

Jing Zhang, Kai Li, Huan Min, Yang Xie, Chunmei Zhou, Bo Shi

Department of Ultrasound, The Second Affiliated Hospital of Chengdu Medical College, Chengdu, Sichuan Province, China

THREE-DIMENSIONAL SPECKLE TRACKING ECHOCARDIOGRAPHY FOR ASSESSING THE DEGREE OF MYOCARDIAL FIBROSIS AND PREDICTING PROGNOSIS IN PATIENTS WITH HYPERTROPHIC CARDIOMYOPATHY

<i>Objective</i>	To investigate the correlation between three-dimensional speckle tracking echocardiography (3D-STE) parameters and degree of myocardial fibrosis in patients with hypertrophic cardiomyopathy (HCM), and to evaluate the prognostic value of 3D-STR.
<i>Material and methods</i>	A retrospective analysis of 300 HCM patients diagnosed between January 2022 and December 2024 was conducted. All the patients had been examined with 3D-STE and cardiac magnetic resonance (CMR) with late gadolinium enhancement (LGE). Based on the LGE percentage, the patients were stratified into mild fibrosis (LGE% $\leq$ 15%, n=168) and moderate-to-severe fibrosis groups (LGE% $\geq$ 15%, n=115). Pearson/Spearman correlation analysis was used to assess the relationship between 3D-STE parameters and LGE%, ROC curve analysis to evaluate the diagnostic performance of 3D-STE, and Cox regression analysis to determine the prognostic value 3D-STE. The primary composite endpoint encompassed cardiac death, heart failure hospitalization, malignant ventricular arrhythmias, cardio-genic syncope, and stroke.
<i>Results</i>	283 patients completed a median follow-up of 18.0 mos. The 3D-GS absolute value demonstrated a strong correlation with LGE% findings ($r=-0.714$, $p<0.001$), outperforming other strain and tor-sion parameters. Multivariate linear regression identified the 3D-GS absolute value as an independent predictor of myocardial fibrosis (as quantified by LGE%) ($\beta=-0.486$, $p<0.001$). The AUC of 3D-GS absolute value for predicting moderate-to-severe fibrosis was 0.896 (95% CI: 0.860–0.932), with an optimal cutoff value of 12.1% (sensitivity 86.1%, specificity 82.7%). During follow-up, 92 patients (32.5%) experienced primary composite endpoint events. Multivariate Cox regression revealed that the 3D-GS absolute value independently predicted major adverse cardiovascular events (HR=0.754, $p<0.001$), with a model C-index of 0.824.
<i>Conclusion</i>	3D-STE parameters, particularly 3D-GS, demonstrate close correlation with the degree of myocardial fibrosis in HCM patients. It exhibited excellent diagnostic performance and prognostic value and may serve as a practical, non-invasive tool for assessment of myocardial fibrosis.
<i>Keywords</i>	Hypertrophic cardiomyopathy; three-dimensional speckle tracking echocardiography; myocardial fibrosis; cardiac magnetic resonance; prognosis
<i>For citations</i>	Jing Zhang, Kai Li, Huan Min, Yang Xie, Chunmei Zhou, Bo Shi. Three-Dimensional Speckle Tracking Echocardiography for Assessing the Degree of Myocardial Fibrosis and Predicting Prognosis in Patients With Hypertrophic Cardiomyopathy. Kardiologiia. 2026;66(3):74–86. [Russian: Цзин Чжан, Кай Ли, Хуань Минь, Ян Се, Чуньмэй Чжоу, Бо Ши. Использование трехмерной спекл-трекинг эхокардиографии в оценке выраженности фиброза миокарда и прогнозировании исходов у паци-ентов с гипертрофической кардиомиопатией. Кардиология. 2026;66(3):74–86].
<i>Corresponding author</i>	Bo Shi. Email: 878017236@qq.com

SUPPLEMENTARY MATERIALS

Table S1. Intra-observer and inter-observer reproducibility analysis of 3D-STE and CMR-LGE parameters

Parameter	Intra-observer ICC (95% CI)	Intra-observer CV (%)	Inter-observer ICC (95% CI)	Inter-observer CV (%)	Intra-observer Bias (95% Limits of Agreement)	Inter-observer Bias (95% Limits of Agreement)
3D-STE Strain Parameters						
3D-GS absolute value	0.94 (0.88–0.97)	4.2	0.91 (0.83–0.96)	5.8	0.08% (–1.2 to 1.4%)	0.15% (–1.6 to 1.9%)
GLS	0.93 (0.86–0.97)	4.5	0.89 (0.79–0.95)	6.2	–	–
GCS	0.89 (0.79–0.95)	5.8	0.86 (0.74–0.93)	7.6	–	–
GRS	0.91 (0.82–0.96)	5.2	0.87 (0.76–0.94)	7.2	–	–
GAS	0.92 (0.84–0.96)	6.3	0.88 (0.78–0.94)	8.1	–	–
3D-STE Torsion Parameters						
Peak twist	0.88 (0.77–0.94)	8.4	0.84 (0.70–0.92)	10.2	–	–
Twist rate	0.86 (0.74–0.93)	9.6	0.82 (0.67–0.91)	11.8	–	–
Synchrony Parameter						
SDT	0.9 (0.81–0.95)	7.2	0.87 (0.76–0.94)	8.6	–	–
CMR-LGE Parameters						
LGE%	0.96 (0.91–0.98)	5.3	0.93 (0.86–0.97)	7.1	0.3% (–2.1 to 2.7%)	0.5% (–2.8 to 3.8%)
LGE mass	0.95 (0.90–0.98)	6.8	0.92 (0.84–0.96)	8.4	–	–
CMR-LVEF	0.94 (0.88–0.97)	3.2	0.91 (0.83–0.96)	4.6	–	–

ICC, intraclass correlation coefficient; CI, confidence interval; CV, coefficient of variation; 3D-GS, three-dimensional global strain; GLS, global longitudinal strain; GCS, global circumferential strain; GRS, global radial strain; GAS, global area strain; SDT, systolic dyssynchrony index; LGE, late gadolinium enhancement; LVEF, left ventricular ejection fraction; CMR-derived LVEF, left ventricular ejection fraction measured by cardiac magnetic resonance.

Table S2. Comparison of the conventional echocardiographic parameters between the two groups

Variable	Mild Fibrosis Group (n=168)	Moderate-to-Severe Fibrosis Group (n=115)	Test Statistic	p Value
LVEDd (mm)	45.8±5.2	46.4±5.8	t=0.937	0.349
LVESd (mm)	28.6±4.3	30.2±5.1	t=2.876	0.042
IVS (mm)	18.3±3.2	21.2±4.1	t=6.626	<0.001
LVPW (mm)	11.8±2.1	12.8±2.4	t=3.799	0.002
MWT (mm)	20.5±3.8	23.9±4.6	t=6.863	<0.001
LAD (mm)	41.2±5.6	45.8±6.3	t=6.527	<0.001
LAVI (ml/m ²)	38.4±9.2	48.6±11.8	t=8.158	<0.001
LVEF (%)	68.5±6.8	62.3±8.2	t=7.015	<0.001
E wave (cm/s)	82.6±18.4	91.3±22.6	t=3.601	<0.001
A wave (cm/s)	68.4±16.2	64.2±18.4	t=2.026	0.044
E/A ratio	1.24±0.35	1.48±0.51	t=4.598	<0.001
e' lateral wall (cm/s)	7.8±2.1	6.2±1.9	t=6.562	<0.001
e' septum (cm/s)	5.6±1.4	4.7±1.3	t=5.524	<0.001
E/e' ratio	12.4±3.8	16.9±5.2	t=8.361	<0.001
Resting LVOT gradient (mmHg)	28.6±24.3	42.8±31.6	t=4.193	<0.001
Valsalva LVOT gradient (mmHg)	52.4±35.2	78.6±42.8	t=5.624	<0.001
SAM positive	84 (50.0)	74 (64.3)	χ ² =5.949	0.015

Data are presented as mean±SD or n (%), where percentages were calculated within each study group using the group total as the denominator. VEDd, left ventricular end-diastolic diameter; LVESd, left ventricular end-systolic diameter; IVS, interventricular septal thickness; LVPW, left ventricular posterior wall thickness; MWT, maximum wall thickness; LAD, left atrial diameter; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction; E wave, early diastolic transmitral peak velocity; A wave, late diastolic transmitral peak velocity; e', early diastolic mitral annular velocity; LVOT, left ventricular outflow tract; SAM, systolic anterior motion; SD, standard deviation.

Table S3. Comparison of longitudinal strain in the 17 left ventricular segments between two groups

Segment	Mild Fibrosis Group (n=168)	Moderate-to-Severe Fibrosis Group (n=115)	Test Statistic	p Value
Basal Segments				
Segment 1 (basal anteroseptal)	-17.6±3.2	-13.4±3.6	t=10.264	<0.001
Segment 2 (basal anterior)	-17.8±2.9	-13.8±3.4	t=10.628	<0.001
Segment 3 (basal lateral)	-17.2±3.1	-13.2±3.5	t=10.082	<0.001
Segment 4 (basal posterior)	-16.8±3.0	-12.6±3.2	t=11.368	<0.001
Segment 5 (basal inferior)	-16.9±2.8	-12.8±3.1	t=11.624	<0.001
Segment 6 (basal inferoseptal)	-17.0±3.2	-12.9±3.6	t=10.086	<0.001
Mid Segments				
Segment 7 (mid anteroseptal)	-17.4±2.8	-13.2±3.2	t=11.628	<0.001
Segment 8 (mid anterior)	-17.2±2.9	-13.1±3.4	t=10.846	<0.001
Segment 9 (mid lateral)	-16.8±3.0	-12.6±3.3	t=11.168	<0.001
Segment 10 (mid posterior)	-16.6±2.7	-12.4±3.1	t=12.086	<0.001
Segment 11 (mid inferior)	-16.4±2.6	-12.3±2.9	t=12.468	<0.001
Segment 12 (mid inferoseptal)	-16.9±2.8	-12.8±3.2	t=11.364	<0.001
Apical Segments				
Segment 13 (apical anterior)	-16.8±3.4	-12.4±3.8	t=10.264	<0.001
Segment 14 (apical lateral)	-16.2±3.6	-11.8±4.0	t=9.782	<0.001
Segment 15 (apical inferior)	-15.6±3.2	-11.2±3.6	t=10.864	<0.001
Segment 16 (apical septal)	-15.8±3.4	-11.4±3.8	t=10.328	<0.001
Segment 17 (apical cap)	-16.1±3.8	-12.1±4.2	t=8.464	<0.001
Regional Mean Values				
Basal segment mean	-17.2±2.8	-13.1±3.2	t=11.526	<0.001
Mid segment mean	-16.9±2.6	-12.8±3.0	t=12.284	<0.001
Apical segment mean	-16.1±3.2	-11.8±3.6	t=10.528	<0.001
Inter-segmental strain difference	4.8±2.1	7.6±3.2	t=8.264	<0.001

Data are mean±SD. All p values underwent Bonferroni correction (corrected significance level $\alpha'=0.003$). Regional mean strain values were calculated by first computing the mean strain of segments within that region for each patient, then calculating mean±SD across all patients. Inter-segmental strain difference represents the difference between maximum and minimum longitudinal strain absolute values among 17 segments in each patient, with values shown as mean±SD across all patients.

Table S4. Comparison of cardiac magnetic resonance imaging parameters between two groups

Parameter	Mild Fibrosis Group (n=168)	Moderate-to-Severe Fibrosis Group (n=115)	Test Statistic	p Value
LVEDV index (ml/m ²)	76.4±14.2	81.8±16.8	t=2.941	0.004
LVESV index (ml/m ²)	24.6±6.8	31.4±9.2	t=7.058	<0.001
LVEF (%)	67.8±6.4	61.6±8.6	t=6.803	<0.001
LVMI (g/m ²)	98.6±18.4	116.8±22.6	t=7.442	<0.001
LGE mass (g)	12.4±6.8	35.6±14.2	t=17.628	<0.001
LGE (%)	8.4 (5.6, 11.2)	21.6 (17.8, 28.4)	Z=-14.862	<0.001
LGE-involved segments	3.2±1.8	7.6±2.8	t=15.618	<0.001
LGE distribution pattern	–	–	$\chi^2=42.683$	<0.001
Focal	132 (78.6)	48 (41.7)	–	–
Diffuse	18 (10.7)	42 (36.5)	–	–
Septal insertion point enhancement	18 (10.7)	25 (21.7)	–	–

Data are mean±SD, median (interquartile range), or number (%), where percentages were calculated using the total number of patients in each study group as the denominator. LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; LVEF, left ventricular ejection fraction; LVMI, left ventricular mass index; LGE, late gadolinium enhancement.

Table S5. Correlation analysis between various parameters and LGE%

Parameter	Correlation Coefficient r	p Value	Correlation Strength
3D-STE Parameters			
GLS absolute value	−0.682	<0.001	Strong correlation
GCS absolute value	−0.598	<0.001	Moderate correlation
GRS	−0.624	<0.001	Strong correlation
GAS absolute value	−0.656	<0.001	Strong correlation
3D-GS absolute value	−0.714	<0.001	Strong correlation
Peak twist	−0.586	<0.001	Moderate correlation
Twist rate	−0.542	<0.001	Moderate correlation
SDT	0.542	<0.001	Moderate correlation
Conventional Echocardiographic Parameters			
MWT	0.524	<0.001	Moderate correlation
LAVI	0.486	<0.001	Moderate correlation
LVEF	−0.458	<0.001	Moderate correlation
E/e' ratio	0.512	<0.001	Moderate correlation
Clinical Parameters			
Age	0.286	<0.001	Weak correlation
NT-proBNP	0.468	<0.001	Moderate correlation

Correlation coefficients were calculated using Pearson correlation analysis for normally distributed data and Spearman rank correlation analysis for non-normally distributed data. 3D-STE, three-dimensional speckle tracking echocardiography; GLS, global longitudinal strain; GCS, global circumferential strain; GRS, global radial strain; GAS, global area strain; 3D-GS, three-dimensional global strain; SDT, standard deviation of time to peak strain; MWT, maximum wall thickness; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction; E/e', ratio of early diastolic transmitral peak velocity to early diastolic mitral annular velocity; NT-proBNP, N-terminal pro-B-type natriuretic peptide; LGE, late gadolinium enhancement.

Table S6. Univariate Cox regression analysis of primary composite endpoint events

Parameter	HR	95% CI	Wald χ^2	p Value
Age (per 1-yr increase)	1.028	1.008–1.048	7.634	0.006
Male	1.246	0.826–1.880	1.086	0.297
BSA (per 0.1 m ² increase)	1.082	0.894–1.310	0.612	0.434
NYHA III–IV CF	2.846	1.892–4.282	22.568	<0.001
Syncope or presyncope	1.982	1.196–3.284	6.982	0.008
Family history	1.428	0.924–2.208	2.542	0.111
NT-proBNP (per 100 pg/ml increase)	1.001	1.001–1.002	18.246	<0.001
Atrial fibrillation	2.134	1.276–3.568	8.324	0.004
Pathological Q wave	1.876	1.128–3.120	5.912	0.015
MWT (per 1 mm increase)	1.086	1.044–1.130	18.742	<0.001
LAVI (per 1ml/m ² increase)	1.042	1.024–1.060	22.486	<0.001
LVEF (per 1% increase)	0.946	0.922–0.970	20.138	<0.001
E/e' ratio (per 1-unit increase)	1.082	1.048–1.117	24.564	<0.001
GLS absolute value (per 1% increase)	0.762	0.702–0.826	36.482	<0.001
GCS absolute value (per 1% increase)	0.884	0.838–0.932	22.146	<0.001
GRS (per 1% increase)	0.952	0.932–0.972	24.682	<0.001
GAS absolute value (per 1% increase)	0.836	0.786–0.889	28.964	<0.001
3D-GS absolute value (per 1% increase)	0.698	0.634–0.769	48.326	<0.001
SDT (per 1 ms increase)	1.032	1.020–1.044	26.482	<0.001
LGE% (per 1% increase)	1.096	1.072–1.120	56.842	<0.001
Moderate-to-severe fibrosis	3.624	2.362–5.562	32.684	<0.001

HR, hazard ratio; CI, confidence interval; BSA, body surface area; NYHA, New York Heart Association; CF, cardiac function; NT-proBNP, N-terminal pro-B-type natriuretic peptide; MWT, maximum wall thickness; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction; E/e', ratio of early diastolic transmitral peak velocity to early diastolic mitral annular velocity; GLS, global longitudinal strain; GCS, global circumferential strain; GRS, global radial strain; GAS, global area strain; 3D-GS, three-dimensional global strain; SDT, standard deviation of time to peak strain; LGE, late gadolinium enhancement.