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RESEARCH ARTICLE

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Normal reference values of left ventricular strain parameters in healthy adults: Real-life experience from the single-center three-dimensional speckle-tracking echocardiographic MAGYAR-Healthy Study

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Abstract

Introduction: A number of studies defined normal reference values of three-dimensional (3D) speckle-tracking echocardiography (3DSTE)-derived left ventricular (LV) strains. The present study aimed to quantify normal reference values of LV strains in healthy adult population in real clinical world settings in different age groups, and to determine age- and gender-dependence of these variables in a high volume single center.

Methods: The present prospective study included 296 healthy adult subjects. Among them, 124 were excluded due to inferior image quality during the 6-year recruitment period (2011-2017). The remaining population was further divided into four subgroups based on age decades.

Results: While global radial (RS) strain showed an increase-decrease-increase pattern with age, circumferential, longitudinal, and area strains (CS, LS, AS, respectively) were nonsignificantly lower in older ages. Only global LV-LS showed gender-dependency with higher values in females. Although moderately higher RS and 3DS and lower LS, and AS were observed in males, clear gender-dependency could not be detected in different age decades.

Conclusions: This study provides normal reference values of 3DSTE-derived global, segmental, mean segmental, and regional LV strains in healthy adult subjects based on real-life clinical experience. Age-, gender-, and functional nonuniformity of LV strains were also defined.

KEYWORDS

echocardiography, healthy subjects, left ventricular strain, three-dimensional

1 | INTRODUCTION

Due to significant developments in cardiovascular imaging, several new echocardiographic techniques emerged over the last few years, including three-dimensional (3D) and/or speckle-tracking echocardiography (STE).[1-8] 3D STE (3DSTE) incorporates advantages of both 3D and STE methodologies: it is able to simultaneously assess volumes and functional (strain) variables from the same 3D dataset.[1-6] A number of studies defining normal values of 3DSTE-derived parameters is presently available, including left ventricular (LV),[9-14] left atrial,[15] and right atrial[16,17] volumetric,[17] strain,[10-12,14] and rotational data.[9,10,13] The present prospective study aimed to quantify normal reference values of LV strains in healthy adult population in real clinical world settings in different age groups and to determine age- and gender-dependence of these variables in a high volume single center.

2 | PATIENTS AND METHODS

2.1 | Patient population

For this study, 296 healthy adult subjects in sinus rhythm were prospectively recruited on a voluntary basis. Among them, 124 subjects were excluded due to inferior image quality during the 6-year recruitment period (2011-2017). All subjects were considered to be healthy due to absence of acute or chronic disease, ECG abnormality, and history of regular drug use. In all subjects, complete two-dimensional Doppler echocardiography was performed and yielded normal results, and the examinations were extended with 3DSTE. All cases were included in the MAGYAR-Healthy Study (Motion Analysis of the heart and Great vessels bYthree-dimensionAl speckle-tRacking echocardiography in Healthy subjects), where 'magyar' means 'Hungarian' in the Hungarian language. MAGYAR-Healthy Study was organized to determine normal reference values of 3DSTE-derived parameters including LV among others in healthy adult subjects. Informed consent was given by all participants. The institutional human research committee approved the study, which complied with the ethical guidelines by the 1975 Declaration of Helsinki.

2.2 | Two-dimensional (speckle-tracking) echocardiography

An Aplio Artida ultrasound imaging system (Toshiba Medical Systems, Tochigi, Japan) with a PST-30SBP (1-5 MHz) phased-array transducer was used for completion of routine 2D Doppler echocardiographic examinations by experienced sonographers. LV dimensions, volumes,

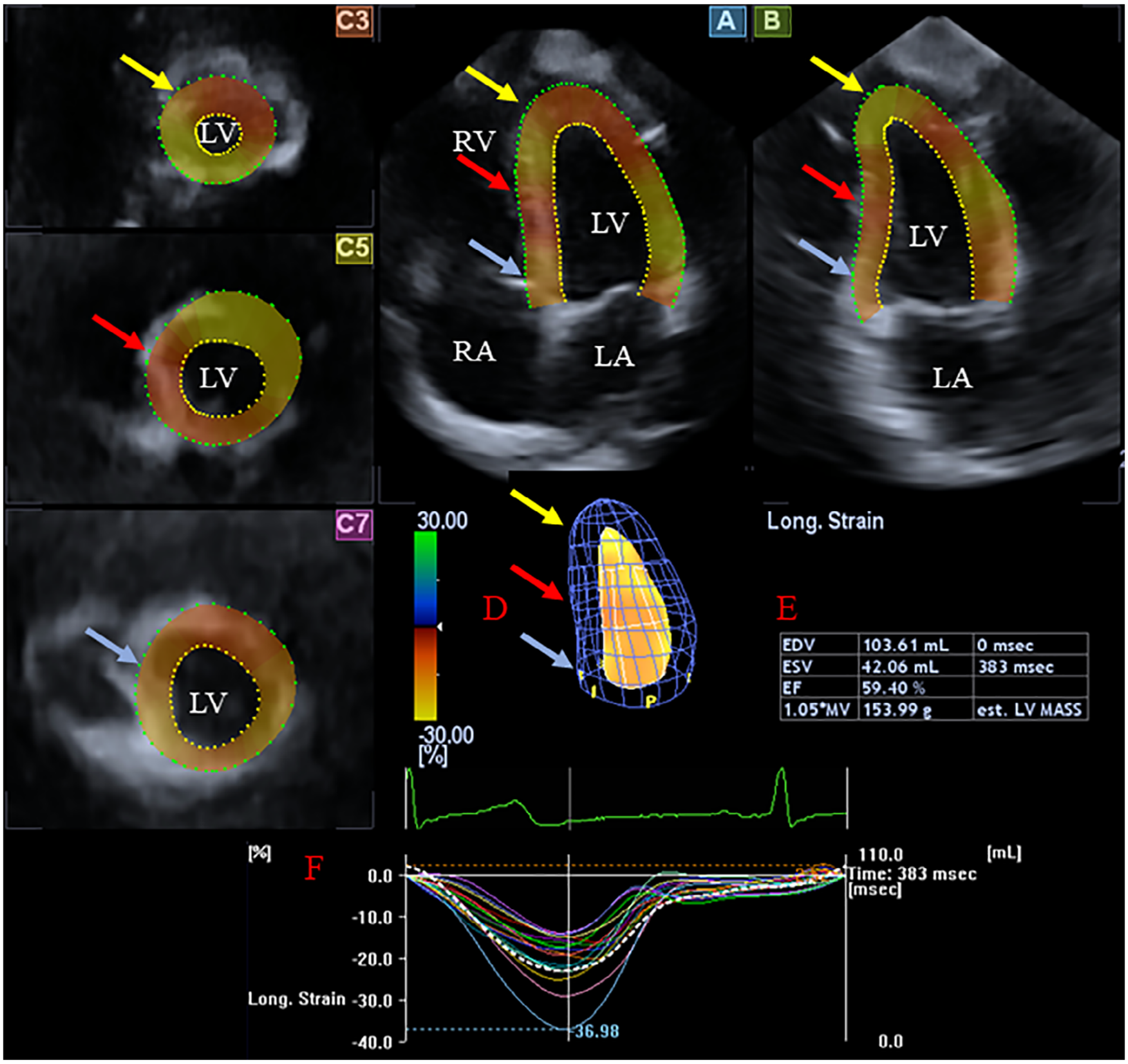

FIGURE 1 Three-dimensional (3D) speckle-tracking evaluation of left ventricular (LV) strain in a healthy subject. Apical four-chamber, A, and two-chamber views, B, and apical (C3), mideventricular (C5) and basal (C7) short-axis views are presented, extracted from the acquired 3D volumetric dataset. A 3D cast of the LV (red D), calculated volumetric LV variables (red E), and segmental longitudinal strain curves (red F) are also demonstrated. Each LV segment is represented by assigned colored curves, and apical, midventricular, and basal LV regions are represented by yellow, red, and blue arrows, respectively LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle

and ejection fraction and LA dimensions were quantified according to clinical standards.[18] Doppler measurements were used to exclude the presence of significant valvular regurgitation and stenosis according to guidelines. The 2DSTE-derived LV analyses were performed on loops recorded on apical four- (AP4CH) and two-chamber (AP2CH) views.

2.3 | Three-dimensional STE

The 3DSTE measurements were performed immediately after the 2D echocardiography with the same equipment, using a 3DSTE-capable PST-25SX matrix-array transducer.[3,4] First, full volume 3D datasets were acquired digitally from the apical window during a single breath-hold. Special settings were carried out acquiring six wedge-shaped sub-volumes in sinus rhythm during six cardiac cycles, from which a complete 3D full volume was automatically created by the software. Following data acquisitions, offline image analysis was performed using 3D Wall Motion Tracking software version 2.7 (Ultra Extend, Toshiba Medical Systems, Tochigi, Japan). Following automatic view selections (AP4CH and AP2CH views, three cross-sectional views at different levels of the LV), and definition of septal and lateral edges of the mitral annulus and the LV apex, sequential analysis and automatic contour detection were performed and LV volumetric and strain analyses were obtained using the 3D LV cast (Figure 1). Global (representing the whole LV) unidirectional/unidimensional longitudinal (LS), circumferential (CS) radial (RS) strains, and complex/multidirectional/multidimensional area (AS), and 3D (3DS) strains were measured. While AS combines LS and CS, 3DS serves as a resultant of all unidirectional/unidimensional LV strains, including RS, LS, and CS. Using a 16-segment LV model, segmental, and mean segmental LV strains were also assessed. Mean segmental values were calculated as an average of values of the 16 segments. LV regional strains were calculated form segmental LV strains calculated for each apical, midventricular, and basal LV regions (Figure 1).

TABLE 1 Demographic and 2D echocardiographic data of enrolled healthy adults

	All subjects (n = 172)	Males (n = 95)	Females (n = 77)
Age (y)	32.7 ± 12.3	33.6 ± 11.0	32.4 ± 13.7
Male gender (%)	95 (55%)	95 (100%)	0 (0%)
Body mass index (kg/m^2)	22.0 ± 1.6	23.0 ± 0.9	21.0 ± 1.3
Body surface area (m^2)	1.86 ± 0.12	1.96 ± 0.22	1.68 ± 0.13
Systolic blood pressure (mm Hg)	114 ± 9	115 ± 8	112 ± 6
Diastolic blood pressure (mm Hg)	78 ± 3	79 ± 2	76 ± 2
LA diameter (mm)	36.5 ± 3.9	38.3 ± 3.1	34.7 ± 4.1
LV end-diastolic diameter (mm)	48.1 ± 3.7	49.2 ± 3.6	46.6 ± 3.4
LV end-diastolic volume (mL)	106.6 ± 23.0	114.0 ± 23.2	97.9 ± 19.8
LV end-systolic diameter (mm)	32.6 ± 7.0	32.7 ± 2.9	31.7 ± 8.7
LV end-systolic volume (mL)	36.4 ± 9.2	40.5 ± 8.7	31.9 ± 7.5
Interventricular septum (mm)	8.9 ± 1.5	9.5 ± 1.2	8.3 ± 1.5
LV posterior wall (mm)	9.0 ± 1.6	9.5 ± 1.4	8.6 ± 1.8
LV ejection fraction (%)	65.9 ± 4.9	64.7 ± 4.0	67.2 ± 5.4
E (cm/s)	80.7 ± 17.4	77.3 ± 16.8	83.4 ± 18.4
A (cm/s)	64.3 ± 19.8	59.2 ± 15.0	70.1 ± 22.2
E/A	1.41 ± 0.34	1.38 ± 0.34	1.40 ± 0.37

Abbreviations: A, late transmitral flow velocity; E, early transmitral flow velocity; LA, left atrium; LV, left ventricle.

TABLE 2 Age-dependency of 3DSTE-derived mean segmental left ventricular strains

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40-49 y (n = 17)	Aged >50 y (n = 27)
RS (%)	27.7 ± 8.8	26.4 ± 8.1[a,b]	29.8 ± 9.2	25.5 ± 8.1	30.3 ± 10.4
CS (%)	−28.6 ± 4.8	−28.8 ± 4.7	−28.9 ± 4.2	−27.8 ± 5.8	−27.9 ± 5.5
LS (%)	−16.9 ± 2.4	−16.9 ± 2.4	−16.8 ± 2.3	−17.5 ± 1.7	−16.5 ± 2.9
3DS (%)	30.2 ± 8.8	29.0 ± 8.1	32.1 ± 9.0	28.0 ± 7.6	32.1 ± 10.2
AS (%)	−41.4 ± 4.9	−42.0 ± 5.0	−41.5 ± 4.1	−40.8 ± 5.1	−40.0 ± 5.2

Abbreviations: 3DS, 3D strain; 3DSTE, three-dimensional speckle-tracking echocardiography; AS, area strain; CS, circumferential strain; LS, longitudinal strain; RS, radial strain.

[a]$P < .05$ vs 30-39 years old group.

[b]$P < .05$ vs 50+ years old group.

2.4 | Statistical analysis

All data are reported as mean ± SD or number and percentage. Statistical significance was considered to be present if $P < .05$. Fisher's exact test was used for categorical variables. Shapiro-Wilks test was used to test normal distribution for continuous variables. Homogeneity of variance was assessed using Levene's test for equality of variances. Student's *t* test was used for normally distributed data, Mann-Whitney-Wilcoxon test was performed for nonnormally distributed data. Intraobserver and interobserver variability were assessed in 25 randomly selected healthy adult subjects, and intraclass correlation coefficient (ICC) was determined. Statistical analyses were performed using RStudio 2015 (RStudio, Boston, Massachusetts). MATLAB (The MathWorks Inc., Natick, Massachusetts) was used for offline data analysis and graph creation.

3 | RESULTS

3.1 | Demographic and two-dimensional echocardiographic data

The following groups of healthy subjects were created based on their age: 18 to 29 years (n = 94 with 45 males, mean age: 23.6 ± 2.8 years), 30 to 39 years (n = 34 with 27 males, mean age: 33.7 ± 2.8 years), 40 to 49 years (n = 17 with 11 males, mean age: 43.4 ± 3.4 years), and ≥50 years (n = 27 with 12 males, mean age: 56.4 ± 5.3 years). All subjects underwent a complete 2D echocardiographic and Doppler assessment yielding normal results (Table 1). None of the healthy subjects showed more than grade 1 valvular regurgitation or significant stenosis on any valve.

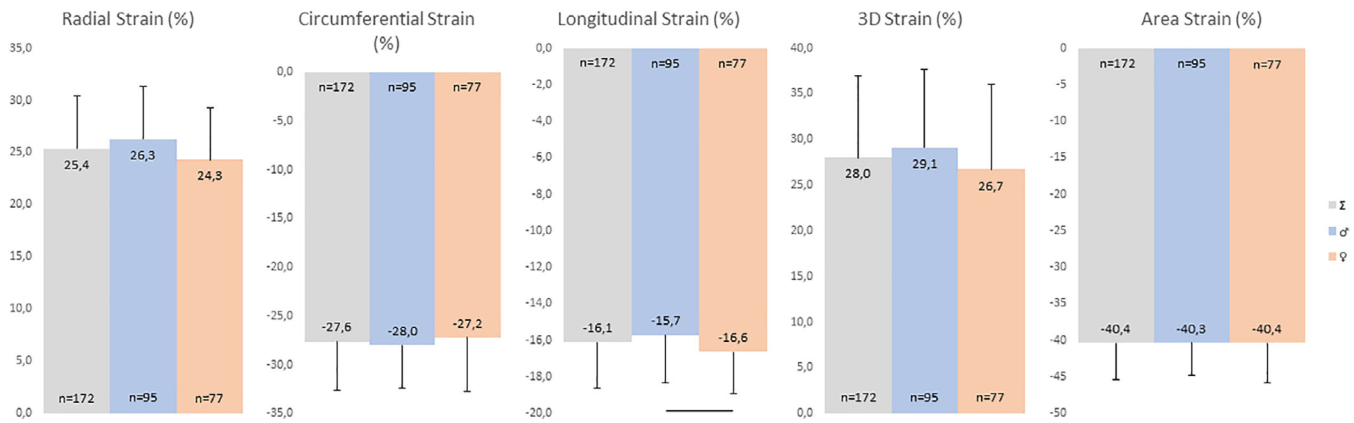

FIGURE 2 Mean global left ventricular strains and their relation to gender. Horizontal line represents significant difference between the groups. Gray filling: all subject; blue: male subjects; red: female subjects

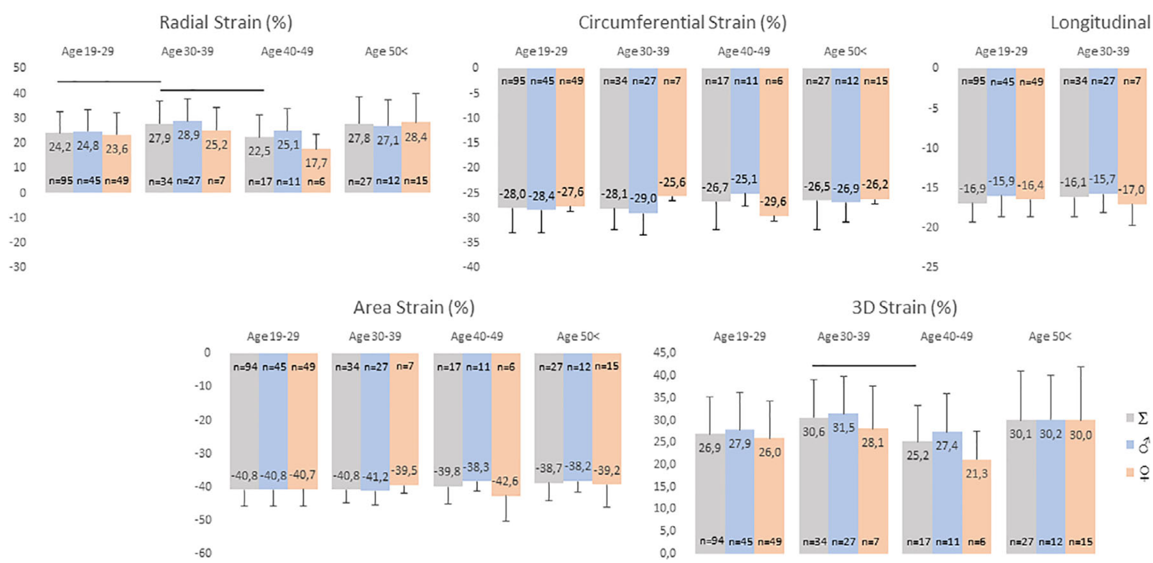

FIGURE 3 Global left ventricular strains in different age decades and their relation to gender are presented. Horizontal lines represent significant differences between the groups. Gray filling: all subject; blue: male subjects; red: female subjects

3.2 | Three-dimensional STE

3DSTE-derived LV global and mean segmental strains are demonstrated in Table 2 and Figures 2 and 3. Segmental LV-LS (Table 3), LV-CS (Table 4), LV-RS (Table 5), LV-3DS (Table 6), and LV-AS (Table 7) are also depicted. Regional LV strains calculated from segmental data are shown on Table 8.

3.3 | Age-dependency of LV strains

Global and mean segmental LV strains in different age groups are presented in Table 2 and Figure 3. While global RS showed an increase-decrease-increase pattern, CS, LS, and AS were nonsignificantly lower in older ages.

3.4 | Gender-dependency of LV strains

Only global LV-LS showed gender-dependency with higher values in females (Figure 2). Although moderately higher RS and 3DS and lower LS and AS were found in males, clear gender-dependency could not be detected in different age decades (Figure 3).

3.5 | Feasibility of 3DSTE-derived LV strain quantification

The measurements were performed between 2011 and 2017, while feasibility of 3DSTE analysis improved as the operators gained experience. The number of adequate measurements was 172 out of 296 (58% success ratio) for the overall time-period. For the last year, the number of good quality measurements, therefore the success ratio, improved significantly (47 out of 59, 80%, $P = .001$).

3.6 | Reproducibility of 3DSTE-derived strain measurements

Intraobserver ICCs were 0.87, 0.80, 0.80, 0.81, and 0.82 for RS, CS, LS, 3DS, and AS, respectively. Interobserver ICCs were 0.80, 0.76, 0.77, 0.77, and 0.78, respectively.

3.7 | Comparison of 3DSTE- and 2DSTE-derived LV-LS

Global and mean segmental LV-LS obtained by 3DSTE were lower than those obtained by 2DSTE for all subject (−16.1% ± 2.6% vs

TABLE 3 3DSTE-derived segmental left ventricular longitudinal strains and their age-dependency

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40–49 y (n = 17)	Aged >50 y (n = 27)
BA segment (%)	−24.3 ± 7.7	−23.4 ± 7.2	−25.4 ± 7.9	−26.3 ± 7.8	−24.5 ± 9.0
BAS segment (%)	−18.3 ± 7.2	−18.7 ± 7.1	−18.4 ± 7.7	−19.1 ± 6.4	−15.9 ± 7.0
BIS segment (%)	−16.3 ± 5.4	−16.9 ± 5.5[a]	−16.7 ± 4.7[a]	−15.7 ± 4.0	−13.9 ± 6.0
BI segment (%)	−17.8 ± 5.8	−17.9 ± 5.8	−18.2 ± 5.2	−17.3 ± 5.0	−17.1 ± 7.1
BIL segment (%)	−19.2 ± 7.6	−17.9 ± 7.4[a]	−19.1 ± 6.6	−20.2 ± 9.2	−23.0 ± 7.2
BAL segment (%)	−23.8 ± 8.0	−21.3 ± 7.5[a,b,c]	−24.7 ± 6.9[a]	−26.6 ± 7.4	−30.0 ± 7.6
MA segment (%)	−13.0 ± 6.9	−13.7 ± 6.8	−11.3 ± 6.9	−14.5 ± 6.9	−11.9 ± 7.2
MAS segment (%)	−13.6 ± 5.6	−13.2 ± 5.4	−13.8 ± 5.0	−14.2 ± 5.0	−14.2 ± 7.2
MIS segment (%)	−14.0 ± 4.7	−13.4 ± 4.4[a]	−13.9 ± 4.7	−14.4 ± 4.0	−15.6 ± 5.8
MI segment (%)	−13.9 ± 4.8	−13.4 ± 4.4	−13.9 ± 4.9	−14.9 ± 4.8	−14.8 ± 4.9
MIL segment (%)	−12.5 ± 5.4	−12.4 ± 5.7	−12.7 ± 5.7	−13.4 ± 5.1	−12.3 ± 4.4
MAL segment (%)	−14.3 ± 6.1	−15.5 ± 5.8[a]	−13.8 ± 6.4	−14.1 ± 6.5	−10.8 ± 5.5
AA segment (%)	−10.4 ± 6.1	−10.6 ± 5.4[a]	−10.4 ± 7.0	−9.2 ± 6.2	−10.2 ± 7.0
AS segment (%)	−23.0 ± 7.6	−23.5 ± 6.5[a]	−22.3 ± 7.0	−26.0 ± 9.5[a]	−20.4 ± 8.9
AI segment (%)	−23.1 ± 8.2	−24.9 ± 7.7[a]	−22.2 ± 8.1	−22.4 ± 8.4	−18.4 ± 8.2
AL segment (%)	−13.1 ± 7.0	−14.4 ± 7.2[a]	−12.1 ± 7.4	−11.0 ± 5.2	−11.1 ± 5.6

Abbreviations: 3DSTE, three-dimensional speckle-tracking echocardiography; AA, apical anterior; AI, apical inferior; AL, apical lateral; AS, apical septal; BA, basal anterior; BAL, basal anterolateral; BAS, basal anteroseptal; BI, basal inferior; BIL, basal inferolateral; BIS, basal inferoseptal; MA, midventricular anterior; MAL, midventricular anterolateral; MAS, midventricular anteroseptal; MI, midventricular inferior; MIL, midventricular inferolateral; MIS, midventricular inferoseptal.

[a] $P < .05$ vs 50+ year-old group.

[b] $P < .05$ vs 30 to 39-year-old group.

[c] $P < .05$ vs 40 to 49-year-old group.

TABLE 4 3DSTE-derived segmental left ventricular circumferential strains and their age-dependency

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40-49 y (n = 17)	Aged >50 y (n = 27)
BA segment (%)	−26.5 ± 11.0	−26.4 ± 10.8	−26.6 ± 10.4	−24.5 ± 11.2	−27.9 ± 12.6
BAS segment (%)	−26.3 ± 9.6	−26.8 ± 9.3	−27.2 ± 9.2	−24.5 ± 9.6	−24.7 ± 11.3
BIS segment (%)	−25.6 ± 10.2	−25.0 ± 9.7	−25.9 ± 11.2	−25.6 ± 8.6	−27.0 ± 11.4
BI segment (%)	−20.6 ± 8.9	−18.6 ± 8.5[a,b]	−22.6 ± 7.6	−20.3 ± 9.7	−24.6 ± 9.5
BIL segment (%)	−23.6 ± 9.9	−23.0 ± 9.5	−24.1 ± 8.1	−24.6 ± 11.8	−24.0 ± 12.1
BAL segment (%)	−29.2 ± 11.0	−28.7 ± 11.1	−28.7 ± 10.2	−26.2 ± 10.5	−32.9 ± 11.6
MA segment (%)	−29.7 ± 9.9	−31.2 ± 9.5	−28.6 ± 11.1	−27.5 ± 9.5	−27.5 ± 9.7
MAS segment (%)	−28.0 ± 9.3	−28.7 ± 9.0	−27.4 ± 9.3	−29.0 ± 8.5	−25.8 ± 10.8
MIS segment (%)	−29.3 ± 9.8	−28.7 ± 10.0	−30.4 ± 9.4	−30.2 ± 9.7	−29.3 ± 10.3
MI segment (%)	−28.7 ± 8.9	−28.5 ± 9.1	−30.6 ± 6.9	−27.0 ± 9.2	−27.8 ± 10.3
MIL segment (%)	−28.9 ± 9.0	−29.1 ± 8.3	−30.4 ± 7.8[c]	−25.7 ± 6.8	−28.1 ± 13.0
MAL segment (%)	−32.1 ± 10.4	−33.8 ± 9.7[b]	−32.0 ± 9.7	−28.8 ± 10.6	−28.6 ± 12.7
AA segment (%)	−26.2 ± 10.7	−27.2 ± 9.6	−25.3 ± 11.2	−27.2 ± 13.7	−23.4 ± 11.3
AS segment (%)	−32.4 ± 12.1	−33.8 ± 11.1[b]	−31.5 ± 11.9	−33.8 ± 13.5	−27.7 ± 13.8
AI segment (%)	−33.0 ± 12.1	−34.9 ± 11.7[b]	−32.5 ± 9.1	−33.3 ± 14.7	−27.6 ± 14.2
AL segment (%)	−34.2 ± 13.4	−35.6 ± 12.7	−33.0 ± 12.6	−36.4 ± 15.4	−30.2 ± 15.0

Abbreviations: 3DSTE, three-dimensional speckle-tracking echocardiography; AA, apical anterior; AI, apical inferior; AL, apical lateral; AS, apical septal; BA, basal anterior; BAL, basal anterolateral; BAS, basal anteroseptal; BI, basal inferior; BIL, basal inferolateral; BIS, basal inferoseptal; MA, midventricular anterior; MAL, midventricular anterolateral; MAS, midventricular anteroseptal; MI, midventricular inferior; MIL, midventricular inferolateral; MIS, midventricular inferoseptal.
[a]$P < .05$ vs 30 to 39-year-old group.
[b]$P < .05$ vs 50+ year-old group.
[c]$P < .05$ vs 40 to 49-year-old group.

TABLE 5 3DSTE-derived segmental left ventricular radial strains and their age-dependency

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40-49 y (n = 17)	Aged >50 y (n = 27)
BA segment (%)	38.4 ± 25.4	38.1 ± 28.6	38.3 ± 21.9	34.4 ± 18.7	42.1 ± 22.5
BAS segment (%)	38.8 ± 20.7	39.3 ± 20.1[a]	41.8 ± 22.9[a]	27.6 ± 13.5[b]	40.1 ± 22.1
BIS segment (%)	29.1 ± 14.1	27.4 ± 13.2[b]	31.1 ± 13.5	25.6 ± 12.4	33.9 ± 17.4
BI segment (%)	24.6 ± 15.7	22.4 ± 13.8	26.2 ± 14.2	25.8 ± 17.3	28.7 ± 21.0
BIL segment (%)	26.8 ± 19.5	22.8 ± 17.6[b,c]	29.6 ± 17.6	29.3 ± 16.0	35.0 ± 26.2
BAL segment (%)	31.3 ± 20.9	26.4 ± 18.4[b,c]	34.3 ± 22.4	33.3 ± 21.9	42.0 ± 22.1
MA segment (%)	33.5 ± 20.1	35.1 ± 22.0	30.7 ± 14.7	30.1 ± 20.8	33.8 ± 19.8
MAS segment (%)	36.6 ± 17.1	37.3 ± 17.4	36.8 ± 16.7	31.9 ± 14.9	36.8 ± 18.0
MIS segment (%)	29.3 ± 12.1	28.9 ± 10.9	32.3 ± 13.3	26.7 ± 13.9	28.1 ± 13.0
MI segment (%)	25.4 ± 13.9	23.6 ± 11.5[c]	29.1 ± 14.8	25.1 ± 14.5	26.3 ± 18.4
MIL segment (%)	25.7 ± 17.7	22.7 ± 14.8[c]	30.3 ± 20.0	26.2 ± 18.2	29.0 ± 21.7
MAL segment (%)	27.8 ± 18.0	26.5 ± 19.1	28.6 ± 15.7	28.0 ± 17.7	30.6 ± 18.2
AA segment (%)	17.2 ± 9.4	16.7 ± 8.1	17.9 ± 9.3	16.8 ± 14.4	18.5 ± 10.1
AS segment (%)	19.0 ± 10.8	18.6 ± 10.7	22.2 ± 11.7	16.7 ± 10.2	17.6 ± 9.8
AI segment (%)	18.4 ± 13.0	18.1 ± 12.7	22.6 ± 14.6[a]	14.4 ± 12.1	16.3 ± 11.5
AL segment (%)	17.1 ± 11.6	17.3 ± 11.7	18.2 ± 12.7	15.5 ± 10.4	15.6 ± 10.7

Abbreviations: 3DSTE, three-dimensional speckle-tracking echocardiography; AA, apical anterior; AI, apical inferior; AL, apical lateral; AS, apical septal; BA, basal anterior; BAL, basal anterolateral; BAS, basal anteroseptal; BI, basal inferior; BIL, basal inferolateral; BIS, basal inferoseptal; MA, midventricular anterior; MAL, midventricular anterolateral; MAS, midventricular anteroseptal; MI, midventricular inferior; MIL, midventricular inferolateral; MIS, midventricular inferoseptal.
[a]$P < .05$ vs 40 to 49-year-old group.
[b]$P < .05$ vs 50+ year-old group.
[c]$P < .05$ vs 30 to 39-year-old group.

TABLE 6 3DSTE-derived segmental left ventricular three-dimensional strains and their age-dependency

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40-49 y (n = 17)	Aged >50 y (n = 27)
BA segment (%)	40.6 ± 25.6	40.5 ± 28.7	41.0 ± 22.4	35.8 ± 17.9	43.2 ± 23.4
BAS segment (%)	40.5 ± 20.3	41.0 ± 19.4[a]	42.5 ± 22.9[a]	30.5 ± 12.3	42.2 ± 22.2
BIS segment (%)	30.2 ± 13.7	28.6 ± 12.8	32.0 ± 13.5	27.5 ± 12.5	34.4 ± 16.7
BI segment (%)	28.5 ± 15.0	26.8 ± 13.6	30.2 ± 13.8	30.3 ± 16.2	30.8 ± 19.6
BIL segment (%)	34.4 ± 18.2	30.9 ± 17.1[b,c]	37.6 ± 15.8	37.3 ± 15.1	40.1 ± 23.7
BAL segment (%)	35.4 ± 19.8	30.6 ± 17.8[b,c]	38.6 ± 19.7	37.8 ± 21.3	45.1 ± 21.4
MA segment (%)	34.3 ± 20.1	35.8 ± 22.2	31.5 ± 14.9	30.9 ± 19.6	35.1 ± 19.2
MAS segment (%)	37.5 ± 16.9	38.1 ± 17.3	37.9 ± 16.7	33.0 ± 13.3	37.8 ± 18.3
MIS segment (%)	30.6 ± 12.1	30.2 ± 10.7	33.4 ± 13.4	28.5 ± 14.4	29.4 ± 12.9
MI segment (%)	26.9 ± 13.6	25.5 ± 11.7[b]	30.5 ± 14.6	26.5 ± 13.9	26.6 ± 17.4
MIL segment (%)	28.6 ± 17.1	26.3 ± 14.4[b]	32.9 ± 19.2	28.4 ± 17.7	30.5 ± 20.9
MAL segment (%)	29.8 ± 17.9	28.9 ± 18.6	30.9 ± 14.9	29.5 ± 18.1	31.3 ± 20.0
AA segment (%)	18.3 ± 10.0	17.7 ± 8.5	18.7 ± 9.6	18.4 ± 14.9	19.5 ± 12.1
AS segment (%)	21.1 ± 11.6	20.5 ± 11.2	23.9 ± 12.6	18.6 ± 10.8	20.9 ± 11.8
AI segment (%)	20.4 ± 13.5	19.9 ± 13.2	24.6 ± 14.9	16.7 ± 12.9	18.8 ± 12.0
AL segment (%)	18.9 ± 12.0	19.0 ± 12.0	19.9 ± 12.9	18.4 ± 12.6	17.6 ± 10.8

Abbreviations: 3DSTE, three-dimensional speckle-tracking echocardiography; AA, apical anterior; AI, apical inferior; AL, apical lateral; AS, apical septal; BA, basal anterior; BAL, basal anterolateral; BAS, basal anteroseptal; BI, basal inferior; BIL, basal inferolateral; BIS, basal inferoseptal; MA, midventricular anterior; MAL, midventricular anterolateral; MAS, midventricular anteroseptal; MI, midventricular inferior; MIL, midventricular inferolateral; MIS, midventricular inferoseptal.

[a]$P < .05$ vs 40 to 49-year-old group.

[b]$P < .05$ vs 30 to 39-year-old group.

[c]$P < .05$ vs 50+ year-old group.

TABLE 7 3DSTE-derived segmental left ventricular area strains and their age-dependency

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40-49 y (n = 17)	Aged >50 y (n = 27)
BA segment (%)	−43.1 ± 11.4	−42.5 ± 10.4	−44.4 ± 11.5	−42.9 ± 11.3	−43.5 ± 14.4
BAS segment (%)	−39.3 ± 10.9	−40.4 ± 9.9[a]	−40.8 ± 9.7[a]	−38.5 ± 9.8	−34.4 ± 14.5
BIS segment (%)	−37.1 ± 11.0	−37.5 ± 970	−37.8 ± 12.0	−36.7 ± 9.3	−34.9 ± 14.2
BI segment (%)	−34.3 ± 9.2	−33.1 ± 8.4[b]	−36.5 ± 6.9	−34.3 ± 9.6	−35.5 ± 13.0
BIL segment (%)	−37.7 ± 11.2	−36.6 ± 10.8	−38.1 ± 9.3	−38.7 ± 12.8	−40.1 ± 13.6
BAL segment (%)	−45.3 ± 11.3	−43.3 ± 11.4[a]	−46.1 ± 8.1	−44.9 ± 9.8	−50.8 ± 14.0
MA segment (%)	−39.2 ± 12.0	−41.4 ± 10.8[a,b]	−36.8 ± 12.5	−38.2 ± 12.7	−35.8 ± 13.7
MAS segment (%)	−40.2 ± 10.2	−40.9 ± 9.1	−40.0 ± 9.5	−42.7 ± 8.1	−36.8 ± 14.3
MIS segment (%)	−39.5 ± 10.4	−39.0 ± 10.0	−40.5 ± 9.3	−40.9 ± 10.1	−38.9 ± 13.2
MI segment (%)	−38.5 ± 9.1	−38.2 ± 9.1	−40.2 ± 7.6	−38.8 ± 7.2	−37.3 ± 11.7
MIL segment (%)	−38.1 ± 9.4	−38.2 ± 8.8	−40.1 ± 7.5	−36.0 ± 5.7	−36.5 ± 13.8
MAL segment (%)	−42.5 ± 11.0	−45.1 ± 9.5[a,c]	−42.1 ± 10.2	−38.9 ± 11.2	−36.6 ± 13.9
AA segment (%)	−36.0 ± 12.3	−37.5 ± 10.5[a]	−35.1 ± 13.8	−36.6 ± 13.8	−32.2 ± 14.6
AS segment (%)	−49.2 ± 13.8	−51.2 ± 11.5[a]	−48.3 ± 13.1	−52.0 ± 14.6	−42.0 ± 18.6
AI segment (%)	−48.6 ± 13.6	−51.3 ± 12.0[a]	−48.7 ± 10.5[a]	−47.8 ± 14.5	−40.2 ± 18.1
AL segment (%)	−44.3 ± 15.0	−46.7 ± 14.0[a]	−42.7 ± 13.6	−44.4 ± 15.8	−38.7 ± 17.9

Abbreviations: 3DSTE, three-dimensional speckle-tracking echocardiography; AA, apical anterior; AI, apical inferior; AL, apical lateral; AS, apical septal; BA, basal anterior; BAL, basal anterolateral; BAS, basal anteroseptal; BI, basal inferior; BIL, basal inferolateral; BIS, basal inferoseptal; MA, midventricular anterior; MAL, midventricular anterolateral; MAS, midventricular anteroseptal; MI, midventricular inferior; MIL, midventricular inferolateral; MIS, midventricular inferoseptal.

[a]$P < .05$ vs 50+ year-old group.

[b]$P < .05$ vs 30 to 39-year-old group.

[c]$P < .05$ vs 40 to 49-year-old group.

TABLE 8 3DSTE-derived regional left ventricular strains and their age-dependency

	All (n = 172)	Aged 18-29 y (n = 94)	Aged 30-39 y (n = 34)	Aged 40-49 y (n = 17)	Aged >50 y (n = 27)
RS_{basal} (%)	31.6 ± 12.9	29.4 ± 12.2[a,b]	34.0 ± 12.2[b]	29.3 ± 11.3[b]	37.6 ± 15.1[b]
$RS_{midventricular}$ (%)	29.9 ± 10.7	29.0 ± 10.1[b]	31.8 ± 10.9[b]	28.0 ± 9.6[b]	31.6 ± 13.2[b]
RS_{apical} (%)	18.1 ± 8.9	17.7 ± 8.5	20.5 ± 10.2	15.9 ± 8.0	17.4 ± 8.5
CS_{basal} (%)	−25.4 ± 5.2	−24.8 ± 5.1[a-c]	27.9 ± 9.2[b,c]	−24.3 ± 4.7[b]	−27.2 ± 6.1
$CS_{midventricular}$ (%)	−29.6 ± 6.0	−30.0 ± 5.7[b]	−30.2 ± 5.3	−28.0 ± 6.2	−28.5 ± 7.5
CS_{apical} (%)	−31.7 ± 10.1	−32.9 ± 9.7[a,c]	−31.0 ± 8.6	−32.7 ± 12.9	−28.2 ± 11.3
LS_{basal} (%)	−19.9 ± 4.7	−19.4 ± 4.7[b]	−20.4 ± 4.3[b,c]	−20.9 ± 3.9[b,c]	−20.7 ± 5.4[b,c]
$LS_{midventricular}$ (%)	−13.5 ± 3.9	−13.6 ± 4.1	−13.2 ± 3.6[b]	−14.3 ± 2.7[b]	−13.3 ± 4.6
LS_{apical} (%)	−17.4 ± 5.7	−18.3 ± 5.3[a]	−16.8 ± 6.2	−17.1 ± 5.0	−15.0 ± 6.0
$3DS_{basal}$ (%)	35.1 ± 12.3	33.1 ± 11.9[a,b]	37.4 ± 11.7[b]	33.2 ± 10.9[b]	39.9 ± 14.2[b]
$3DS_{midventricular}$ (%)	31.5 ± 10.4	30.8 ± 9.8[b]	33.3 ± 10.8[b]	29.5 ± 8.9[b]	32.7 ± 13.0[b]
$3DS_{apical}$ (%)	19.8 ± 9.4	19.3 ± 8.9	22.1 ± 10.6	18.0 ± 8.8	19.7 ± 9.6
AS_{basal} (%)	−39.8 ± 6.0	−38.9 ± 6.1[b]	−41.1 ± 4.5	−39.3 ± 5.5	−41.5 ± 6.9
$AS_{midventricular}$ (%)	−40.0 ± 6.4	−40.5 ± 6.2[b]	−40.3 ± 5.6	−39.2 ± 5.9	−38.6 ± 8.1
AS_{apical} (%)	−44.9 ± 11.6	−46.7 ± 10.5[a]	−44.1 ± 10.5	−45.2 ± 13.1	−39.9 ± 14.3

Abbreviations: 3DS, 3D strain; 3DSTE, three-dimensional speckle-tracking echocardiography; AS, area strain; CS, circumferential strain; LS, longitudinal strain; RS, radial strain.
[a]$P < .05$ vs 50+ year-old group.
[b]$P < .05$ vs apical segment (same type of strain).
[c]$P < .05$ vs midventricular segment (same type of strain).

−20.3% ± 0.3% and −16.9% ± 2.4% vs −20.4% ± 0.2%, $P < .05$ and $P < .05$, respectively), for males (−15.7% ± 2.5% vs −19.8% ± 0.4% and 15.9% ± 2.1% vs −20.1% ± 0.2%, $P < .05$), and for females (−16.6% ± 2.4% vs −20.6% ± 0.5% and 16.9% ± 2.1% vs −20.6% ± 0.4%, $P < .05$).

4 | DISCUSSION

The present study aimed to determine normal reference values of 3DSTE-derived LV strains and their age- and gender-dependency in healthy adult subjects in a single academic high-volume center with 10-year 3DSTE experience. In a recent meta-analysis, normal ranges of the most preferably used unidirectional STE-derived LV strains were defined from 2597 subjects out of 24 studies.[19] Normal values of global LS, CS, and RS varied from −15.9% to −22.1% (mean −19.7%), −20.9% to −27.8% (mean −23.3%), and 35.1% to 59.0% (mean 47.3%), respectively. Such a broad range of strain values in apparently healthy subjects underscores significant between-study heterogeneity and inconsistency.[19] Another specific meta-analysis by Truong et al was conducted to define the normal ranges of different 3DSTE-derived LV strains.[14] Global LS varied from −15.8% to −23.4% (mean −19.1%), CS varied from −15.5% to −39.5% (mean −22.4%), RS varied from 19.8% to 86.6% (mean 47.5%), and AS varied from −27.4% to −50.8% (mean −35.0%). One of the most important messages of this meta-analysis is that variations in the normal ranges are significantly associated with the software used for strain analysis, emphasizing its importance during the interpretation of strain data.[14] Using the same vendor's machine (Toshiba Medical Systems) and 3D Wall Motion Tracking software, the global strains we found were in a narrower range. Strains were −16.2% to −17.9% for global LS, −24.7% to −32.9% for global CS, 24.4% to 42.0% for global RS, and −39.9% to −46.3% for global AS.[14] We found LS, CS, and AS values almost similar to those from a meta-analysis and a multicenter study.[10,12] However, we reported significantly lower global RS values, suggesting measurement inaccuracies. Moreover, in most cases, SD of strains proved to be much higher in our real-life settings than those reported by other studies.

Our results are in agreement with previous studies demonstrating gender-dependency only of global LS.[12] No large gender differences in LV strains could be demonstrated between the values of males and females. Moreover, different LV levels and walls showed differences in magnitude of some LV strains, suggesting their functional non-uniformity.[12] However, further studies are warranted to confirm the present findings. Moreover, significant cooperative works are necessary between vendors to solve the above-mentioned problems, including measurement inconsistency.

The relevance of the present study lies in that it reports normal reference values of not only global, but also segmental/regional LV strains representing segmental/regional heterogeneity of myocardial function in healthy adult subjects. Some disorders show segmental/regional changes in LV myocardial function (contractility, deformation) represented by LV strains due to necrosis, edema, storage, fibrosis, and so forth, affecting only some LV segments or regions. Therefore, determination of normal reference values of these LV strains has unquestionable importance for comparative purposes. This information could affect care and management of patients and their consecutive long-term outcome.

5 | LIMITATIONS

Results of the present study could have been affected by the fact that 3DSTE has a lower frame rate and spatial resolution than conventional 2D echocardiography.[3,4] Image quality is also highly dependent on stitching and motion artifacts. A large proportion of healthy subjects (about 42%) was excluded because of poor image quality, when 3 or more out of the 16 myocardial segments could not be analyzed. This highlights the difference between real-life experience and initial validation studies, and emphasizes the necessity for further improvements in image quality. Only 3DSTE-derived LV strains were measured, and strains of other heart chambers were not examined.[3,4,15] Although it would have been possible to determine LV rotational variables using the same 3D LV cast, they were also not assessed in the present study. However, normal reference values for 3DSTE-derived ones are already available,[13] and 3DSTE-derived LV strain measurements have already been validated.[20]

6 | CONCLUSION

This study reports normal reference values of 3DSTE-derived global, segmental, mean segmental, and regional LV strains in healthy adult subjects, in a real-life clinical settings, and shows age, gender, and functional nonuniformity of LV strains.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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

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