Ventricular Diastolic Dimension over Maximal Myocardial Thickness is Robust Landmark of Systolic Impairment in Patients with Hypertrophic Cardiomyopathy

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Background: The effects of focal hypertrophy on geometry of the left ventricle and systolic function have not been studied in patients with hypertrophic cardiomyopathy (HCM), despite the fact that the former is the most prominent disease characteristic. The aim of our study was to analyze systolic function over ventricle geometry, generating a functional index made from left ventricle end diastolic dimension (LVEDD) divided by end diastolic thickness of the region with maximal extent of hypertrophy and interventricular septum.

Material/Methods: Our hospital database of cardiac magnetic resonance was screened for HCM. Geometric functional index (GFI) was calculated for LVEDD over maximal end diastolic thickness (MaxEDT) giving GFI-M, while LVEDD over interventricular septum was expressed as GFI-I. There were 55 consecutive patients with HCM.

Results: There were 43 males (78.2%) and 12 females (21.8%). The mean age was 52.3±16.7 years (range: 15.5–76.4 years). A significant difference of GFI was found for preserved versus impaired systolic function of the left ventricle (preserved systolic function); GFI-M 2.28±0.60 versus 3.66±0.50 (p<0.001), and GFI-I 2.75±0.88 versus 3.81±0.87 (p<0.001), respectively. Diagnostic value was tested using receiver operating curve (ROC) analyzes, with GFI-M area under curve (AUC)=0.959 (95% CI: 0.868–0.994); (p<0.001) and GFI-I-AUC=0.847 (0.724–0.930); (p<0.001). GFI-M was superior to GFI-I for appraisal of left ventricle systolic dysfunction in HCM; ΔAUC=0.112 (0.018–0.207); (p=0.020).

Conclusions: GFI is a simple tool, with high sensitivity and specificity for detecting impairment of systolic function in patients with HCM. Further studies would be necessary to investigate its clinical and prognostic impacts, as well as reproducibility with prospective validation.

MeSH Keywords: Cardiomyopathy, Hypertrophic • Heart Ventricles • Magnetic Resonance Imaging, Cine

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Background

Hypertrophic cardiomyopathy (HCM) is the most common among all cardiomyopathies with prevalence of 1 per 200–500 of the general population, or 0.2–3% in imaging studies [1]. Myocardial hypertrophy commonly develops as result of mutations to the contractile proteins, causing plethora of phenotypic appearances, clinical presentations, as well as variable set of prognostic courses [2]. Histopathology reveals hypertrophy and disarray of cardiomyocytes, interstitial fibrosis and changes to the intramural coronary arterioles [3]. Cardiac magnetic resonance (CMR) brought significant advances to clinical diagnostic of HCM [4]. This is particularly important for marginal cases and differential diagnosis to physiological changes of the competitively trained athletes [5]. Hypertrophy of the wall, not caused by secondary reason as valvular stenosis or hypertension, which extends over 15 mm, or 13–15 mm in first degree siblings of people with HCM are among the most important diagnostic parameters on imaging studies [6]. Certain types of hypertrophy cause left ventricular outflow gradient, which was shown to be in correlation with clinical presentation and prognosis of patients [7]. By the virtue of tissue characterization and recognition of fibrosis using late gadolinium enhancement further advances were made in the field of risk stratification, especially about sudden cardiac death and heart failure [8,9]. Hypertrophic changes to myocardial wall are dominantly segmental, however, circumferential hypertrophy could be found as well [10]. Structural changes in HCM lead to decrease of end systolic volume (ESV) and consequential rise of ejection fraction and impaired relaxation, which frequently is out of correlation with patients' symptoms and prognosis [11,12]. Due to difficulties in volumetric assessment of systolic function with HCM, which is frequently classified as hyperdynamic and shows discrepancy regarding prognostic value, supplementary diagnostic tools that could offer reproducible insight on pump function independently on three dimensional volumetric would be worthwhile. Studies with regard to non-pharmacologic treatments of left ventricle outflow tract obstruction and their prognosis generally had focus on peak velocity flow and interventricular septal thickness, which were used both as diagnostic and prognostic parameters [13,14]. Interestingly, studies only rarely showed interest for dedicated region with most hypertrophied myocardium outside interventricular septum, although other localizations are common in HCM [15-17]. Furthermore, CMR imaging currently lacks the tools that would be able to analyze function in manner comparable with echocardiographic flow, tissue Doppler and strain characteristics [18].

Effects of ventricle geometry for functional analyzes in patients with HCM were not studied systematically. Currently, there are no cardiac magnetic resonance imaging (CMRI) studies available on connection existing between the segmental hypertrophy and myocardial functionality, considering former as the most prominent sign of HMC. The aim of our study was to analyze availability to appraise systolic impairment over the left ventricle geometry, generating functional index made from left ventricle end diastolic dimension (LVEDD) divided by end diastolic thickness of the region with maximal extent of hypertrophy. Secondly, we tested whether the diagnostic utility of geometric ratio based on maximal myocardial thickness would be superior to geometric ratio based on interventricular septal thickness using cardiac magnetic resonance imaging.

Material and Methods

Consecutive sample of patients with diagnosis of hypertrophic cardiomyopathy were recruited from our CMR database for 1.5 year period. Diagnosis was established in accordance with guidelines of the cardiovascular societies [19,20]. Patients with significant valvular disease, uncontrolled hypertension, heart surgery, cardiac tumors, significant pericardial effusion, and known ischemic heart disease, including ischemic types of late gadolinium enhancement, were excluded.

Imaging of patients was executed on 1.5 T Magnetom Avanto, Siemens® (Erlangen, Germany, EU), using ECG gating and breath hold after two respiratory cycles, using Body Matrix chest and spine coils. Routine protocol included setting of localizers, half-Fourier acquisition single-shot turbo spin echo (HASTE) sequences, steady state free precession (SSFP) of standardized heart 2, 4, 3, chamber planes and 6 mm stack of short axial slices (8–12 slices through ventricle. In particular cases short tau inversion recovery (STIR) or turbo spin echo (TSE) T1 and T2 sequences dark blood, and fat saturation were performed, which was indicated prior or during exam on a case based indications. Gadolinium contrast was used, in dose 0.2 mL/kg (0.1 mmol/kg). Intravenous bolus of Omniscan® (Gadodiamide) or Dotarem® (gadoterate meglumine), was followed by inversion time recovery scout, with acquisition of phase-sensitive inversion-recovery (PSIR) and STIR late gadolinium enhancement (LGE) sequences 20–30 minutes following contrast application.

Post processing studies were done on Siemens AG- NUMARIS/4, Syngo MR B17® software package (Erlangen, Germany, EU), whilst volumetric analyzes were done using Siemens AG-Syngo Console Argus®, by two CMR high throughput cardiologists (over 300–450 exams per year), one cardiologist experienced in echocardiography and radiologist. Standard reporting included clinical question from referring cardiologist, previous medical history, interpretation of studied planes, sequences, tissue sequences, volumetrics, dedicated measurements of myocardial thickness in standard and dedicated regions, visual analyzes of valvular function, late gadolinium enhancement and conclusion of exam, with final interpretation of results within standardized 17-myocardial segmentation. Maximal end

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diastolic wall thickness (MaxEDT) was estimated from 6-mm stack of short axis planes and interventricular septum (IVS) end diastolic thickness was recorded in 4-chamber view. GFI was calculated for LVEDD over MaxEDT i.e., GFIM, as well as GFII of LVEDD over IVS.

Patients were included subsequently to signing of informed consent. Study was performed in accordance with the "Declaration of Helsinki and good clinical practice" principles. Approval was given by ethical board of our hospital. There were no stipends or grants, study was not financed and there were no relations with the medical industry. There were no benefits or other reimbursements for patients, as well as study personnel.

Population and studied groups were analyzed using descriptive statistic and presented as means combined with standard deviations or numbers with percentages. Data on numeric variables were tested for differences with Mann-Whitney U test or Kruskal Wallis. Analyzes of group data were done with chi square. Connections of studied CMR parameters and GFI were done by Spearman Rho, as well as for GFI to systolic function in partial correlation, controlled for age. bi-nominal regression model analyzed studied CMR parameters and left ventricle ejection fraction (LVEF) impairment. Diagnostic value of GFIs and left ventricular systolic function in HCM was calculated separately and in head to head settings using receiver operating curve analyzes (ROC). A p value less than 0.05 was considered significant. Statistical analyses were done by experienced statistician using IBM-SPSS12® v 20 (IBM co, Chicago, IL, USA), MedCalc v. 12.2® for Windows (MedCalc Software Co., Belgium, EU) and Statistica 10® for Windows (StatSoft Inc., Tulsa, OK, USA).

Results

Studied sample

This study included 55 consecutive patients with hypertrophic cardiomyopathy (HCM). There were 43 male (78.2%) and 12 females (21.8%). The mean age was 52.3±16.7 years (range: 15.5–76.4 years); LVEDD in 4-chamber view 5.25±0.83 cm; IVS in 4-chamber view 1.97±0.57 cm (0.75–3.41); right ventricle in 4-chamber view, end diastole (RV) 3.54±0.62 cm; left atrium square dimension at end-systole (LA) 27.6±6.9 cm^2; right atrium (RA) 24.9±5.7 cm^2; end-diastolic-volume (EDV) 146.8±46.3 mL; end-systolic-volume (ESV) 60.8±47.4 mL; stroke-volume (SV) 85.7±26.0 mL and myocardial mass estimated at end-diastole 159.4±51.0 gr (84.7–334.0). Left ventricle mean systolic function was 61.1±16.9% (18.1–86.8) and 12 (21.8%) had systolic impairment i.e., LVEF <50%. Baseline differences of patients with preserved and impaired LVEF are shown in Table 1.

Maximal-end-diastolic-thickness (MaxEDT) of LV was 2.18±0.58 cm (1.50–3.60 cm). Localizations and extent of the MaxEDT were as follows: only septal9 (16.4%); bi-locational 22 (40.0%) and affecting ≥3 regions (septum, anterior, inferior, lateral) and circumferential 24 (43.6%). When LV was analyzed in stack of short axis planes, MaxEDT was found in basal region 47 (85.5%); medial 49 (89.1%) and apical 16 (29.1%). Systolic anterior motion (SAM) of mitral valve was found in 10 (18.2%). Late gadolinium enhancement was existing in 38 (69.1%), of which 34 (61.8%) were focal midventricular, 4 (7.3%) linear midventricular and further 10 (18.2%) of patients had non-formed, diffuse light-scattered enhancements (diagnostically less specific, due to technical characteristics of inversion recovery annulation process) [21].

Geometry functional index (GFI)

Geometry functional index (GFI) was expressed as LVEDD/MaxEDT(GFI-M) or LVEDD/IVS(GFI-I), Figure 1. GFIM was 2.58±0.81 (0.99–4.68) and GFI-I 2.98±0.97 (0.96–5.73). Significant difference of GFI was found for preserved versus impaired systolic function of left ventricle (preserved systolic function); GFI-M 2.28±0.60 versus 3.66±0.50 ($p < 0.001$), and GFI-I 2.75±0.88 versus 3.81±0.87 ($p<0.001$), respectively; data are shown in Figures 2 and 3. Spearman's rank correlation of GFIM was found for LVEF (Rho-correlation coefficient [CC]=–0.575; $p<0.001$) and group of systolic impairment (Rho-CC=0.657; $p<0.001$); as well as of the GFII for LVEF (Rho-CC=–0.472; $p<0.001$) and group of systolic impairment (Rho-CC=0.496; p<0.001). Although GFIs did not show significant Rho-correlations with age of patients (both $p>0.05$), partial correlations controlled for age were significant; GFI-M to systolic impairment (CC=0.706; $p<0.001$) and GFI-I to systolic impairment (CC=0.443; $p=0.001$). Diagnostic value of GFIs was tested using ROC-analyzes as follows; impairment of systolic function was detected by GFI-M >2.98 with sensitivity of 100 (95% CI: 73.5–100.0), specificity 86.1 (72.1–94.7), positive likelihood ratio (+LR) of 7.2 and negative (–LR) of 0; area under curve (AUC) ROC=0.959 (0.868–0.994); ($p<0.001$). On the other hand, impairment of systolic function was detected with GFI-I >3.26 with sensitivity of 83.3 (51.6–97.9); specificity 76.7 (61.4–88.2); +LR 3.58; –LR 0.22; AUC=0.847 (0.724–0.930); ($p<0.001$), Figure 4. In same manner, difference of ROC-AUCs was significantly in favor of GFI-M superiority over GFI-I; ΔAUC=0.112 (0.018–0.207); $p=0.020$. There also was high grade of correlation between GFI-M and GFI-I (Rho-CC=0.768; $p<0.001$).

GFIs (GFI-M and GFI-I) did not correlate significantly with age of patients ($p=0.060$; $p=0.168$, respectively); LA ($p=0.923$; $p=801$, respectively); RA ($p=0.219$; $p=113$, respectively); LGE ($p=0.517$; $p=102$, respectively); localizations of hypertrophy ($p=0.767$; $p=920$, respectively); systolic anterior motion of mitral valve ($p=0.217$; $p=979$, respectively) and LV-myocardial mass ($p=0.363$; $p=347$, respectively).

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Table 1. Principal characteristics and differences of patients based on preservation of systolic function.

	Preserved LVEF (n=43)	Impaired LVEF (n=12)	Chi-square
	n (%)	n (%)	
Male	33 (76.7%)	10 (83.3%)	0.625
Female	10 (23.3%)	2 (16.7%)	
SAM	6 (14.0%)	0 (0.0%)	0.170
Existence of LGE	28 (65.1%)	10 (83.3%)	0.227
Localizations of hypertrophy*	**n (%)**	**n (%)**	**Kruskal-Wallis**
Interventricular septum	4 (9.3%)	5 (41.7%)	0.992
Three regions or circumferential	24 (55.8%)	0 (0.0%)	
Bi-locational	15 (34.9%)	7 (58.3%)	
	Preserved LVEF (n=43)	**Impaired LVEF (n=12)**	**Mann-Whitney**
	Mean ±SD	**Mean ±SD**	
Age (years)	51.3±17.5	55.7±13.5	0.488
LVEDD (cm)	5.03±0.66	6.07±0.89	**0.001**
IVS (cm)	1.99±0.61	1.63±0.24	0.068
RV (cm)	3.54±0.62	3.54±0.65	0.992
LA (cm^2)	26.8±6.8	30.3±6.8	0.119
RA (cm^2)	24.2±5.4	27.2±6.1	0.328
MaxEDT (cm)	2.33±0.57	1.66±0.16	**<0.001**
EDV (mL)	133.4.±33.6	194.7±54.9	**<0.001**
ESV (mL)	41.6±18.9	129.5±56.2	**<0.001**
SV (mL)	91.4±25.0	65.1±18.5	**0.001**
MM (gram)	157.0±54.2	168.1±37.8	0.285

LVEF – left ventricular ejection fraction; LVEDD (cm) – left ventricle end diastolic dimension in 4 chamber view; IVS (cm) interventricular septum thickness in 4 chamber view; RV (cm) – right ventricle end diastolic dimension in 4 chamber view; LA & RA (cm^2) – left and right atrial area in square centimeters in 4 chamber view; MaxEDT – maximal hypertrophied region end diastolic thickness; EDV (mL) – end diastolic volume; ESV (mL) – end sistolic volume; SV (mL) – stroke volume; MM (gram) – myocardial mass in end-diastole; * localizations: interventricular septum, anterior, inferior, lateral. Significant values outlined in bolded text.

Discussion

Our study analyzed two novel geometric parameters in connection with systolic function of the left ventricle in patients with hypertrophic cardiomyopathy (HCM). Ratio of LVEDD and myocardial thickness at region with maximal hypertrophy or interventricular septum thickness made the geometric functional index (GFI). It was shown that GFI is connected with systolic function of the left ventricle on several levels. There was significant difference of GFI in patients with impaired systolic function and controls. Furthermore, difference was further proven with intermediate to high grade of correlations. Interestingly, although there was no correlation of GFI with age of patients, adding age as control in partial correlations of GFI and systolic function has yielded additional synergistic power. This could be explained with effects of age on the hypertrophied heart, and potential loss of contractile function, which might not be represented best through volumetric appraisal of systolic function [22]. The latter is exceedingly challenging point, since ESV is commonly decreased in HCM and makes false overshot, which does not correlate with prognosis of patients and loses one of the important supplementary values of ejection fraction [23]. On the other hand, impairment of the systolic function in hypertrophic cardiomyopathy below cutoff point set at 50% was previously shown to have important impact on the adverse prognosis of patients in terms of major adverse events rates [24]. This critical value of systolic function was also setoff point excellently recognized using

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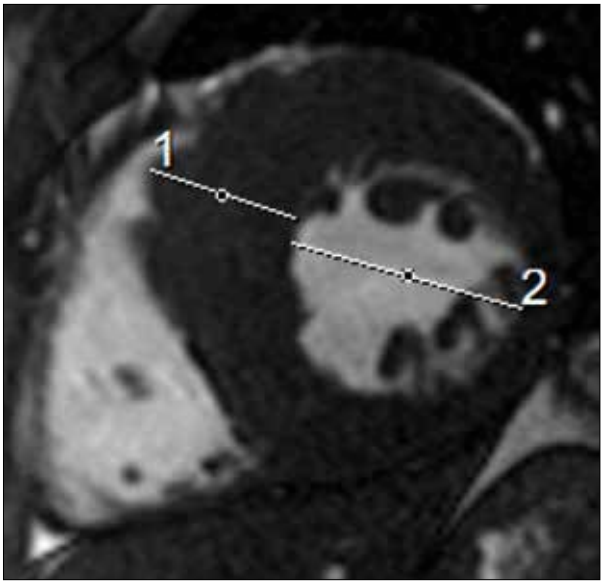

Figure 1. Illustration of geometrical functional index (GFI). Cine steady free precession at end diastole, short axis plane: 27.7-year-old male patient with hypertrophic cardiomyopathy, preserved systolic function: 1) maximal end diastolic myocardial thickness of 3.38 cm; 2) left ventricle end diastolic dimension of 5.26 cm, giving geometric functional index over maximal end diastolic thickness (GFI-M) of 1.56.

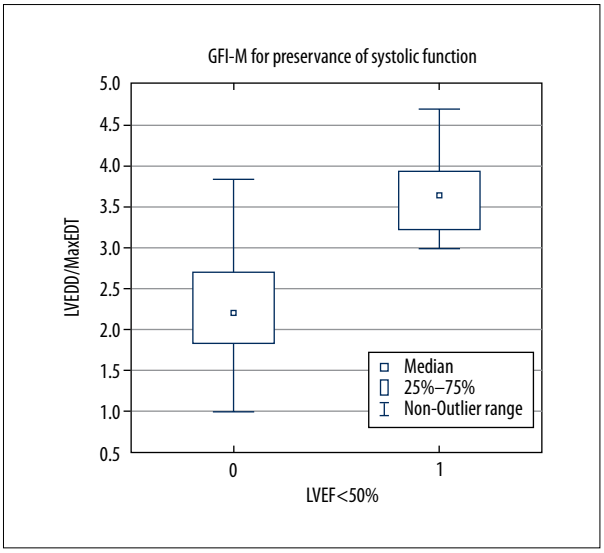

Figure 2. Geometric functional index (GFI) for maximal end diastolic ventricular thickness. Box plot of GFI-M in regard to preservation of systolic function. Data labels: GFI-M-geometry functional index for maximal myocardial end diastolic thickness (MaxEDT); LVEDD – left ventricle end diastolic dimension; LVEF – left ventricle ejection fraction.

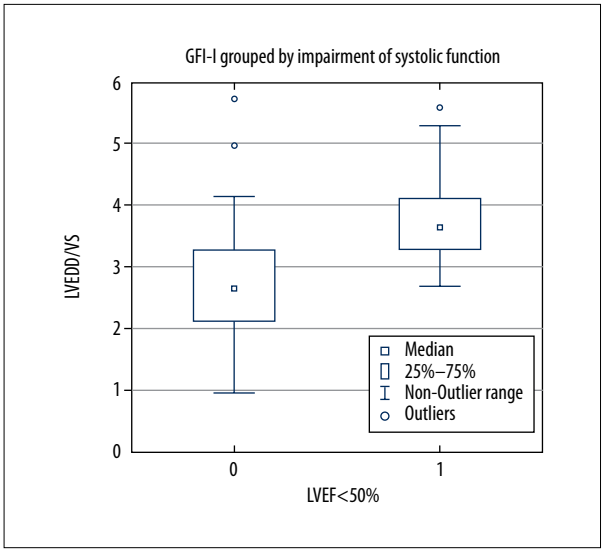

Figure 3. Geometric functional index (GFI) for maximal interventricular septal thickness. Box plot of GFI-I regarding the preservation of systolic function. Data labels: GFI-I-geometry functional index for interventricular septum end diastolic thickness (IVS); LVEDD – left ventricle end diastolic dimension; LVEF – left ventricle ejection fraction.

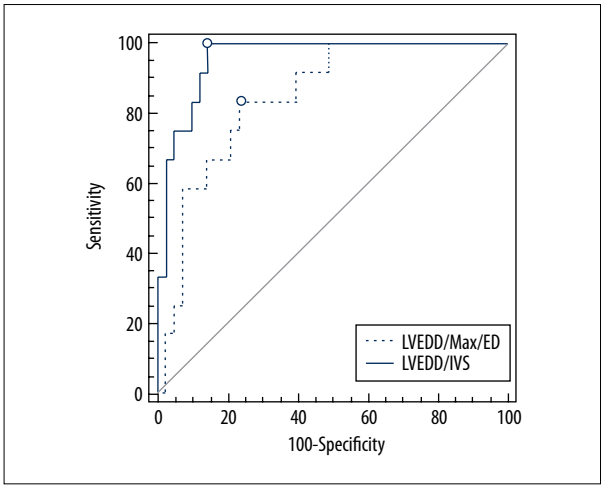

Figure 4. Comparison of receiver operating curves (ROC) analyzes for studied geometric indexes. ○-value with highest Youden index. Geometric functional indexes (GFIs): 1) GFI-M = Left ventricle end diastolic dimension (LVEDD)/MaxED (maximal end diastolic thickness), showed as blue line and 2) GFI-I = left ventricle end diastolic dimension (LVEDD)/interventricular septal thickness (IVS), presented as dashed blue line.

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our novel geometry function index of dedicated region with most pronounced hypertrophy, revealing its further clinical potential. Patients with HCM and preserved ejection fraction experience dyspnea, physiological activities limitation, angina-like chest pain, and experience inconspicuous risk of sudden cardiac death, which is diagnostically difficult to characterize using cardiovascular imaging [25]. The latter is among the most important reasons on necessity of novel studies that would yield innovative diagnostic parameters, with sufficient reproducibility and convenience of use in wide number of centers [26,27]. In the context of given arguments our preliminary findings are in part inspiring since tests for diagnostic potential of GFI reported on very high sensitivity and specificity of left ventricle diastolic dimension over maximal thickness of hypertrophied myocardium for recognizing systolic dysfunction [28]. Region with most pronounced hypertrophy was superior diagnostic parameter than interventricular septal thickness in ROC analyzes, which could easily be explained by the fact that septal region in some share of patients is not the region of most pronounced functional changes of cardiomyocytes, outlining segmental characteristics of HCM to be essential parameter that affects clinical course and prognosis, in addition to its elucidative value as diagnostic parameter [10,29]. Further potential of maximal myocardial thickness GFI on therapeutic indications or follow-up of interventional treatments would have to be examined in prospective controlled settings [13,14]. Confirming of superiority for GFI that included maximal hypertrophy thickness over interventricular septal dimension in statistical tests has indirectly underscored clinical value of our hypothesis on having diagnostic potential and showing different power of correlations, which depended on the contribution of wall thickness to the LVEDD [30]. Since LVEDD is known to change in relation with function of the left ventricle, alternations of GFI in case of LV-dilatation would extreme cases cause downslope, with potential to go towards pseudo-normalization of functional index [31]. However, extent of change when severe systolic dysfunction develops hardly ever goes beyond 1–2 cm, which is relatively minor contribution, whilst hypertrophied myocardium due to stable basic characteristics (difficulties in potential to significantly change size over time), hence, has relatively smaller potential to significantly deviate index. The latter was also presented in general lack of overlapping values, whilst more powerful changes in solid manner correlated with changes of systolic function. Lack of connections existing between GFIs and late gadolinium enhancement lays in the fact that deposition of gadolinium in patients with HCM has little or none effects on myocardial wall thickness, as well as symptoms of heart failure [32,33]. Furthermore, patients with and without late enhancements could have similar systolic function, although greater volume of fibrosis is underprivileged for clinical prognosis and rate of major adverse cardiac events [34]. Further improvements on recognizing diffuse fibrosis and its clinical impact might be solved using novel CMR technologies for tissue mapping, which were also only partially identified in our study by late contrast sequences, however, burdened with technical inability to quantify those [21]. These as well might be points of potential for supplementary value of the GFI, since it was shown to act independently of conventional left ventricle volumetrics, where the latter has effects on causing falsely hyperdynamic function and consequential loss of prognostic value [35].

Important disadvantages of our study are contained by retrospective settings and lacking of ability to add further parameters in to modeling. Due to necessity to have relatively short time constant relations in order to appraise actual systolic function our study is further limited by lack of follow-up, especially one which would include clinical parameters like NYHA grade, quality of life, and prevalence rate of major adverse cardiovascular events. It is not withstanding to point out relative limitation of population number. However, initial power tests pointed that even a two-fold smaller population than we used would be sufficient to test applicability of GFIs for estimation of systolic dysfunction. Results of our study could be considered as preliminary, due to necessity to include prospective validation with inclusion different groups of controls and standardization in multicentric settings, with greater number of population, in order to gain greater reproducibility.

Conclusions

Our study tested diagnostic utility of an index made from LVEDD over myocardial thickness in dedicated region with most pronounced hypertrophy or interventricular septal thickness. We found significant discriminative difference based on preservation of systolic function, which were confirmed by high grade of correlations and satisfactory levels of sensitivity and specificity in patients with hypertrophic cardiomyopathy. GFI of maximal hypertrophy was superior to one that included interventricular septum, pointing out that segmental disease characteristics as its prominent diagnostic parameter also have functional implications. Further studies would be necessary in order to gain reproducibility and correlations with clinical endpoints.

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Conflict of interest

None.

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