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Correlations between left atrial volumes and strains in healthy adults: Detailed analysis from the three-dimensional speckle-tracking echocardiographic MAGYAR-Healthy Study

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Abstract

Introduction: Little is known about the relationship between left atrium (LA) volumes and contractility features along the cardiac cycle. The present study aimed to assess, by three-dimensional speckle-tracking echocardiography (3DSTE), correlations between LA volumes, volume-based functional properties, and strains during the cardiac cycle in healthy adults.

Methods: We included 217 healthy adult volunteers (mean age 33.4 ± 12.7 years, 112 males) who underwent complete two-dimensional Doppler echocardiography with 3DSTE.

Results: LA stroke volumes were greater in subjects with the greater maximum LA volume (V_{max}) in reservoir, conduit, and booster pump phases of LA function. While LA emptying fraction in LA reservoir phase was not different between subjects depending in their V_{max} value, a significantly lower LA emptying fraction could be detected in LA conduit phase in subjects whose V_{max} was >50 mL. In booster pump function, LA emptying fraction was not significantly different whatever the V_{max}. Only global and mean segmental peak LA radial strain (RS) and 3D strain (3DS) and the same strains at atrial contraction appeared greater in subjects with greater V_{max}, whereas the other strain parameters were not different.

Conclusions: In healthy subjects, LA-RS and LA-3DS, objective features of LA contractility, are greater in subjects with greater LA volumes up to a point beyond which this association disappears.

KEYWORDS
echocardiography, healthy subjects, left atrium, strain, three-dimensional

1 | INTRODUCTION

Left atrium (LA) is a dynamic structure, which can be characterized by several volumetric and functional properties.[1] Not only LA volume, but also contractility, change during the cardiac cycle.[2] Three-dimensional (3D) speckle-tracking echocardiography (3DSTE) is a new imaging technique with capability of featuring changes in both LA volume and function by several parameters based on virtual 3D LA model taking into account the phases of the cardiac cycle.[2-5] Thus, 3DSTE can be used to assess correlations between LA volumes and contractility features,[2] which has been scarcely investigated so far. The present study used 3DSTE to assess correlations between LA volumes, volume-based functional properties, and strains during the cardiac cycle in healthy adults.

2 | PATIENTS AND METHODS

2.1 | Study population

The present study comprised 217 healthy adult volunteers (mean age: 33.4 ± 12.7 years, 112 males) without any symptoms, known disease, or other abnormal state that could affect results. None of them received any medication at the time of examination or were smoker. Complete two-dimensional (2D) Doppler echocardiography and 3DSTE have been performed in all cases. A special study has been organized in our department to examine physiological correlations among 3DSTE-derived parameters in healthy adults named Motion Analysis of the heart and Great vessels bY three-dimensionAl speckle-tRacking echocardiography in Healthy subjects (MAGYAR-Healthy Study). 'Magyar' means 'Hungarian' in Hungarian language. The local human research committee approved the study, which complied with the Declaration of Helsinki, and all patients gave informed consent.

2.2 | Two-dimensional Doppler echocardiography

An Artida echocardiography system (Toshiba Medical Systems, Tokyo, Japan) was used with its PST-30SBP (1-5 MHz) phased-array transducer. Chamber quantifications were performed following recent guidelines and routine clinical practices.[6] Valvular regurgitations and stenoses were detected by Doppler echocardiography, with early and late mitral inflow E and A measurement.

2.3 | Three-dimensional speckle-tracking echocardiography

During data acquisitions the same echocardiographic system, equipped with its PST-25SX matrix-array transducer, was used, and 3D echocardiographic datasets were acquired within a single breath-hold from the apical window. Data acquisitions were performed with the subjects in sinus rhythm, during 6 consecutive heart cycles, and LA-focused 6 wedge-shaped sub-volumes were obtained, from which a pyramidal-shaped 3D full volume echocardiographic dataset was created automatically by the software. Offline analysis was performed by 3D Wall Motion Tracking software version 2.7 (Toshiba Medical Systems, Tokyo, Japan). The resulting 3D datasets were displayed in apical 4-chamber and 2-chamber views and 3 short-axis views in basal, mid-atrial, and superior LA regions, respectively (Figure 1). In the apical longitudinal views, the endocardial border was traced by setting several multiple reference points starting at the LA base at the level of the mitral valve, moving toward around the LA, and excluding LA appendage and pulmonary veins from the LA cavity. Starting at the end-diastolic reference frame, 3D wall motion tracking was automatically performed by the software. Manual corrections could be performed throughout the whole measurement.[2-5]

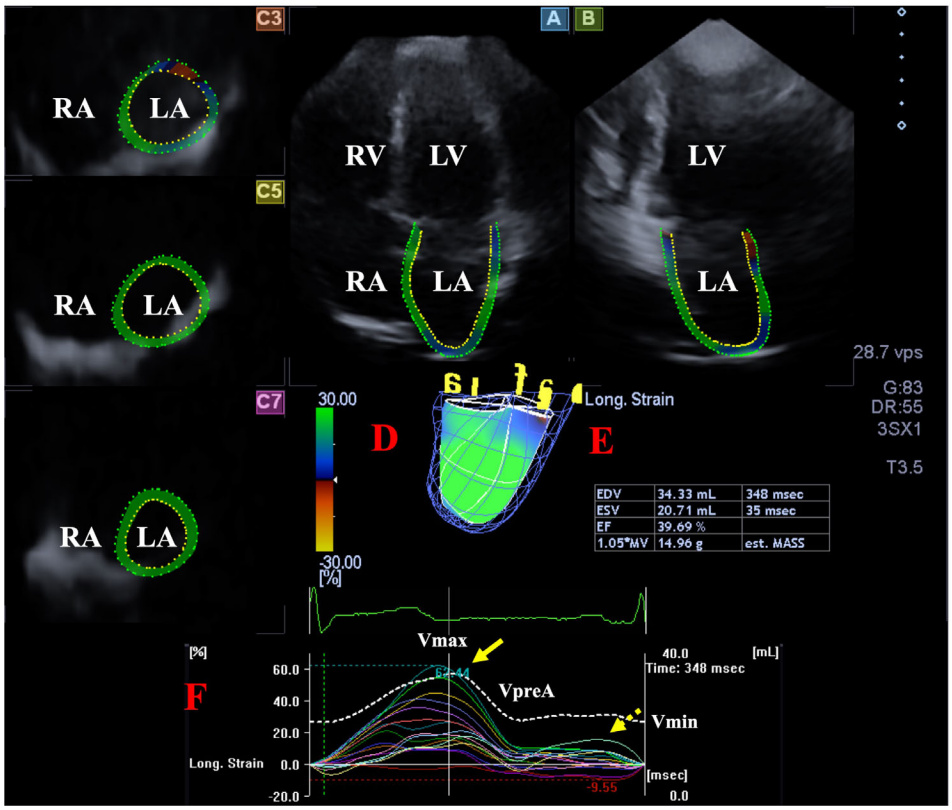

FIGURE 1 Three-dimensional speckle tracking echocardiographic left atrial (LA) analysis using a full-volume dataset in a healthy subject: (A) Apical four-chamber and (B) two-chamber views, short-axis views (C3) at basal, (C5) mid-atrial, and (C7) superior LA levels are demonstrated (D) with a three-dimensional LA cast. (E) Time-global LA volume change (dashed line) and time-segmental LA longitudinal strain curves (colored lines) with (F) calculated volumetric LA data are presented. Yellow arrow represents peak LA strains, while yellow dotted arrow represents LA strains at atrial contraction. EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction; LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle; V_{max}, maximum LA volume, V_{preA}, pre-atrial contraction LA volume; V_{min}, minimum LA volume

2.4 | 3DSTE-derived LA quantifications

Several LA volumes in respect of the cardiac cycle were determined using the above-mentioned 3D LA cast (Figure 1).[2,7,8] End-systolic maximum LA volume ($V_{max,}$ at the time of mitral valve opening), LA volume at the onset of atrial systole ($V_{preA,}$ at the p wave on electrocardiography), and end-diastolic minimum LA volume (V_{min}, at mitral valve closure) were measured. Using these LA volumetric data, several LA functional parameters were calculated. The *systolic reservoir function* was featured by LA total stroke (emptying) volume (TASV = $V_{max} - V_{min}$) and LA total emptying fraction (TAEF = TASV/V_{max}). The *early diastolic conduit function* was characterized by LA passive stroke (emptying) volume (PASV = $V_{max} - V_{preA}$) and LA passive emptying fraction (PAEF = PASV/V_{max}). Finally, *late diastolic booster pump function or active contraction phase* was typified by LA active stroke (emptying) volume (AASV) = $V_{preA} - V_{min}$), and LA active emptying fraction (AAEF) = AASV/V_{preA}). All measurements were averaged over three cardiac cycles. Several unidimensional (unidirectional) radial (RS), longitudinal (LS) and circumferential (CS), and two multidimensional (multidirectional) complex 3D (3DS) and area (AS) LA strains were measured automatically using the same 3D virtual LA model. RS represents thickening/thinning of a certain LA segment, LS represents lengthening/shortening of a certain LA segment, and CS represents widening/narrowing a certain LA segment. AS is a combination of LA-LS and LA-CS, while 3DS is a combination of LA-RS, LA-LS, and LA-CS. For detailed analysis, regional strains were also calculated from segmental values. During 3DSTE analysis, LA strain curves show two peaks: the first represents LA reservoir function in end-systole, while the second represents atrial contraction at end-diastole (LA systole) (Figure 1). In a recent study, normal reference value for V_{max} was demonstrated with no age- and gender-dependency.[8] The lower and upper limits of normal values were selected as cut-offs for the present study, which proved to be about 30 and 50 mL.

2.5 | Statistical analysis

Continuous and categorical data were presented as mean ± standard deviation (SD) or in frequencies and percentage, where appropriate. A value of $P < .05$ was considered to be statistically significant. Shapiro-Wilks test was used to assess normality of distribution, and Levene's test was applied to test homogeneity of variances. Normally distributed datasets were compared by Student's *t*-test; non-normally distributed data were compared by Mann-Whitney Wilcoxon test. Fisher's exact test was performed for categorical variables. To establish significant relationships between variables, Pearson's correlation coefficients were calculated. Intraobserver and interobserver agreements were evaluated using the Bland-Altman method. Linear regression plots demonstrating relationship between V_{max} and peak LA-RS, LA-LS, LA-CS, LA-AS, and LA-3DS have been created. RStudio (RStudio, Boston, Massachusetts) and MATLAB version 8.6 software package (The MathWorks Inc., Natick, Massachusetts) were used for statistical analyses.

3 | RESULTS

3.1 | Two-dimensional Doppler echocardiography

Left ventricular (LV) end-diastolic diameter and volume (48.0 ± 3.1 mm and 104.8 ± 22.5 mL, respectively), LV end-systolic diameter and volume (32.1 ± 3.0 mm and 37.8 ± 9.0 mL, respectively), thickness of the interventricular septum and LV posterior wall (9.1 ± 1.2 mm and 9.3 ± 1.4 mm, respectively), LV ejection fraction (64.6 ± 4.0%), and LA diameter measured in the parasternal long-axis view (37.5 ± 3.5 mm) were in normal range. Mean transmitral E/A ratio was 1.39 ± 0.35 cm/s. None of the subjects showed grade ≥1 valvular regurgitation or significant valvular stenosis.

3.2 | 3DSTE-derived LV data

3DSTE-derived LV end-diastolic and end-systolic volumes, LV mass, and LV ejection fraction were 86.0 ± 23.4 mL, 36.1 ± 10.5 mL, 158 ± 32 g, and 58.3 ± 5.5%, respectively.

3.3 | 3DSTE-derived LA volumetric data

V_{max}, V_{preA}, and V_{min} calculated for all subjects and separately for females and males and their indexed counterpart were greater in subjects with a greater V_{max} (Table 1). LA stroke volume in all LA reservoir (TASV), conduit (PASV), and booster pump (AASV) phases were also greater in subjects with a greater V_{max}. While LA emptying fraction showed no difference in LA reservoir phase (TAEF) in relation with a greater V_{max}, a significantly lower LA emptying fraction was observed in LA conduit phase (PAEF) in subjects in whom V_{max} was greater than 50 mL. In booster pump function, LA emptying fraction did not show significant difference in relation with V_{max}(AAEF) (Table 2).

3.4 | 3DSTE-derived LA strains

Only global and mean segmental peak LA-RS and LA-3DS and LA-RS and LA-3DS at atrial contraction were greater in subjects with a greater V_{max}; the other strain parameters were not different (Figures 2 and 3). Regional peak LA strains and LA strains at atrial contraction are demonstrated in Tables 3 and 4. Linear regression plots demonstrating relationship between V_{max} and peak LA-RS, LA-LS, LA-CS, LA-AS, and LA-3DS are seen in Figure 4.

3.5 | Correlations

LV mass correlated only with peak LA-3DS ($r = -0.202$, $P = .03$); significant correlations could not be detected with peak LA-RS

TABLE 1 Three-dimensional speckle-tracking echocardiography-derived left atrial volumes in healthy subjects with different maximum left atrial volumes

	V_{max} < 30 mL (n = 46)	30 mL ≤ V_{max} ≤ 50 mL (n = 131)	V_{max} > 50 mL (n = 40)
V_{max} (mL)	25.4 ± 3.6	39.3 ± 5.4[a]	62.8 ± 8.3[a,b]
V_{max}-indexed (ml)	13.7 ± 2.1	20.9 ± 3.8[a]	34.5 ± 5.4[a,b]
V_{max} (males) (mL)	25.6 ± 3.6	39.5 ± 5.5[a]	62.7 ± 7.8[a,b]
V_{max} (females) (mL)	26.1 ± 2.1	38.8 ± 5.7[a]	60.9 ± 8.9[a,b]
V_{preA} (mL)	16.8 ± 4.3	26.1 ± 6.7[a]	46.0 ± 11.7[a,b]
V_{preA}-indexed (mL)	9.0 ± 2.3	13.9 ± 4.1[a]	25.7 ± 7.0[a,b]
V_{preA} (males) (mL)	17.3 ± 4.3	26.9 ± 7.2[a]	42.8 ± 9.7[a,b]
V_{preA} (females) (mL)	16.7 ± 3.5	25.0 ± 6.3[a]	48.0 ± 10.9[a,b]
V_{min} (ml)	12.2 ± 3.9	18.5 ± 5.3[a]	31.0 ± 8.7[a,b]
V_{min}-indexed (ml)	6.6 ± 2.0[a]	9.9 ± 3.3[a]	17.0 ± 4.7[a,b]
V_{min} (males) (mL)	13.0 ± 3.7	18.9 ± 5.9[a]	30.0 ± 5.6[a,b]
V_{min} (females) (mL)	12.1 ± 3.9	18.0 ± 5.0[a]	31.1 ± 9.3[a,b]

Abbreviations: AAEF, active atrial emptying fraction; AASV, active atrial stroke volume; PAEF, passive atrial emptying fraction; PASV, passive atrial stroke volume; TAEF, total atrial emptying fraction, TASV, total atrial stroke volume; V_{max}, maximum left atrial volume; V_{min}, minimum left atrial volume; V_{preA}, preatrial contraction left atrial volume.
[a]vs Vmax < 30 mL.
[b]vs 30 mL ≤ V_{max} ≤ 50 mL.

TABLE 2 Three-dimensional speckle-tracking echocardiography-derived left atrial volume-based functional properties in healthy subjects with different maximum left atrial volumes

	V_{max} < 30 mL (n = 46)	30 mL≤ V_{max} ≤ 50 mL (n = 131)	V_{max} > 50 mL (n = 40)
TASV (mL)	13.2 ± 4.0	20.8 ± 5.0[a]	31.8 ± 7.2[a,b]
TASV-indexed (mL)	7.1 ± 2.5	11.0 ± 2.9[a]	17.6 ± 4.9[a,b]
TASV (males) (mL)	12.6 ± 4.2	20.7 ± 4.5[a]	32.6 ± 5.8[a,b]
TASV (females) (mL)	14.0 ± 4.2	20.8 ± 5.8[a]	30.4 ± 9.8[a,b]
PASV (ml)	8.6 ± 3.5	13.3 ± 4.7[a]	16.9 ± 7.1[a,b]
PASV-indexed (mL)	4.7 ± 2.0	7.0 ± 2.7[a]	8.8 ± 3.7[a,b]
PASV (males) (mL)	8.3 ± 3.9	12.6 ± 4.6[a]	19.9 ± 6.9[a,b,c]
PASV (females) (mL)	9.4 ± 3.6	13.8 ± 5.1[a]	12.9 ± 6.2
AASV (mL)	4.6 ± 3.0	7.6 ± 3.5[a]	14.9 ± 7.8[a,b]
AASV-indexed (mL)	2.4 ± 1.6	4.0 ± 1.8[a]	8.7 ± 5.3[a,b]
AASV (males) (mL)	4.3 ± 2.1	8.0 ± 3.3[a]	12.7 ± 6.8[a,b]
AASV (females) (mL)	4.6 ± 3.3	7.0 ± 3.3[a]	17.5 ± 9.6[a,b]
TAEF (%)	51.9 ± 13.7	53.1 ± 11.2	50.9 ± 10.9
TAEF (males) (%)	49.1 ± 13.9	52.8 ± 11.1	52.0 ± 7.2
TAEF (females) (%)	53.4 ± 14.7	53.5 ± 12.6	49.8 ± 13.7
PAEF (%)	34.0 ± 13.2	34.1 ± 12.3	27.5 ± 12.6[a,b]
PAEF (males) (%)	32.4 ± 14.4	32.6 ± 12.7	32.0 ± 11.5
PAEF (females) (%)	35.9 ± 12.8	35.8 ± 13.2	21.6 ± 11.1[a,b]
AAEF (%)	26.9 ± 14.7	28.8 ± 10.2	31.7 ± 11.7
AAEF (males) (%)	25.1 ± 9.9	29.9 ± 9.6	28.5 ± 9.2
AAEF (females) (%)	27.1 ± 16.6	27.9 ± 10.7	35.6 ± 15.8[b]

Abbreviations: AAEF, active atrial emptying fraction; AASV, active atrial stroke volume; PAEF, passive atrial emptying fraction; PASV, passive atrial stroke volume; TAEF, total atrial emptying fraction; TASV, total atrial stroke volume; V_{max}, maximum left atrial volume; V_{min}, minimum left atrial volume; V_{preA}, preatrial contraction left atrial volume.
[a]$P < .05$ vs Vmax < 30 mL.
[b]$P < .05$ vs 30 mL ≤ V_{max} ≤ 50 mL.
[c]$P < .05$ vs PASV (females).

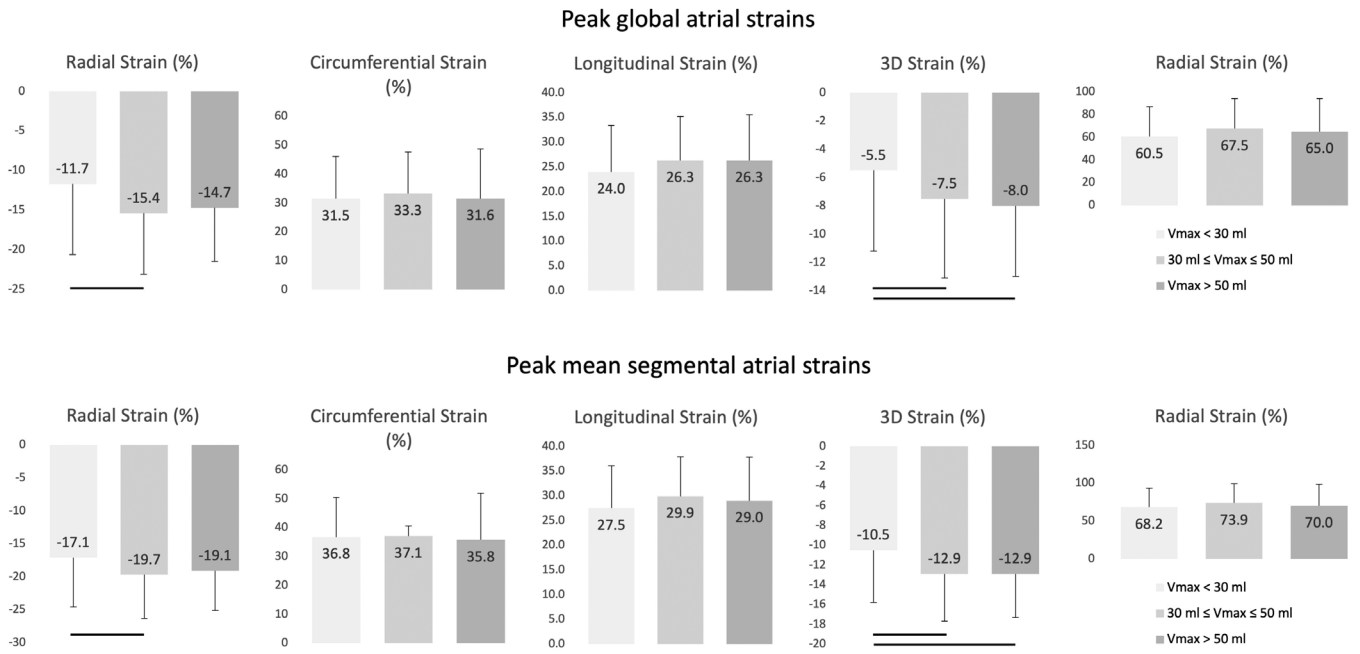

FIGURE 2 Peak global and mean segmental left atrial strains in different maximum left atrial volume groups

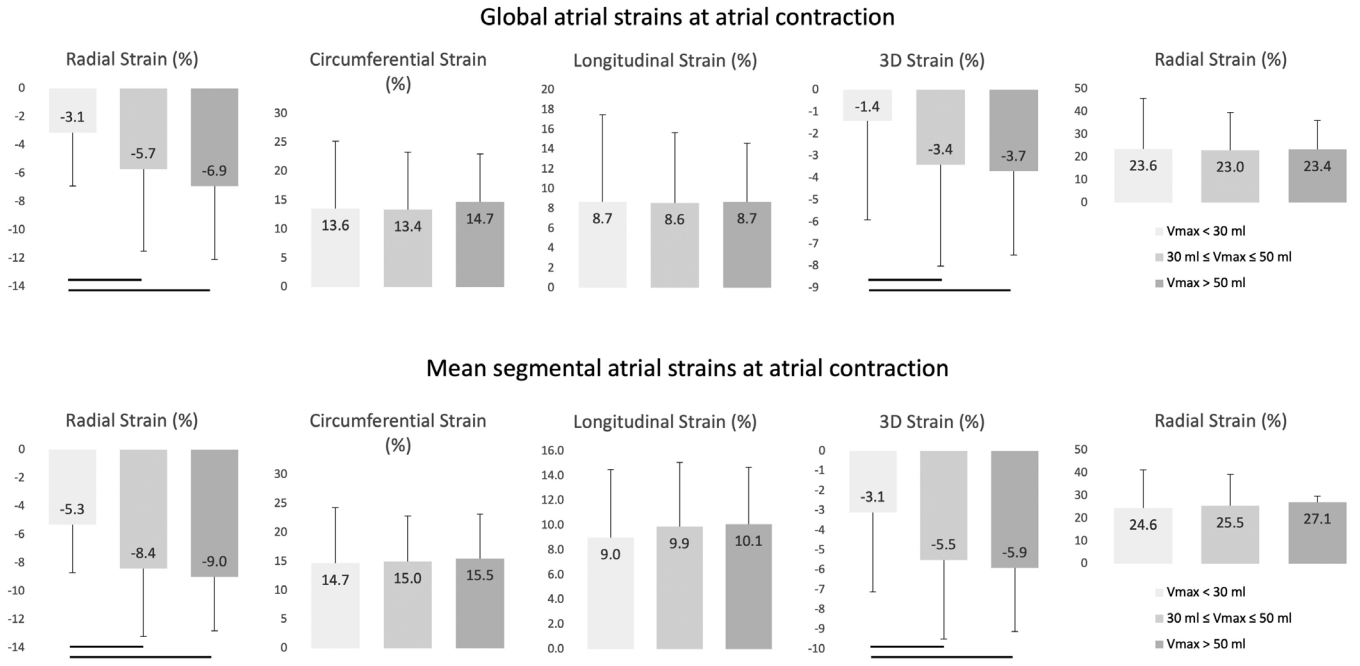

FIGURE 3 Global and mean segmental left atrial strains at atrial contraction in different maximum left atrial volume groups

(r = –0.179, *P* = .06), LA-LS (r = –0.176, *P* = .06), LA-CS (r = –0.109, *P* = .30), or LA-AS (r = –0.135, *P* = .20). E/A did not correlate with peak LA-RS (r = 0.132, *P* = .2), LA-LS (r = –0.159, *P* = .09), LA-CS (r = –0.076, *P* = .4), LA-AS (r = –0.144, *P* = .1), and LA-3DS (r = 0.145, *P* = .1). None of LA strains at atrial contraction correlated with LV mass and E/A (Table 4).

3.6 | Inter- and intra-observer agreements

The mean ± SD difference between values obtained by two observers for the measurements of V_{max}, V_{preA}, V_{min}, and peak LA-RS, LA-LS, LA-CS, LA-AS, and LA-3DS were 0.8 ± 4.6 mL, –1.0 ± 7.1 mL, 0.5 ± 3.1 mL, –2.0 ± 10.8%, 4.3 ± 14.0%, 0.4 ± 7.9%, 9.9 ± 34.9%,

TABLE 3 Three-dimensional speckle-tracking echocardiography-derived regional peak left atrial strains in healthy subjects with different maximum left atrial volumes

	V_{max} < 30 mL (n = 46)	30 mL ≤ V_{max} ≤ 50 mL (n = 131)	V_{max} > 50 mL (n = 40)
Basal RS (%)	−16.5 ± 8.8	−17.8 ± 9.1	−19.4 ± 6.9
Mid RS (%)	−17.6 ± 8.4	−19.4 ± 7.4[c]	−18.3 ± 6.5
Superior RS (%)	−17.7 ± 12.9	−22.3 ± 11.7[a,b]	−19.2 ± 9.9
Basal CS (%)	39.6 ± 14.4	41.5 ± 14.2	40.6 ± 16.4
Mid CS (%)	29.6 ± 11.9[b,c]	32.5 ± 12.3[b,c]	31.0 ± 13.9[b]
Superior CS (%)	40.5 ± 27.7	39.2 ± 25.1	36.0 ± 25.4
Basal LS (%)	21.7 ± 9.9	22.3 ± 11.2	22.6 ± 11.3
Mid LS (%)	33.1 ± 13.7[b,c]	37.9 ± 13.4[a,b,c]	37.5 ± 12.4[b,c]
Superior LS (%)	25.5 ± 15.1	27.9 ± 15.1[b]	26.0 ± 13.7
Basal 3DS (%)	−10.2 ± 6.1	−12.7 ± 7.4[a]	−13.9 ± 5.9[a]
Mid 3DS (%)	−10.2 ± 5.9	−11.8 ± 5.4[c]	−11.7 ± 4.8
Superior 3DS (%)	−11.6 ± 9.7	−14.4 ± 8.7	−12.5 ± 6.9
Basal AS (%)	57.3 ± 21.0	63.8 ± 24.2	62.4 ± 23.5
Mid AS (%)	64.9 ± 25.3	77.5 ± 27.0[a,b]	74.6 ± 27.8[b]
Superior AS (%)	82.3 ± 71.3[b]	102.2 ± 73.3[b]	74.8 ± 57.3

Abbreviations: 3DS, three-dimensional strain; AS, area strain; CS, circumferential strain; LS, longitudinal strain; RS, radial strain.
[a]P < .05 vs same strain at V_{max} < 30 mL.
[b]P < .05 vs basal same strain in the same V_{max} group.
[c]P < .05 vs superior same strain in the same V_{max} group.

TABLE 4 Three-dimensional speckle-tracking echocardiography-derived regional left atrial strains at atrial contraction in healthy subjects with different maximum left atrial volumes

	V_{max} < 30 mL (n = 46)	30 mL ≤ V_{max} ≤ 50 mL (n = 131)	V_{max} > 50 mL (n = 40)
Basal RS (%)	−5.1 ± 4.2	−7.9 ± 5.8[a]	−9.1 ± 4.2[a]
Mid RS (%)	−5.4 ± 3.9	−8.2 ± 5.3[a]	−8.7 ± 4.2[a]
Superior RS (%)	−5.6 ± 7.1	−9.6 ± 8.3[a,b]	−9.3 ± 8.2[a]
Basal CS (%)	15.3 ± 10.8	17.1 ± 8.5	16.8 ± 7.8
Mid CS (%)	12.7 ± 9.5	12.8 ± 8.4[b]	13.3 ± 6.6[b]
Superior CS (%)	16.9 ± 14.6	15.1 ± 13.8	16.8 ± 15.8
Basal LS (%)	7.5 ± 6.0	7.5 ± 5.0	7.6 ± 4.7
Mid LS (%)	9.7 ± 7.8	11.4 ± 7.5[b]	11.8 ± 7.2[b]
Superior LS (%)	10.4 ± 9.0	10.8 ± 8.9[b]	11.3 ± 6.6[b]
Basal 3DS (%)	−2.9 ± 3.9	−5.3 ± 5.3[a]	−6.7 ± 4.0[a]
Mid 3DS (%)	−3.1 ± 4.2	−5.1 ± 4.5[a]	−5.5 ± 3.6[a]
Superior 3DS (%)	−3.4 ± 7.9	−6.4 ± 7.1[a]	−5.6 ± 5.9
Basal AS (%)	22.7 ± 17.5	22.9 ± 11.7	23.0 ± 11.1
Mid AS (%)	22.9 ± 15.7	25.4 ± 14.9	28.3 ± 15.7
Superior AS (%)	30.2 ± 29.4	29.5 ± 28.9[b]	32.7 ± 28.8[b]

Abbreviations: 3DS, three-dimensional strain; AS, area strain; CS, circumferential strain; LS, longitudinal strain; RS, radial strain.
[a]P < .05 vs same strain at V_{max} < 30 mL.
[b]P < .05 vs basal same strain in the same V_{max} group. P < .05 vs superior same strain in the same V_{max} group.

and −1.0 ± 9.5%, respectively, with a correlation coefficient between these independent measurements of 0.95 (P < .0001), 0.87 (P < .0001), 0.95 (P < .0001), 0.65 (P = .004), 0.79 (P < .0001), 0.65 (P = .004), 0.62 (P = .004), and 0.65 (P = .005), respectively (inter-observer variability). The mean ± SD difference between values obtained by 2 measurements of observer 1 for the same parameters were 0.9 ± 5.7 mL, −1.1 ± 7.7 mL, 0.4 ± 4.3 mL, −1.3 ± 9.8%, 4.2 ± 15.0%, 1.2 ± 12.9%, 4.3 ± 35.1%, and 0.9 ± 9.1%, respectively, with a correlation coefficient between these independent measurements of 0.96 (P < .0001), 0.86 (P < .0001), 0.96 (P < .0001), 0.72

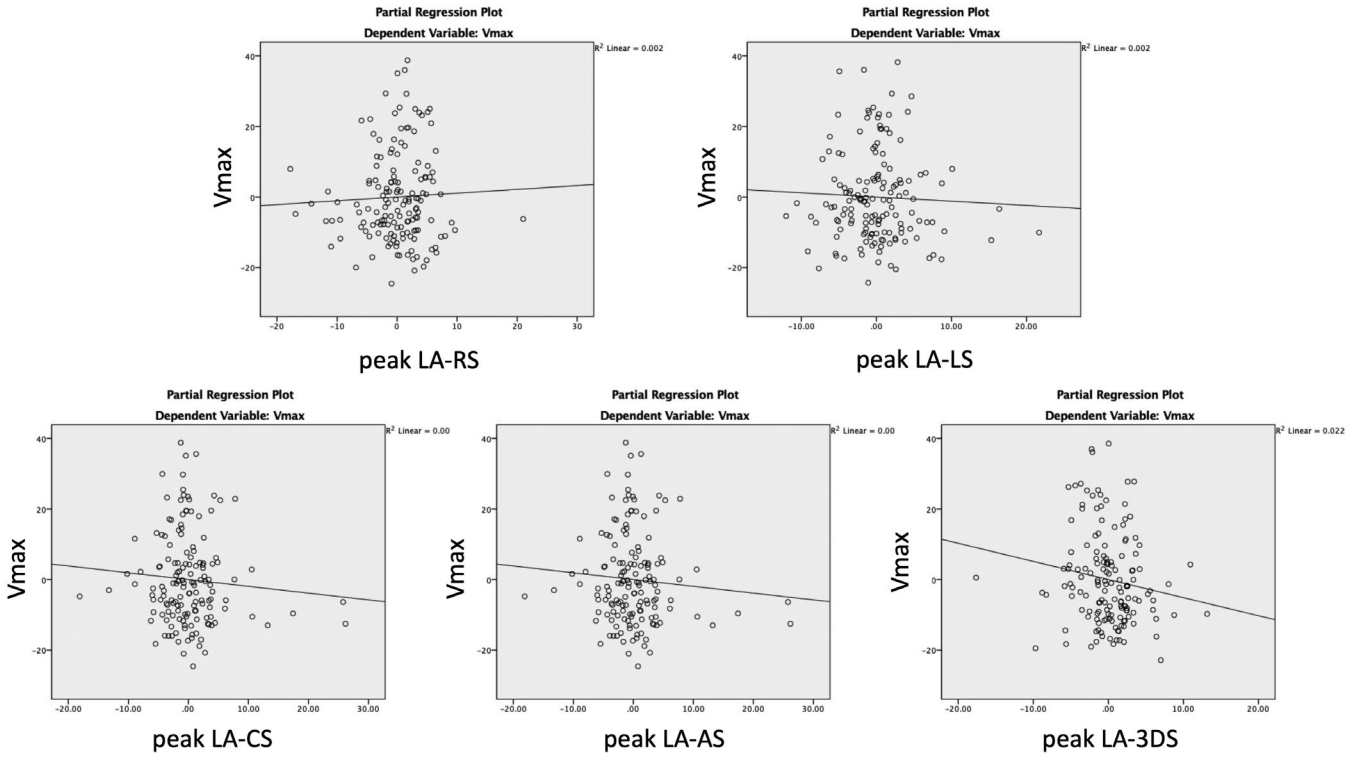

FIGURE 4 Linear regression plots demonstrating relationship between maximum left atrial volume and peak left atrial strains. LA-3DS, peak left atrial three-dimensional strain; LA-AS, peak left atrial area strain; LA-CS, peak left atrial circumferential strain; LA-LS, peak left atrial longitudinal strain; LA-RS, peak left atrial radial strain; V_{max}, maximum left atrial volume

(*P* = .0004), 0.75 (*P* < .0001), 0.58 (*P* = .05), 0.71 (*P* = .002) and 0.70 (*P* = .002), respectively (intraobserver variability).

3.7 | Informed consent

Informed consent was obtained from all individual participants included in the study.

4 | DISCUSSION

Due to recent developments in cardiovascular imaging, several echocardiographic, computed X-ray tomographic, and magnetic resonance imaging techniques become available not only for LA volumetric, but also contractility assessment.[2,7,9-11] Real-time 3D echocardiography (RT3DE) was found to be an alternative for LA volumetric measurements,[7] but the newly developed 3DSTE offers an opportunity for simultaneous assessment of LA volumes, volume-based functional properties, and strains using the same virtual 3D LA cast.[2,3,8] It allows a non-invasive, rapid, relatively low-cost examination of all phases of LA function without need for contrast or radiation.[2-5] Normal reference values of 3DSTE-derived LA volumes, and volume-based functional properties are also available.[8] The LA serves as a reservoir during LV systole, as a conduit during early diastole, and as a booster pump during late diastole.[1,9-11] LA volumes obtained by 3D echocardiography are a better index of LA size than LA diameter. Moreover, not only diagnostic, but also prognostic impact of LA strains is confirmed.[1,2,8,12]

In normal circumstances, if a larger blood volume flows into a cardiac chamber, increased contraction force ensues due to muscle streching (Frank-Starling mechanism). For ventricles, it features the effect of preload (end-diastolic volume) on systolic function.[13] However, similar relationship could be demonstrated for atria.[7,14,15] In a recent RT3DE study by Anwar et al., the Frank–Starling mechanism was demonstrated by an increase in LA contractility in response to an increase in LA preload only up to a point, beyond which LA contractility decreased.[7] Although our study and that of Anwar et al. are comparable, significant differences exist between subjects included. In the present study, only healthy subjects were evaluated, without known disease or pathological states with lower LA volumes, whereas there was a higher ratio of patients with hypertension, coronary disease, or noncompaction cardiomyopathy with dilated LA in the study of Anwar et al.[7] Moreover, LA strains were not assessed in Anwar's study, which investigated only similar LA volume-based functional properties. While AASV was greater in subjects with greater LA volumes and AAEF remained similar in our healthy cases with lower LA volumes, AASV and AAEF showed a higher-lower pattern in the presence of higher (50-70 mL and >70 mL, respectively) LA volumes in their patients. PASV was the greatest above 70 mL in the Anwar's study, while a continuous positive relationship could be demonstrated in our healthy subjects. PAEF was the lowest above 50 mL maximum LA volume in our study, but showed a lower-higher pattern in pathological cases with greater LA volumes. In both studies, TASV was greater with greater LA volumes with unchanged

TAEF.[7] However, we cannot incriminate the Frank-Starling mechanism in the differences we observed between patients depending on their LA volumes since we did not evaluate induced (eg, by posture or fluid challenge test) LA filling changes.

These results suggest different pattern of changes in stroke volumes and emptying fractions in parallel with a greater LA volume in healthy subjects with LA volumes in the lower range and in pathological cases with higher LA volumes. Higher LA strains, quantitative features of LA contractility, could be seen in the presence of higher LA volumes only up to a point in our healthy subjects. No further increase in LA strains representing LA function could be demonstrated above 50 mL maximum LA volume. These result suggest that an increase in LA contractility occurs only up to a point in healthy subjects in parallel with higher LA volumes. According to Anwar's study, a similar increase happens with LA volume-based functional properties in pathological cases with high LA volumes.[7]

There are several clinical implications of the present study. The above mentioned findings could help better understanding what happens in heart failure. With increasing hemodynamic load seen in early phases of cardiac decompensation, appropriate LA adaptation can be seen, which later disappear or is overrun.[7] LA strains have prognostic role in predicting morbidity and mortality.[16] However, further studies are warranted to confirm these findings.

4.1 | Limitations

One of the most important limitations of our study is that the 3DSTE-capable Toshiba tool provides lower image quality than 2D echocardiography. Moreover, the present study did not serve as a validation study due the validated nature of 3DSTE-derived LA volumetric and functional properties.[2,8] Therefore comparison of LA dimensions or volumetric and strain parameters by other methods than 3DSTE including 2DSTE was not aimed to be performed. Maybe it would have been better to use indexed LA volumes for comparisons, but LA volumes in respect of the cardiac cycle are also accepted for featuring LA size.[17] Finally, no volumetric or functional parameters of other chamber than LA were evaluated in this study. As we included only healthy subject, who were investigated at rest, and as we did not assess induced changes in atrial preload, we cannot draw definitive conclusion regarding the mechanisms involved in the relation we observed between LA volumes and strain.

4.2 | Conclusions

3DSTE seems to be an accurate and reproducible non-invasive tool for simultaneous assessment of LA volumetric and strain parameters. In healthy subjects, LA-RS and LA-3DS, objective features of LA contractility appear greater in healthy subjects with greater LA volumes, but only up to a point. Further studies are required to investigate underlying mechanisms and compare healthy and pathological subjects.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

Author elects to not share data

ETHICS STATEMENT

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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