonferroni correction were used where appropriated. For categorical variables, comparisons were performed by Fisher's exact test. Reproducibility was assessed in 30

Table 2 Three-dimensional speckle-tracking echocardiography-derived data

Data	Controls (n=83)	All athletes (n=67)	Group 1 (n=12) (high dynamic/low static)	Group 2 (n=22) (high dynamic/moderate static)	Group 3 (n=33) (high dynamic/high static)
LV-ED-V (mL)	89.1±22.7	107.4±26.1*	100.7±30.2	102.8±21.2	113.6±26.6*
LV-ED-V-indexed (mL/m^2)	47.6±11.3	57.4±12.6*	53.9±14.6	55.0±10.4	60.7±13.2*
LV-ES-V (mL)	36.8±10.8	43.9± 11.4*	42.5±12.4	41.2±11.4	46.8±10.5*
LV-ES-V-indexed (ml/m^2)	19.7±5.9	23.5±10.1*	22.7±6.8	22.0±6.1	25.0±5.8*
LV-EF (%)	58.9±5.3	58.9±5.7	57.4±4.7	60.3±5.4	58.3±6.0
Global LV strains					
Radial (%)	25.0±8.5	24.5±11.5	21.0±11.8	26.8±10.7	23.4 ±11.5
Circumferential (%)	–28.1±4.8	–29.9±5.2*	–29.5±4.8	–30.6±4.9*	–29.6±5.4
Longitudinal (%)	–16.3±2.3	–18.5±3.0*	–17.1±4.1	–18.8±3.3	–18.4±2.4*
3D (%)	27.7±8.1	29.3±11.0	26.5 ±11.7	30.9±10.3	28.2±11.1
Area (%)	–40.9±4.8	–43.7±5.4*	–42.8±5.3	–44.5±5.0*	–43.0±5.6
Mean segmental LV strains					
Radial (%)	27.2±7.9	27.8±10.3	25.3±10.0	30.3±10.0	26.9±10.6
Circumferential (%)	–28.9±4.6	–30.9±4.9*	–30.5±4.6	–31.5±4.8	–30.6±5.1
Longitudinal (%)	–17.0±2.3	–19.4±2.9*	–18.2±3.9	–19.9±3.1*	–19.4±2.2*
3D (%)	29.6±7.7	31.8±9.9	29.7±9.4	33.7±9.5	31.2±10.5
Area (%)	–41.9±4.9	–44.0±5.2*	–43.6±5.3	–45.4±5.1*	–43.9±5.1

*, P<0.05 *vs.* Controls. LV, left ventricular; ED, end-diastolic; V, volume; EF, ejection fraction; ES, end-systolic; 3D, three-dimensional.

randomly selected elite athletes, and standard error of measurement (SEM) was determined. Statistical significance was defined in the event of $P<0.05$. Statistical analysis was performed by MedCalc software (MedCalc, Inc., Mariakerke, Belgium).

Results

Clinical and two-dimensional Doppler echocardiographic data

Athletes spent 10.8±3.3 years, 10.1±5.9 years and 6.9±4.2 years in elite sport in Groups 1, 2 and 3, respectively. The ratio of athletes being in an actual race period was similar between Groups 1, 2 and 3 [n=3 (25%), n=11 (50%) and n=11 (32%), respectively] (*Table 1*). *Table 1* contains conventional echo data on the LV as well.

3DSTE-derived volumetric data, LV strains and twist

Increased LV-ED-V and LV-ES-V could be seen in all athletes, the largest values were seen in the Group 3 (*Table 2*). Global LV-LS, LV-CS and LV-AS were increased in elite athletes as compared to those of non-athlete controls. All apical LV strains proved to be increased in all athletes together with enhanced basal RS, basal and midventricular LS, midventricular AS and 3DS. Global and regional LV strains showed no differences between the athlete groups (except in midventricular LV-LS) (*Tables 2,3*). LV twist proved to be 13.8±3.1 degrees in healthy participants and 13.4±4.6 degrees in Group 1, and showed significant impairment in Group 2 (11.5±3.9 degrees) and Group 3 (11.2±4.0 degrees). None of the LV strains and twist parameters showed correlations with heart rate in athletes.

Reproducibility data

Intraobserver ICCs were 0.86, 0.81, 0.80, 0.82, 0.82 and 0.83 for LV-RS, LV-CS, LV-LS, LV-3DS, LV-AS and LV twist, respectively. Interobserver ICCs were 0.81, 0.78, 0.76, 0.77, 0.79 and 0.80, respectively (*Figures 2,3*).

Table 3 Regional left ventricular strains as assessed by three-dimensional speckle-tracking echocardiography

Data	Controls (n=83)	All athletes (n=67)	Group 1 (n=12) (high dynamic/low static)	Group 2 (n=22) (high dynamic/moderate static)	Group 3 (n=33) (high dynamic/high static)
RS_{basal} (%)	30.2±12.5	26.6±14.2*	23.7±9.29	30.0±13.4	25.5±15.7*
RS_{mid} (%)	29.7±9.2	31.9±13.2	28.5±13.7	34.5±12.2*	30.4±13.0
RS_{apex} (%)	18.4±8.5	24.6±13.4*	22.7±13.8	24.6±13.6*	24.0±13.3
CS_{basal} %)	−25.0±5.0	−24.7±5.6	−23.6±5.7	−25.9±5.2	−24.6±5.9
CS_{mid} (%)	−30.2±5.5	−31.0±5.2	−30.4 ±3.9	−31.9±5.1	−30.5±5.4
CS_{apex} (%)	−32.6±9.5	−40.1±11.4*	−41.2±10.3*	−39.2±10.4*	−39.6±12.8*
LS_{basal} (%)	−19.6±4.6	−21.1±4.6*	−22.0±5.0	−21.2±4.3	−20.6±4.6
LS_{mid} %)	−13.8±3.9	−16.3±5.2*	−12.9±6.0‡	−17.4±4.7*	−16.2±5.3*
LS_{apex} (%)	−18.1±5.3	−22.2±6.3*	−20.5±5.0	−21.7±7.9*	−22.5±5.8*
$3DS_{basal}$ (%)	34.1±11.9	31.9±14.0	30.0± 10.9	34.8±13.2	30.7±15.4
$3DS_{mid}$ (%)	31.4±8.9	35.7±12.4*	32.8±11.6	37.6±11.4*	34.6±12.7
$3DS_{apex}$ (%)	19.9±8.9	26.8±13.4*	24.5±12.7	26.4±13.5*	26.7±13.6*
AS_{basal} (%)	−39.2± 5.9	−39.5±6.4	−39.6±5.3	−40.7±6.0	−38.8±7.0
AS_{mid} (%)	−40.8±6.0	−43.0±6.0*	−40.3±6.0	−44.5±5.7*	−42.6±6.0
AS_{apex} (%)	−46.3±10.5	−54.5±11.7*	−54.7±9.6*	−53.8±11.8*	−53.9±13.0*

*, P<0.05 *vs.* Controls; ‡, P<0.05 *vs.* Group 2. RS, radial strain; CS, circumferential strain; LS, longitudinal strain; 3DS, three-dimensional strain; AS, area strain.

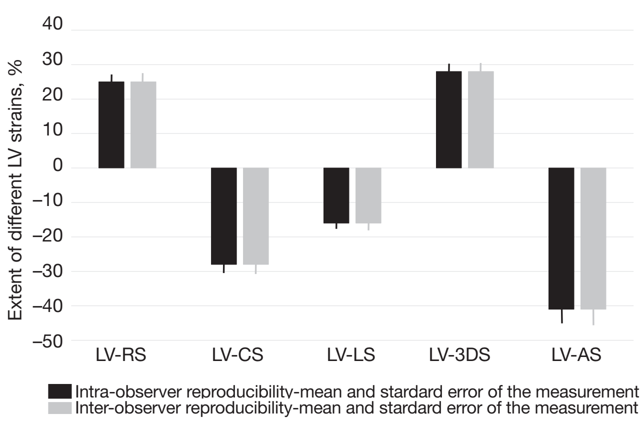

Figure 2 Intra- and interobserver reproducibility of three-dimensional speckle-tracking echocardiographic measurement of left ventricular strains. LV, left ventricular; RS, radial strain; CS, circumferential strain; LS, longitudinal strain; 3DS, three-dimensional strain; AS, area strain.

Discussion

In the present study, increased LV strains in longitudinal and circumferential directions could be detected, these results suggested enhanced contractility in elite athletes playing high dynamics sports as compared to non-athlete healthy volunteers. Apical LV strains were increased in all directions together with basal and midventricular enhancement in certain directions. Global and regional LV strains showed no differences between the athlete groups based on static component of their training.

Results on the effect of elite sport activity on resting LV contractility represented by LV strains are contradicting and seem to be dependent on the type and level of training (1). While global LS of marathon runners (C.I. group) was found to be increased (15) and decreased (16), as well, global RS and CS proved to be preserved (16). Bodybuilders (B.III. group) showed reduced global CS with preserved global RS and LS suggesting different pattern of LV deformation in certain directions in elite athletes with varying levels of static and dynamic components. Reduced LS and RS were found in soccer players (C.I. group) and in triathletes

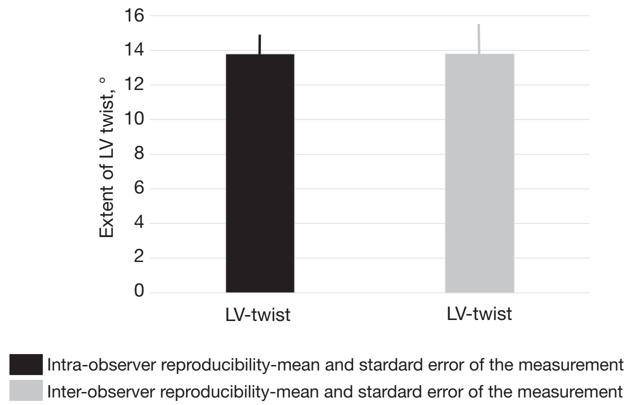

Figure 3 Intra- and interobserver reproducibility of a three-dimensional speckle-tracking echocardiographic measurement of left ventricular twist. LV, left ventricular.

(C.III. group) with greater strain reduction in soccer players (17). Global CS was greater in male elite cyclists (C.III. group) compared to non-athletes (18). Moreover, according to recent findings investigating strain values in the heart of female elite athletes playing football (C.I. group) and volleyball (B.I. group), global RS, LS and CS did not differ between the athletes and controls or between sports disciplines (19). Our early results demonstrated increased global LS and CS in a mixed group of runners (C.I. group) and basketball (C.II. group) and water polo players (C.III. group) (20).

In the present study, quantitative features of LV deformation, LV strains were determined by 3DSTE, which is a non-invasive and easy-to-learn/easy-to-use echocardiographic technique, capable of parallel 3D evaluation of cardiac chambers and valves at the same time (5-8). Morphological and functional characteristics of ventricles and atria could be detailed at the same time using the same 3D dataset. Although 3DSTE-derived LV-EF is known to be lower compared to that calculated with 2D echocardiographic measurements due to 3DSTE-derived underestimation of LV volumes with more affection on EDV than ESV resulting in a lower EF (21). The method is validated for LV strains (22), normal references values are also available (23).

In a recent study, significant abnormalities in LV rotational mechanics with impaired LV basal rotation and twist was seen in athletes playing sports with high dynamics with moderate/high static components (14). Finding of the present study widens our knowledge in this group of elite athletes demonstrating increased LV strains, which could be partially considered to be a compensation and adaptation to deteriorated LV rotational mechanics (14). The impact of intensive sport activity on aortic elasticity and its effect on LV contractility could explain the findings as well (24). In a recent study, adaptive changes of LV circular function of the apical and midventricular LV fibers and longitudinal motion of the basal septum and LV anterior wall due to aortic stiffness were found in elite athletes (24). Moreover, factors affecting inflow from the left atrium via the mitral valve and outflow in the aorta (like its elasticity) via the aortic valve may have significant effects and could influence the results, as well. No laboratory or imaging techniques were used to exclude any disorders or pathological states. However, elite athletes were considered to be healthy according to their own report and negative ECG and echocardiographic tests. However, subclinical state of any pathologies cannot be excluded. Further studies are warranted to confirm our findings and provide further insights into the elite sport activity-related changes in LV mechanics. The real clinical importance of the findings in not known at this moment, and its role in the screening of elite athletes should also be clarified.

Limitations

- ❖ All athletes were classified according to their discipline, which could affect the results.
- ❖ All athlete group consisted of a relatively low number of cases, which group was further divided into 3 subgroups. Due to these facts, further gender-specific analyses could not be performed, which would have made the study more relevant clinically and stronger scientifically.
- ❖ Only 3DSTE-derived LV strains were determined, rotational parameters have already been examined (14), detailed analysis of volumetric and functional features of other chambers would have exceeded the scope of this paper.
- ❖ Temporal and spatial resolution of 2D echocardiography is better than that of 3DSTE (5,6,25,26).
- ❖ Non-homogeneous groups of athletes were compared, it would have been better to compare athletes doing the same sports in each groups.

Conclusions

Increased LV-LS, LV-CS and LV-AS represents enhanced

LV deformation in longitudinal and circumferential directions in athletes playing sports with high dynamics. This enhancement is not related to the grade of the static component of training. Some regional differences in LV strains could be detected.

Acknowledgments

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-22-417/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-417/coif). AN serves as an unpaid editorial board member of *Quantitative Imaging in Medicine and Surgery*. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The Institutional and Regional Human Biomedical Research Committee of University of Szeged (Hungary) approved the study (No. 71/2011). Informed consent was given by all the patients.

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