Echocardiographic assessment of left ventricular systolic function

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Abstract:

Early and accurate recognition of myocardial dysfunction offers the potential to optimize the timing of intervention in Concentric Left Ventricular Hypertrophy. Since global left ventricular function index account for relation between left ventricular mass and left ventricular dimensions it can predicts incident heart failure in patients with concentric left ventricular hypertrophy.

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Introduction:

The most common and quickest assessments made using echocardiography, either in the intraoperative or intensive care setting, are the left ventricular chamber size and its contractile or systolic function. Left ventricle (LV), being the pressure generator for the blood supply to the body, is endowed with a chamber which has thick myocardial walls. LV chamber does not exactly match any measurable geometric shape, and in a healthy heart, it may resemble an elongated ellipse with a conical apex. In diseased states, the shape may change globally or regionally, and this nonconformity of shape, both in healthy and diseased condition, is the primary reason for the difficulty in measuring its volume or volume surrogates during different phases of cardiac cycle using echocardiography **(1)**.

Two-dimensional (2D) echocardiography, M-mode echocardiography, Doppler echocardiography, and 3D echocardiography are all used to assess the function of LV, both during systole as well as in diastole. LV systolic function assessment gained prominence early during the development of echocardiography. All modalities of echocardiography were used to assess LV systolic function either quantitatively or qualitatively. Most of the early validation studies in LV systolic function assessment were done using transthoracic echocardiography (TTE), and it is only in the last couple of decades the interest in intraoperative transesophageal echocardiography (TEE) has gained momentum **(2)**.

1.Tissue doppler imaging for LV function assessment:

Tissue Doppler (TD) uses the same principle of pulse wave Doppler (PWD) and its derivative the color flow Doppler. Here, the high-velocity low-amplitude signals from red blood cells are eliminated to display only the low-velocity high-amplitude signals from the myocardium. Main drawbacks are the limitations of PWD, i.e., angle dependency and its inability to differentiate the velocity generated by actual myocardial contraction and that produced by translational motion by akinetic myocardial segments when they get pulled by the adjacent normally contracting myocardium **(3)**.

PW tissue doppler imaging (TDI) was obtained at the septal, lateral, inferior, anterior, and posterior annular ring of the mitral valve, measuring s′, e′, and a′ peak velocities **(4)**.

Left ventricular TDI systolic parameters:

I)S.WAVE:

The LV TDI systolic parameters are shown in Tables 1 and 2. s wave velocity was higher in men than in female in any mitral annulus location, except in the anterior mitral annulus (septal s′: 8.4 + 1.4 vs. 7.9 + 1.3; P , 0.001). Table 3 shows LV systolic TDI parameters according to age categories. s′ wave velocity was lower in older patients (septal s′: 7.5 + 1.3 cm/s) and higher in the younger ones (8.6 + 1.3 cm/s). There was a significant negative correlation between average s′ wave velocity and age (r ¼ 20.41; P ≤ 0.001) **(4)**.

Table (1): Left ventricular TDI systolic parameters according to gender **(4)**.

Parameters	Total Mean ± SD	Total 1st–3rd quartile	Total 95% CI	Male Mean ± SD	Male 95% CI	Female Mean ± SD	Female 95% CI	P*
Septal s′ wave (cm/s)	8.1 ± 1.4	7.0–9.0	6.0–11.0	8.4 ± 1.4	6.0–11.1	7.9 ± 1.3	5.0–10.0	<0.001
Lateral s′ wave (cm/s)	9.8 ± 2.4	8.0–12.0	5.0–14.1	10.1 ± 2.6	5.0–16.0	9.5 ± 2.3	5.1–14.0	0.028
Average septal and lateral s′ wave (cm/s)	8.9 ± 1.6	7.5–10.0	6.0–12.1	9.2 ± 1.7	6.0–13.1	8.7 ± 1.5	6.0–12.0	0.001
Inferior s′ wave (cm/s)	8.9 ± 1.5	8.0–10.0	6.0–12.0	9.2 ± 1.6	6.0–12.0	8.7 ± 1.4	6.0–12.0	0.001
Anterior s′ wave (cm/s)	9.1 ± 3.4	7.0–11.0	5.0–13.0	9.0 ± 2.2	5.0–13.0	9.3 ± 4.9	5.0–13.0	0.509
Posterior s′ wave (cm/s)	9.5 ± 2.1	8.0–11.0	6.0–14.0	10.0 ± 2.3	6.0–14.1	9.1 ± 1.9	6.0–13.0	<0.001
Average s′ wave (cm/s)	9.0 ± 1.7	7.8–10.0	6.2–12.3	9.3 ± 1.6	6.2–12.4	8.8 ± 1.7	6.1–12.0	0.005

CI, confidence interval.
*P differences between male vs. female.

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Table (2): Left ventricular TDI systolic parameters according to age **(4)**

Parameters	Total 20–40 years Mean ± SD	20–40 years 95% CI	40–60 years Mean ± SD	40–60 years 95% CI	>60 years Mean ± SD	>60 years 95% CI	P*	r P**
Septal s′ wave (cm/s)	8.6 ± 1.3	6.0–12.0	7.9 ± 1.4	5.9–11.0	7.5 ± 1.3	5.0–10.0	<0.001	−0.30; <0.001
Lateral s′ wave (cm/s)	10.7 ± 2.3	6.1–16.0	9.4 ± 2.2	5.0–14.0	8.5 ± 2.5	4.0–15.0	<0.001	−0.37; <0.001
Average septal and lateral s′ wave (cm/s)	9.6 ± 1.6	7.0–13.0	8.7 ± 1.5	6.0–12.0	8.1 ± 1.6	5.5–12.5	<0.001	−0.39; <0.001
Inferior s′ wave (cm/s)	9.3 ± 1.5	7.0–12.0	8.8 ± 1.5	6.0–12.0	8.2 ± 1.5	5.0–12.0	<0.001	−0.26; <0.001
Anterior s′ wave (cm/s)	10.0 ± 2.1	6.6–13.4	8.6 ± 2.0	5.0–13.0	7.6 ± 2.1	4.0–12.0	<0.001	−0.45; <0.001
Posterior s′ wave (cm/s)	10.2 ± 1.8	7.0–14.0	9.2 ± 1.9	6.0–13.2	8.8 ± 2.7	5.6–18.6	<0.001	−0.27; <0.001
Average s′ wave (cm/s)	9.7 ± 1.7	7.2–12.9	8.7 ± 1.4	6.2–11.9	8.1 ± 1.6	5.7–12.7	<0.001	−0.41; <0.001

*P differences between groups according to age category (two-way ANOVA).
**P and r correlation with age for both genders (Pearson correlation test).

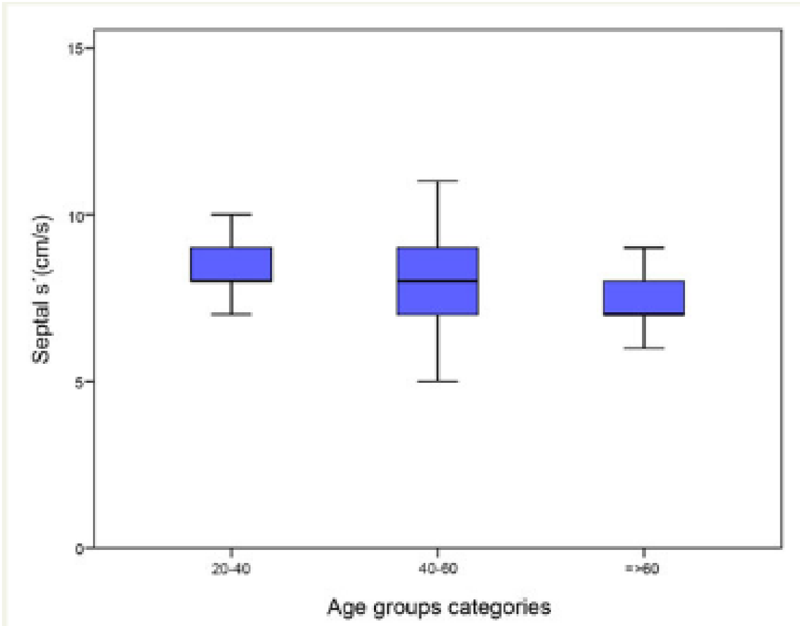

Figure (1): Septal s’ wave velocities obtained by TDI according to age categories**(4).**

II)Isovolumetric contraction time (IVCT):

With placement of a 2- to 4-cm straight M-mode line through the septal half of the mitral leaflet in the color TDI 4- chamber view, the cardiac time intervals were measured directly from the color diagram 19,22 (Figure 2). The IVCT was defined as the time interval from the mitral valve closure, determined by the color shift from blue/turquoise to red at end diastole, to the aortic valve opening determined by the color shift from blue to red (Figure 2 **) (5)** .

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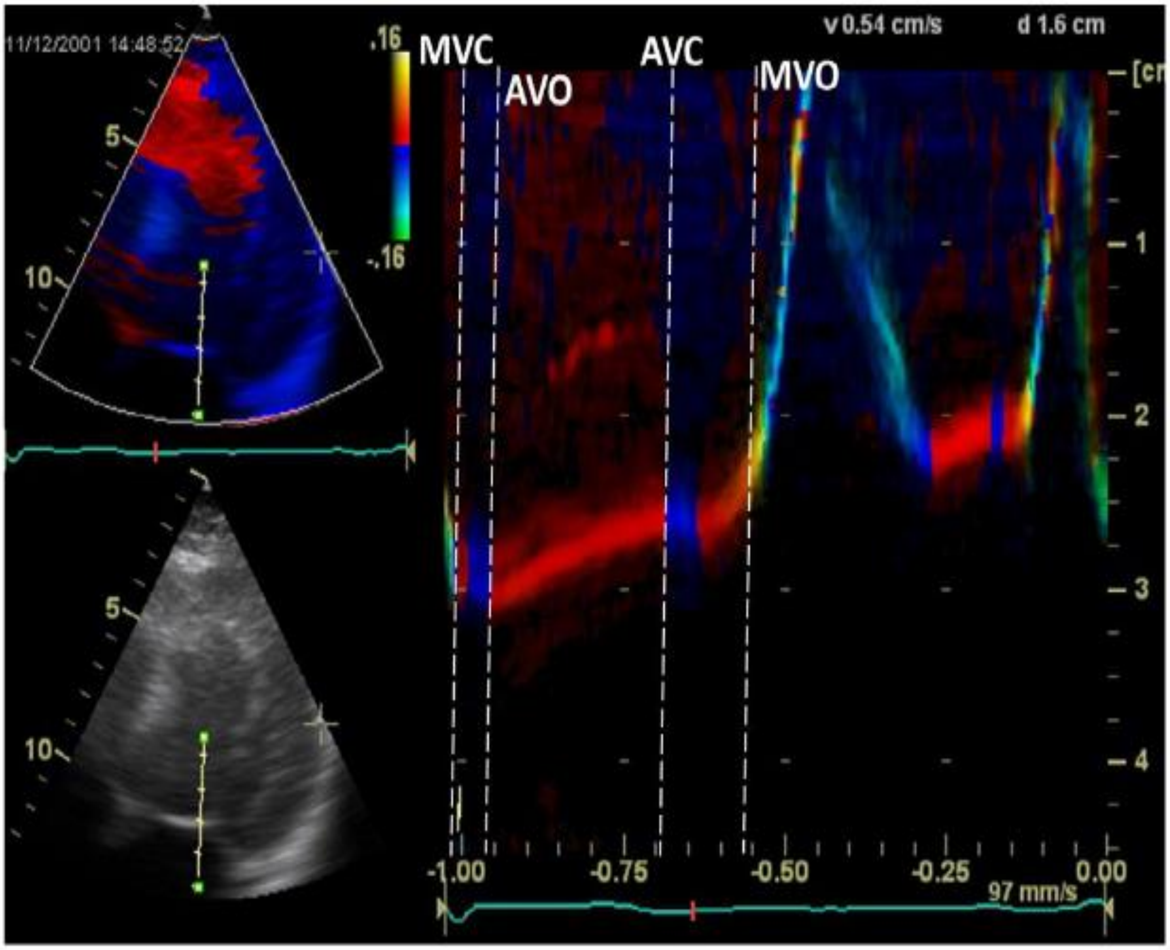

Figure (2): The cardiac time intervals assessed by a color tissue Doppler imaging (TDI) M-mode line through the mitral leaflet. Left: Four-chamber gray-scale (bottom) and color TDI (top) views in end systole displaying the position of the M-mode line used for measuring the cardiac time intervals. Right: Color diagram of the TDI M-mode line through the mitral leaflet. AVC indicates aortic valve closure; AVO, aortic valve opening; MV, mitral valve; MVC, MV closing; MVO, MV opening **(5)**.

Table (3): Normal values of the cardiac time intervals by TDI M-mode in healthy participants stratified according to age category and gender obtained from the derivation cohort (group A, n = 974) **(5)**.

	Women (n = 553)					Men (n = 421)					
	Overall (n = 553)	Age category 20 to 39 (n = 150)	Age category 40 to 59 (n = 252)	Age category 60 or above (n = 151)	*p-value for age category difference*	Overall (n = 421)	Age category 20 to 39 (n = 101)	Age category 40 to 59 (n = 210)	Age category 60 or above (n = 110)	*p-value for age category difference*	*p-value for gender difference*
IVRT (ms)	92 (20)	78 (16)	93 (16)	106 (20)	*<0.001*	94 (20)	78 (15)	95 (16)	109 (18)	*<0.001*	*0.13*
IVCT (ms)	36 (13)	32 (12)	37 (12)	38 (14)	*<0.001*	34 (11)	35 (11)	33 (11)	36 (12)	*0.07*	*0.012**
ET (ms)	293 (21)	291 (19)	296 (20)	289 (23)	*0.001*	281 (24)	284 (19)	280 (23)	279 (28)	*0.34*	*<0.001**
IVRT/ET	0.32 (0.07)	0.27 (0.05)	0.31 (0.06)	0.37 (0.07)	*<0.001*	0.34 (0.08)	0.28 (0.06)	0.34 (0.06)	0.40 (0.08)	*<0.001*	*<0.001**
IVCT/ET	0.12 (0.05)	0.11 (0.04)	0.13 (0.04)	0.13 (0.05)	*<0.001*	0.12 (0.04)	0.13 (0.04)	0.12 (0.04)	0.13 (0.05)	*0.10*	*0.61*
MPI	0.44 (0.10)	0.38 (0.08)	0.44 (0.08)	0.51 (0.10)	*<0.001*	0.46 (0.10)	0.40 (0.08)	0.46 (0.09)	0.53 (0.10)	*<0.001*	*0.002**

Numbers in parenthesis are standard deviations. BMI = Body Mass Index; LVMI = Left Ventricular Mass Index; LVIDd = left ventricular dimension in end-diastole; LAD = Left atrium diameter in end-systole; DT = deceleration time of early diastolic inflow; IVCT = Isovolumic Contraction Time; IVRT = Isovolumic Relaxation Time; ET = Ejection Time; MPI = Myocardial Performance Index

* remained statistical significantly different between the genders after multivariable adjustment for age, BMI, heart rate, systolic and diastolic blood pressure, LVMI, LVIDd, LAD, and DT. Age category difference was determined by ANOVA.

$IVCT_t$ (IVCT measured by TDI) was measured from the end of A_m to the onset of S_m **(6).**

III)The myocardial performance index or (Tei index):

Systolic and diastolic functions influence each other in concert to generate cardiac output. They can be assessed separately using echocardiographic parameters such as the ejection fraction or fractional shortening for systolic function and the quantification of mitral waves (E and A) for diastolic function. Thus far, the classical distinction between diastolic and systolic contractile dysfunction is made, although the validity of this practice has been questioned. Therefore, several attempts have been made to develop parameters assessing contractile function as a whole, considering both the systolic and diastolic components at the same time **(7)**.

The myocardial performance index (MPI), or Tei index, is a Doppler echocardiographic parameter and defined as the sum of the isovolumic contraction and relaxation times (ICT and IRT) divided by the ejection time (ET). MPI has been demonstrated to be a reliable and reproducible parameter for the evaluation of left ventricular systolic and diastolic dysfunction in many kinds of heart disease in human. Furthermore, a number of studies have documented that MPI is independent of heart rate, arterial pressure, and preload. However, the value of MPI in diastolic dysfunction is not yet fully clear and the evaluation of its value in animals has been mainly limited to spontaneously hypertensive rats. The purpose of this study was to determine MPI in a model of pressure-overload-induced heart failure in rats displaying diastolic dysfunction with or without systolic dysfunction and to examine its usefulness as a parameter for cardiac function. **(7)(Figure 3)**.

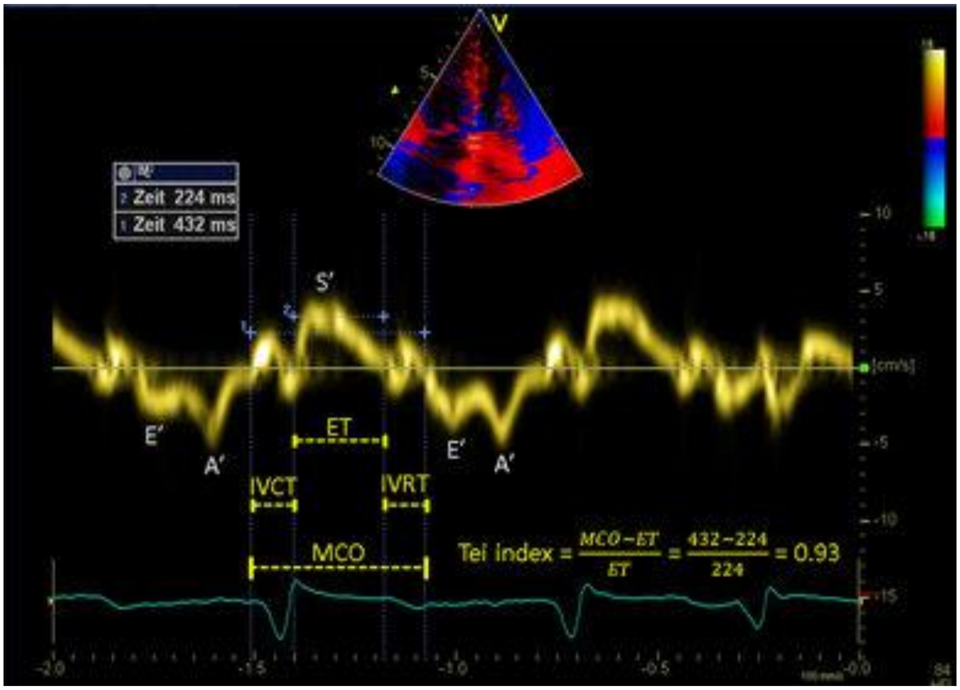

Figure (3): Example of a Tissue Doppler derived Tei index. Time intervals of left ventricle are measured with tissue Doppler imaging and the Tei index is calculated by the formula: (MCO-ET)/ET. MCO mitral valve closure-to-opening time, ET ejection time, IVCT isovolumetric contraction time, IVRT isovolumetric relaxation time, S′ peak systolic septal mitral annular velocity, E′ peak early-diastolic septal mitral annular velocity, A′ peak late-diastolic septal mitral annular velocity **(8).**

2. Speckle tracking and global longitudinal systolic strain:

The ASE/EACVI 2015 guidelines have recommended GLS as a reliable and reproducible index of global LV systolic function **(9)**.

Strain and strain rate:

When force is applied on a deformable system, different points in the system move at different velocities resulting in deformation. Strain (ε) is the ratio of the difference between the final length (L) and the initial length (L0) to that of the initial length after the application of the force for a time duration of Δt**(9)**.

That is, ε = L – L0/L0.

The rate at which this happens is the SR, i.e., SR = ε/Δt.

Now, it is obvious that if the distance between two points, moving at different velocities, is shortened, the strain will be a negative (−) value, and if it lengthens, strain will be a positive value **(9)**.

Extrapolating it to the LV myocardium, contraction is the force and the deformation that happens in the LV myocardium is shortening from apex to the base, shortening of the circumference, and lengthening or radial thickening of the LV walls. This is due to the three types of myocardial fibers in the heart; longitudinal, circumferential, and radial myocardial fibers. Thus, longitudinal and circumferential strain will be a negative value while the radial strain will be a positive value **(10).**

Angle between the direction of movement of myocardium and that of the ultrasound beam is a great hurdle in Doppler-based techniques of LV function assessment. This is overcome by the technique of speckle tracking and has been validated thoroughly in TTE. Prerequisites for a STE are good quality 2D image, preferably a harmonic mode image with a higher frame rate, regular and constant HR with clear ECG trace, and properly timed aortic valve closure **(11)**.

One major issue with STE is the intervendor and intersoftware variability of normal values, especially for the circumferential and radial strain even though there has been a consensus and understanding for the peak global longitudinal systolic strain. Age and loading conditions also have an effect on these values**(12)**.

GLS describes the relative length change of the LV myocardium between end diastole and end systole. Mathematically, it can be calculated by the following formula **(10).**

GLS % = (MLs − MLd /MLd.

MLs is myocardial length at end systole, MLd is myocardial length at end diastole. As mentioned earlier, because MLs is smaller than MLd, peak GLS is a negative number **(12)**.

GLS measurements should be made in the three standard ME views and then averaged. Measurements should begin with the ME LAX view to visualize aortic valve closure, followed by the ME 4C and ME 2C views. A peak GLS in the range of (18% ±2%) can be expected in a healthy person **(12).**

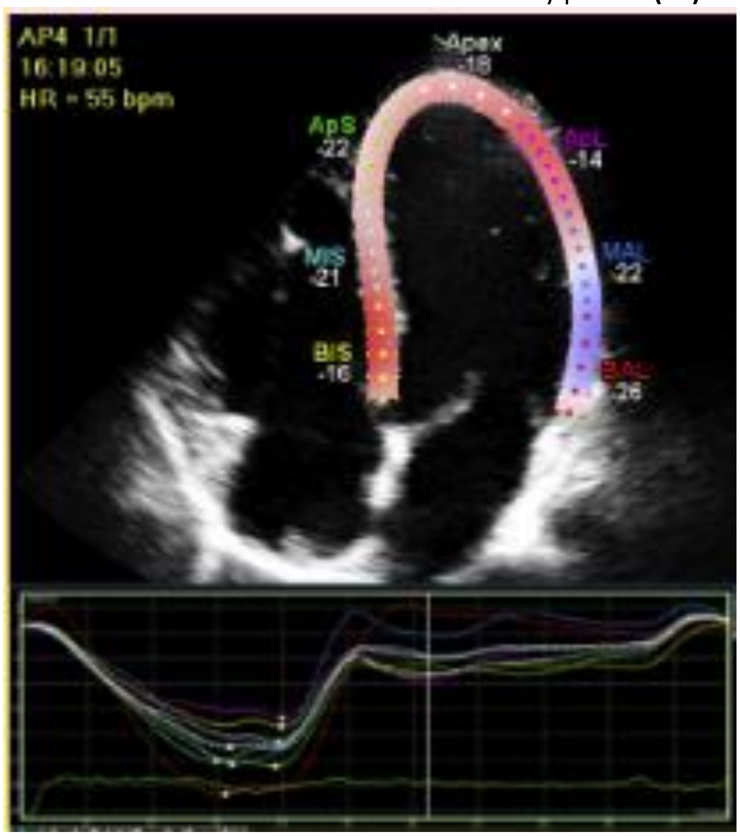

Figure (4): Global longitudinal strain .peak value of 2D longitudinal speckle tracking derived strain (%) **(1)**.

3. Global Left ventricular function index (GLVFI):

The left ventricular (LV) global function index (GFI) has been introduced by Mewton et al. as a novel metric that integrates LV structure with global function, and was shown to be a powerful predictor of incident heart failure and hard cardiovascular events. It is stated that a higher LVGFI reflects better LV cardiac performance (**13**).

LVGFI was calculated and expressed as a percentage. LV global volume was defined as the sum of the mean LV cavity volume [(LVEDV + LVESV)/2] and the myocardial volume. LV myocardial volume was calculated as LV myocardial mass divided by myocardial density, which is specified as1.05 g/mL22 **(14)**.

$$LVGFI = \frac{\mathrm{EDV} - \mathrm{ESV}}{\frac{\mathrm{EDV} + \mathrm{ESV}}{2} + LV\ mass/1.05} X100\%$$

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Because stroke volume will vary with heart size in healthy individuals, a relationship between SV and total heart size, including the LV mass and overall LV cavity size (mean of end-diastolic and end-systolic volumes), can be predicted **(14)**.

The most frequently used index of LV function in clinical practice, the LV ejection fraction (LVEF), does not account for the relationship between LV mass and LV dimensions. This might partly explain its limited sensitivity and specificity in various stages of cardiovascular (CV) diseases **(14)**[)].

The impact of the term "SV" in the formula is already partly covered by the combination of ESV and EDV. The only extra element introduced in the definition formula compared to the familiar EF concerns LV mass. Of course, LV mass is a relevant piece of information. However, physiology does not refer to the art of mixing various variables into a single mathematical construct, and certainly not in case of a dimensionless composition. Numerous variations on this theme can be developed (**13)**.

The assessment of LVGFI incorporates elements of LVEF as well as of LV MVR and the LV mass index. Importantly, the assessment of SV with respect to total LV volume is a combined functional and structural quantification of whether a given SV is matched by a proper myocardial mass- and LV cavity size. Thus, it includes information of physiological adaptation as well as pathological remodeling by measures of both cavity size and myocardial mass. Average cavity volume was chosen as a marker of cavity size that reflects the LV operating volume and not one of the extreme values like EDV or ESV, and thus should serve as an improved measure of overall cavity size**(15).**

The combination of left ventricular mass, volumes and stroke volume in one single left ventricular global functional index (LVGFI) integrating all the dimensions of the left ventricle functional anatomy is new. The LV global function index was strongly and consistently associated with adverse cardiovascular events during follow-up across various categories of cardiovascular events. If the LV global function index predictive power was comparable to indexed LV mass alone, it was more powerful and consistent than LV mass to volume ratio and LV ejection fraction **(15)**.

Previous studies have shown that LVGFI by ECHO and CMR was independently associated with the subsequent development of HF, cardiovascular events, and a combined endpoint of all adverse events in community-dwelling individuals **(16).**

LVGFI is a strong, independent predictor of incident HF and CVD that provides incremental prognostic value compared with LVEF **(17)**.

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