Original Article

Left ventricular rotational mechanics and left ventricular volumes: is there a relationship in healthy adults?—three-dimensional speckle-tracking echocardiography-derived insights from the MAGYAR-Healthy Study

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Background: Left ventricular (LV) rotational mechanics play a crucial role in LV pump function by strengthening and improving its efficacy. Dependence of LV rotational parameters on left atrial volumes has already been demonstrated. The evaluation of the effect of LV rotational mechanics on LV volumes was purposed in a population of healthy subjects by three-dimensional speckle-tracking echocardiography (STE).

Methods: The study comprised 175 healthy subjects with a mean age of 32.8±12.2 years (79 males). All subjects underwent a complete physical examination, laboratory assessments, standard 12-lead electrocardiography and two-dimensional Doppler and three-dimensional STE, the results of these examinations were within the normal range.

Results: Increased basal LV rotation was associated with increased LV volume measured in end-systole and impaired LV ejection fraction. Increased apical LV rotation was associated with reduced LV volumes assessed in end-diastole and in end-systole and increased ejection fraction of the LV. Elevated basal LV rotation showed associations with increased LV mass. In case of increasing basal LV rotation, apical LV rotation showed a decreasing tendency and LV twist showed a tendency of increasing. Similarly, lower basal LV rotation and increased LV twist were seen with increasing apical LV rotation. Increasing LV end-diastolic volume was associated with increasing LV volume measured in end-systole and preserved ejection fraction of the LV. Increasing LV end-systolic volume was associated with increasing LV end-diastolic volume and reduction of LV ejection fraction. Increasing LV volumes were associated with increasing LV mass. While increased LV volumes were associated with reduced apical LV rotation and twist, basal LV rotation did not show significant changes.

Conclusions: LV rotational mechanics are strongly associated with LV volumes in healthy adults suggesting its volume-dependence.

Keywords: Left ventricular (LV); volume; rotation; three-dimensional; echocardiography

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Introduction

Three-dimensional (3D) echocardiography enhances diagnostic accuracy of intracardiac structures with their spatial recognition and provides volumetric measurements using virtual models of certain cardiac chambers of an actual subject (1). 3D speckle-tracking echocardiography (STE) combines volumetric 3D assessments with quantitative featuring of wall contractility by strain measurements (2-5). Moreover, this is the first echocardiographic technique that quantifies left ventricular (LV) rotational mechanics in a way that is acceptable to the profession (6-8). Simultaneous measurement of volumetric, strain and rotational features of LV enables (patho)physiologic studies to examine the effect of these factors on each other (9).

LV rotational mechanics play a crucial role in LV pump function by strengthening and improving its efficacy (10,11). However, several factors could affect it including aortic stiffness, degree of contraction and relaxation, balance between the subepicardium and subendocardium and orientation of myocardial fibres and vegetative autonomic function (10,12,13). All these factors are affected by LV volumes, which depend on left atrial (LA) preload. Dependence of 3DSTE-derived LV rotational parameters on LA volumes has already been demonstrated (9). Our aim was to make a complete analysis evaluating relationships between LV rotational parameters and LV volumes assessed at the same time in the same healthy population by non-invasive 3DSTE. For these purposes, subgroups of healthy subjects were created based on LV rotation and LV volume to see potential changes in case of parameters larger/smaller than the mean values.

Methods

Subject population

The present single center cohort study consisted of 175 subjects (average age: 32.8±12.2 years, 79 men). Not only two-dimensional Doppler echocardiography (2DE) and 3DSTE, but complete standard 12-lead electrocardiography (ECG), laboratory assessments and physical examination were performed in all volunteers with a result being within the normal range. 2DE and 3DSTE measurements were performed by the same observer (Kormányos Á). No subject had any disorder or pathological state in their medical history or took any medication regularly. The present study serves as a part of the 'Motion Analysis of the heart and Great vessels bY three-dimensionAl speckle-tRacking echocardiography in Healthy subjects' (MAGYAR-Healthy) Study. It has been organized at the University of Szeged partly for physiologic studies assessing interplay between atria, ventricles and valves ('Magyar' means 'Hungarian' in Hungarian language). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional and Regional Human Biomedical Research Committee (University of Szeged, Hungary, registration number: 71/2011 and updated versions). All subjects gave informed consent when echocardiographic studies were performed.

2DE

Complete 2DE assessments were performed by a Toshiba Artida™ echocardiographic machine (Toshiba Medical Systems, Tokyo, Japan) attached to a PST-30BT (1–5 MHz) phased-array transducer. 2DE examinations were accomplished in accordance with the actual guidelines including chamber quantifications and Simpson's determination of LV ejection fraction. Doppler assessment of valvular stenosis and/or regurgitations and calculation of mitral inflow velocities at early (E) and late (A) diastole and E/A were also performed (14).

3DSTE

Complete detailed 3DSTE-derived LV analysis included a volumetric measurement and determination of LV rotational parameters (2-5). Firstly, 3D echocardiographic dataset called 'echocloud' was acquired digitally using a PST-25SX matrix transducer with 3D capability attached to the same echocardiographic equipment. Cases were lying on their left side, the transducer was positioned apically, then during a breathhold, to achieve optimal image quality, 6 subvolumes were acquired, which were merged together for full volume datasets for offline analysis to be performed later by the software. Offline analysis was accomplished with the vendor-provided 3D Wall Motion Tracking software version 2.7 (Ultra Extend, Toshiba Medical Systems, Tokyo, Japan). Firstly, several apical longitudinal [4-chamber (AP4CH) and 2-chamber (AP2CH)] and cross-sectional (basal, midventricular and apical) views were selected automatically from the acquired dataset, then after defining the LV—mitral annulus (MA) edges at the septum and the lateral LV wall and the LV apical region, the endocardial LV surface was determined by a sequential analysis in order to create a digital 3D echocardiographic model of the LV. Using this model, not only LV volume changes respecting the cardiac cycle were determined, but features of LV rotational mechanics including apical and basal LV rotations, LV twist and time-to-peak LV twist were also measured (*Figure 1*).

Statistical analysis

Continuous variables were shown as mean ± standard deviation, while categorical variables were presented as n (%). Significant difference between variables was considered to be present if P was less than 0.05. The Shapiro-Wilk test is a test of normality: Student's *t*-test with Welch correction was performed, when distribution proved to be normal and Mann-Whitney-Wilcoxon test, when distribution was non-normal. Bonferroni method following one-way ANOVA was used, where appropriate. Fisher's exact test was used to determine whether or not there is a significant association between two categorical variables. Correlations were assessed by calculating Pearson's correlation coefficients. Intraobserver and interobserver reproducibility was assessed by calculation the intraclass correlation coefficient (ICC). SPSS Statistics (SPSS Inc., Chicago, IL, USA) was used for advanced analytics.

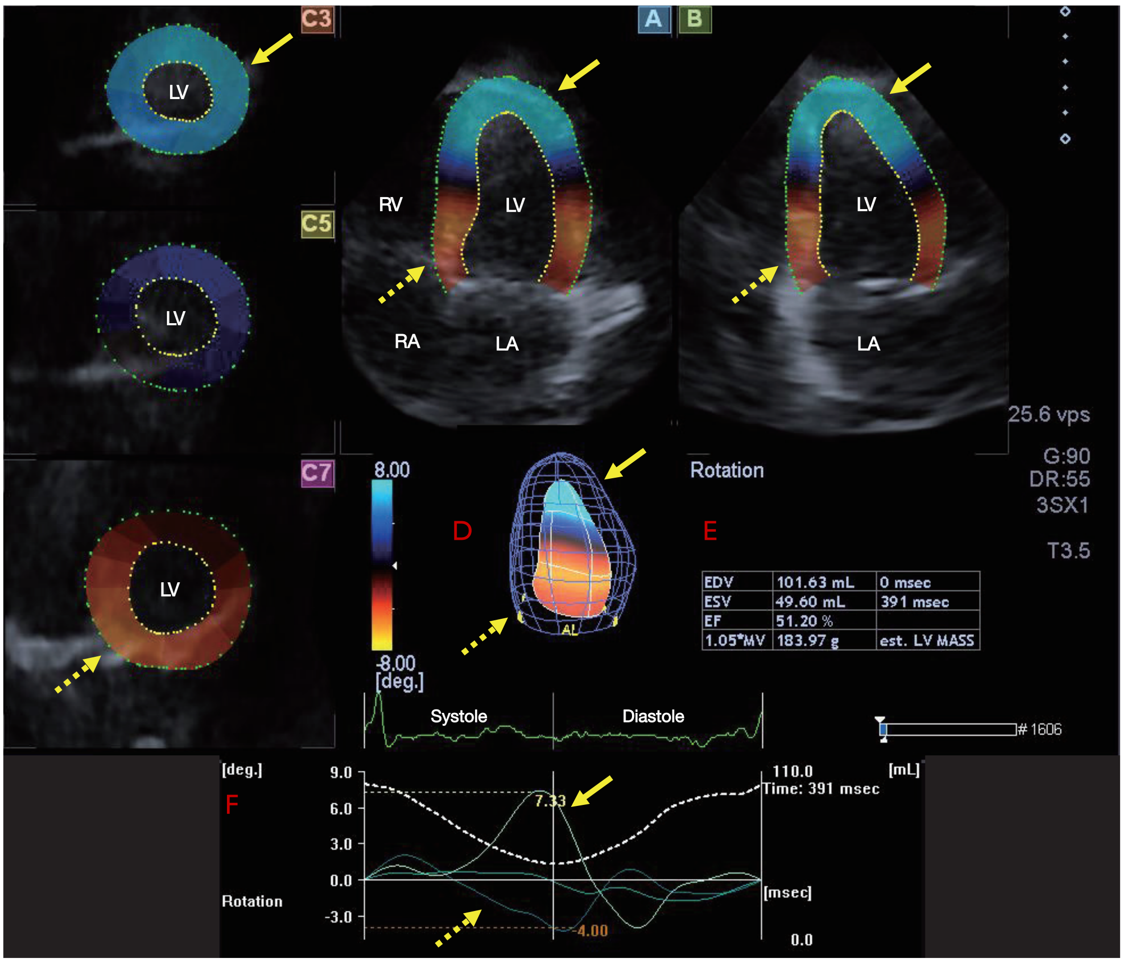

Figure 1 3D speckle-tracking echocardiographic assessment of LV volumes and rotational parameters. Apical longitudinal four-chamber (A) and two-chamber views (B) and basal (C3), midventricular (C5) and apical (C7) short-axis views are demonstrated together with a 3D virtual model of the LV (D), volumetric LV parameters with calculated LV ejection fraction (E), time—LV volume changes during cardiac cycle (dashed white curve) and apical (yellow arrows) and basal (yellow dashed arrows) LV rotations (F). 3D, three-dimensional; LV, left ventricle; LA, left atrium; RA, right atrium; RV, right ventricle.

Table 1 LV volumes and rotational parameters in different LV rotation groups

Data	Basal LVrot (°)			Apical LVrot (°)		
	<–1.99 (n=22)	–1.99 to –6.27 (n=127)	>–6.27 (n=26)	<5.55 (n=26)	5.55–13.11 (n=121)	>13.11 (n=28)
LV-EDV (mL)	80.7±13.6	85.7±24.2	89.4±20.1	87.1±19.5	87.6±22.5	75.5±23.1‡#
LV-ESV (mL)	33.8±7.1	35.5±10.7	40.5±9.8*†	37.5±8.3	36.9±10.4	31.0±10.6‡#
LV-EF (mL)	58.3±4.3	59.0±5.6	54.4±5.2*†	56.8±4.4	57.9±5.0	60.8±7.7‡#
3D LV mass (g)	159.4±31.6	154.0±31.5	177.1±27.8*†	162.5±28.7	158.0±32.8	153.8±31.1
Basal LVrot (°)	–1.30±0.62	–3.81±1.11*	–8.11±1.14*†	–4.40±2.60	–4.15±2.04	–3.80±2.02
Apical LVrot (°)	9.85±4.38	9.36±3.67	8.71±3.66	3.70±1.53	9.09±1.88‡	15.56±1.86‡#
LV twist (°)	11.14±4.53	13.17±3.62*	16.82±3.94*†	8.10±3.14	13.24±2.54‡	19.36±2.53‡#
LV twist time (ms)	292±103	360±142*	340±82	323±137	355±136	345±105

Data are presented as mean ± standard deviation. *, P<0.05 *vs.* basal LVrot <1.99°; †, P<0.05 *vs.* 1.99°≤ basal LVrot ≤6.27°; ‡, P<0.05 *vs.* apical LVrot <5.55°; #, P<0.05 *vs.* 5.55°≤ apical LVrot ≤13.11°. EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction; 3D, three-dimensional; LV, left ventricular; LVrot, left ventricular rotation.

Results

Clinical data

Systolic and diastolic blood pressures and heart rate were 120.2±4.3 mmHg, 79.4±3.1 mmHg and 72.2±2.2 bpm, respectively. Mean height, weight, calculated body surface area and body mass index were 172.3±8.7 cm, 69.1±12.8 kg, 1.82±0.19 m^2 and 23.3±5.2 kg/m^2, respectively.

2DE data

Normal routine 2DE measurements were performed in all subjects. Diameter of the left atrium was assessed in long-axis section from parasternal view (36.7±4.0 mm) together with LV end-diastolic (48.0±3.7 mm) and end-systolic (32.3±2.9 mm) diameters, interventricular septum (8.9±1.5 mm) and LV posterior wall (9.0±1.6 mm). LV end-diastolic (106.6±22.8 mL) and end-systolic (36.5±9.1 mL) volumes and LV ejection fraction (65.8%±4.9%) were calculated by Simpsons' method in AP2CH and AP4CH views. Mean diastolic mitral inflow velocities were 80.2±17.5 and 64.5±19.8 cm/s, respectively. Greater than grade 1 regurgitation or significant stenosis in any valves could not be detected in any cases.

Classification of subjects

The study population was divided into subgroups according to the mean ± standard deviation of 3DSTE-derived LV-EDV, LV-ESV, basal and apical LV rotations, which was 85.6±22.7 mL, 36.0±10.4 mL, –4.13°±2.14° and 9.33°±3.78°, respectively. The healthy subjects were classified into subgroups based on the lower (62.9 mL, 25.6 mL, –1.99° and 5.55°, respectively) and upper (108.3 mL, 46.4 mL, –6.27° and 13.11°, respectively) values of these parameters.

3DSTE data

Increased basal LV rotation was associated with increased LV-ESV and reduced LV-EF. Increased apical LV rotation was associated with reduced LV-EDV, LV-ESV and increased LV-EF. Elevated basal LV rotation showed associations with increased 3D LV mass. In case of increasing basal LV rotation, apical LV rotation showed a decreasing tendency and LV twist showed a tendency of increasing. Similarly, tendency of lowering of basal LV rotation and increased LV twist were seen with increasing apical LV rotation (*Table 1*).

Increasing LV-EDV was associated with increasing LV-ESV and preserved LV-EF. Increasing LV-ESV was associated with increasing LV-EDV and reduction of LV-EF. Increasing LV volumes were associated with increasing 3D LV mass. While increased LV volumes were associated with reduced apical LV rotation and twist, basal LV rotation did not show significant changes (*Table 2*).

Correlations

Correlations could not be detected between 3DSTE-

Table 2 LV volumes and rotational parameters in different LV volume groups

Data	LV-EDV (mL)			LV-ESV (mL)		
	<62.9 (n=23)	62.9–108.3 (n=132)	>108.3 (n=20)	<25.6 (n=23)	25.6–46.4 (n=128)	>46.4 (n=24)
LV-EDV (mL)	54.2±11.1	84.4±11.7*	129.6±19.0*†	62.3±11.9	82.6±14.5‡	123.7±21.5$^{\ddagger\#}$
LV-ESV (mL)	24.0±5.2	35.2±6.6*	55.4±8.6*†	21.8±3.0	35.1±5.6‡	54.7±7.9$^{\ddagger\#}$
LV-EF (mL)	58.9±7.2	58.3±5.5	57.1±4.0	64.6±5.8	57.5±5.0‡	55.4±3.7$^{\ddagger\#}$
3D mass (g)	131.4±22.7	157.6±28.8*	190.9±31.5*†	130.4±21.3	157.0±28.7‡	190.8±30.0$^{\ddagger\#}$
Basal LVrot (°)	−4.37±1.92	−4.10±2.22	−4.08±1.74	−3.58±1.15	−4.22±2.26	−4.29±2.10
Apical LVrot (°)	11.77±4.65	8.54±3.58*	9.06±2.77*	11.54±4.12	9.05±3.66‡	8.61±3.36‡
LV twist (°)	16.14±4.36	13.04±4.00*	13.14±3.16*	15.12±3.59	13.26±4.17‡	12.92±3.86‡
LV twist time (ms)	330±69	351±147	352±72	331±98	352±142	341±97

Data are presented as mean ± standard deviation. *, P<0.05 *vs.* LV-EDV <62.9 mL; †, P<0.05 *vs.* 62.9 mL ≤ LV-EDV ≤108.3 mL; ‡, P<0.05 *vs.* LV-ESV <25.6 mL; $^{\#}$, P<0.05 *vs.* 5.6 mL ≤ LV-ESV ≤ 46.4 mL. LV, left ventricular; EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction; 3D, three-dimensional; LVrot, left ventricular rotation.

derived LV volumetric and rotational parameters.

Intraobserver and interobserver reproducibility

Intraobserver ICCs were 0.83, 0.83, 0.85, 0.90, 0.91 and 0.90 for basal and apical LV rotations, LV twist, LV-EDV, LV-ESV and LV-EF, respectively. Interobserver ICCs proved to be 0.84, 0.84, and 0.82, 0.89, 0.90 and 0.90 for the same parameters, respectively.

Discussion

Myofiber orientation of the LV layers is opposite, the left-handed subepicardial orientation is gradually changes from the right-handed subendocardial orientation. This spiral architecture leads to LV having a special towel-wringing motion in systole called LV twist, which is considered to be the net difference between opposite clockwise and counterclockwise rotations of the basal and apical regions of the LV. LV rotational mechanics serve as an essential determinant of LV performance by improving systolic ejection. LV mechanics and function are partly but highly dependent on its preload. Frank-Starling law demonstrates an increase in contractile force in response to LV preload and ultimately to changes in LV volumes (10,11).

3DSTE has been shown to provide precise characterization and quantification of LV rotational mechanics on a non-invasive way (6-8). Moreover, from the same LV-focused single acquired 3D echocardiographic database, volumetric measurements can be made with an accuracy comparable to magnetic resonance imaging (15-18). These facts make detailed (patho)physiological assessments possible as well as detailed investigations of interactions of different parameters (like LV rotations and volumes) even under healthy conditions. 3DSTE is validated for LV rotational parameters (6,7) and volumes (15-17), their normal reference values have also been determined (8,18).

In conclusion, clinicians should know the clinical relevance of LV twist and its load-dependence corresponding to the cardiac cycle. Based on the presented results, strong relationship exists between LV rotational mechanics and volumes even in healthy circumstances. The above mentioned facts may be of more interest in pathologies associated with large LV volumes. Therefore, further studies are needed to prove the findings of the present study with other imaging techniques including more subjects.

Limitation section

Several important limitations should be taken into consideration when interpreting the results:

(I) 3DSTE still suffers image quality problems, which could have effects on findings (2-5).

(II) Although LV strains, rotational and volumetric parameters could be measured simultaneously, the present study did not aim such analysis (2-5).

(III) No further validation of LV parameter as assessed by 3DSTE was purposed in this study (6,7,15-17).

(IV) Quantification of 3DSTE-derived volumetric and strain parameters of atria has been confirmed in several studies. However, their analysis was not aimed in this study (19,20).

Conclusions

LV rotational mechanics are strongly associated with LV volumes in healthy adults suggesting its volume-dependence.

Acknowledgments

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-178/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 study was approved by the Institutional and Regional Human Biomedical Research Committee (University of Szeged, Hungary, registration number: 71/2011 and updated versions) and informed consent was taken from all subjects.

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