International Journal of Cardiology 203 (2016) 947–958

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

A new method to estimate left ventricular circumferential midwall systolic function by standard echocardiography: Concordance between models and validation by speckle tracking

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ARTICLE INFO

Article history:
Received 3 August 2015
Received in revised form 3 November 2015
Accepted 5 November 2015
Available online 10 November 2015

Keywords:
Echocardiography
Systole
Left ventricular function
Speckle tracking

ABSTRACT

Background: Assessment of left ventricular circumferential (LV_{circ}) systolic function by standard echocardiography can be performed by estimating midwall fractional shortening (mFS) and stress-corrected mFS (ScmFS). Their determination is based on spherical or cylindrical LV geometric models, which often yield discrepant values. We developed a new model based on a more realistic truncated ellipsoid (TE) LV shape, and explored the concordance between models among hypertensive patients. We also compared the relationships of different mFS and ScmFS estimates with indexes of LV_{circ} systolic strain.
Methods: In 364 hypertensive subjects, mFS was determined using the spherical (mFS_{spher}), cylindrical (mFS_{cyl}), and TE model (mFS_{TE}). Corresponding values of $ScmFS_{spher}$, $ScmFS_{cyl}$, and $ScmFS_{TE}$ were obtained. Global circumferential strain (GCS) and systolic strain rate (GCSR) were also measured by speckle tracking.
Results: The three models showed poor concordance for the estimation of mFS, with average differences ranging between 11% and 30% and wide limits of agreement. Similar results were found for ScmFS, where reclassification rates for the identification of abnormal LV_{circ} systolic function ranged between 18% and 29%. When tested against strain indexes, mFS_{TE} and $ScmFS_{TE}$ showed the best correlations ($R = 0.81$ and $R = 0.51$, $p < 0.0001$ for both) with GCS and GCSR. Multivariable analysis confirmed that mFS_{TE} and $ScmFS_{TE}$ showed the strongest independent associations with LV_{circ} strain measures.
Conclusions: Substantial discrepancies in LV_{circ} midwall systolic indexes exist between different models, supporting the need of model-specific normative data. The use of the TE model might provide indexes that show the best associations with established strain measures of LV_{circ} systolic function.

1. Introduction

Left ventricular (LV) midwall fractional shortening (mFS) and stress-corrected mFS (scmFS) are established echocardiographic indexes of LV circumferential (LV_{circ}) systolic function [1,2]. The rationale for the use of midwall indexes is based on the evidence that a dishomogeneous distribution of myocardial fibers through LV wall exists, with circumferential fibers predominantly distributed in the midwall layers and longitudinal-helical ones mostly in the subendocardial and subepicardial ones [3]. During systole, a greater radial thickening of inner than outer LV myocardial layers occurs, so that midwall fibers show a relative migration towards the epicardium [4]. As a result, fractional shortening at the level of endocardium is higher than that at the level of midwall and overestimates the true performance of circumferential fibers, a phenomenon that is enhanced in patients with hypertension, particularly in those with concentric LV hypertrophy [5,6]. In these subjects, this mechanism allows maintenance of normal chamber performance and cardiac output, despite an impairment in LV_{circ} fiber performance can be unmasked by detection of depressed mFS and scmFS [7–9]. From a clinical point of view, estimation of circumferential midwall indexes in these patients allows to

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http://dx.doi.org/10.1016/j.ijcard.2015.11.051
0167-5273/

identify a subset of patients with subtle LV_{circ} systolic dysfunction despite normal ejection fraction, who are at increased risk of cardiovascular events [10].

To date, two methods based on different geometrical models of the left ventricle – spherical and cylindrical – are used for the estimation of mFS by echocardiography [11,12]. However, they represent very simplified approximations of LV shape. This raises the question of whether the use of alternative geometrical models, more accurate in reflecting real LV shape, could provide a better estimation of LV_{circ} systolic function than conventional methods. Moreover, while the spherical and cylindrical models have been commonly used interchangeably, they yield considerably different mFS and ScmFS values in most patients. Nonetheless, a concordance analysis between different methods of calculating LV_{circ} midwall indexes has never been performed.

In this paper, we developed a new method to calculate mFS by standard echocardiography, based on a more realistic truncated ellipsoid (TE) shape for the left ventricle. We applied this method to compute mFS and ScmFS in a population of hypertensive subjects, together with the corresponding values based on the standard spherical and cylindrical models. Then, we explored the concordance between models, and compared the relationships of different mFS and ScmFS values provided by the three methods with established indexes of LV_{circ} systolic function obtained by speckle tracking echocardiography.

2. Methods

2.1. Study population

The study population was selected among consecutive uncomplicated hypertensive subjects who were referred to our Laboratories for an echocardiographic examination over a 6-month enrolment period. Patients were considered eligible for the study if they were ≥16 years old and were affected by systemic hypertension, defined as current antihypertensive treatment in the presence of a documented diagnosis, or evidence of high blood pressure in multiple measurements according to current European Society of Hypertension – European Society of Cardiology guidelines [13]. Exclusion criteria were: evidence or clinical suspicion of secondary hypertension; mitral regurgitation of higher degree than trivial; aortic regurgitation; any degree of valvular stenosis; overt coronary artery disease (defined as history of angina, myocardial infarction or coronary revascularization procedure; evidence of positive stress test; or segmental wall segmental abnormalities at echocardiography); atrial fibrillation, atrial flutter, or other major arrhythmias; hypertrophic cardiomyopathy; left bundle branch block; pacemaker implantation; previous cardiac surgery; inadequate acoustic windows. Extensive clinical, laboratory, and instrumental examinations were performed for the exclusion of causes of elevated blood pressure in patients with clinical features potentially suggestive of secondary hypertension, particularly in younger subjects or in the presence of poor response to therapy. A total of 364 patients met all selection criteria during the period of study. Within this study population, 279 subjects were under antihypertensive medications and had a previous physician diagnosis of hypertension. In the remaining 85 subjects where the diagnosis was based on the European Society of Hypertension – European Society of Cardiology criteria, hypertension was graded as mild in 54 (63.5%), moderate in 26 (30.6%), and severe in 5 (5.9%). A control sample of 182 age- and gender-matched healthy subjects, sampled using a 1:2 scheme with exact matching for gender and a ± 5 years criterion for age, was also considered to derive equations for stress-adjustment of mFS values.

2.2. Standard echocardiography

2.2.1. LV measurements

Studies were performed using a commercially available ultrasound system (GE Vivid 7, Horten, Norway). Standard LV measurements, including end-diastolic and end-systolic ventricular septum thicknesses ($IVST_d$ and $IVST_s$), LV internal diameters ($LVID_d$ and $LVID_s$), and posterior wall thicknesses (PWT_d and PWT_s), were performed from the parasternal long-axis view in accordance with ASE recommendations [14,15]. LV diastolic relative wall thickness (RWT) was computed as $2 \cdot PWT_d/LVID_d$. Mean wall thickness at end-diastole (T_d) and end-systole (T_s) was obtained as the average of septal and posterior wall thicknesses. LV long-axis length at end diastole and end systole (L_d and L_s, respectively) was determined by measuring the distance between the apex of LV cavity and the central point of the mitral plane, averaging values obtained in the apical 4- and 2-chamber views. LV ejection fraction was computed using the biplane modified Simpson's rule from apical views. LV sphericity index was calculated as the ratio of LV end-diastolic volume divided by the volume of a sphere with diameter equal to L_d [16]. The normal LV shape is characterized by an end-diastolic sphericity index <0.5, whereas higher values approaching 1 indicate progressive LV spherical remodeling [17]. Pulsed Doppler interrogation of LV inflow was performed in the apical 4-chamber view, positioning the sample volume at the level of the mitral leaflet tips. The peak of LV early (E) and late (A) filling were measured and their ratio E/A was determined. Pulsed tissue Doppler imaging of long-axis LV motion was obtained by placing the sample volume at the junction of septal and lateral basal segments with the mitral annulus. Peak systolic (s'), early diastolic (e'), and late diastolic (a') velocities were obtained by averaging septal and lateral values. All measurements were obtained by averaging values obtained in three consecutive cardiac cycles.

2.2.2. Determination of mFS by conventional geometrical models

Similarly to the standard fractional shortening measured at the endocardium, mFS is defined as the change in LV midwall diameter during systole, divided by end-diastolic LV midwall diameter. At end diastole, when the midwall is by definition assumed to be in the middle of LV wall, equidistant from the epicardium and the endocardium, the midwall diameter is by definition equal to $LVID_d + T_d$. On the other hand, because the inner LV shell thickens more than the outer one during systole as a result of the cross-fiber thickening phenomenon [18], the position of the midwall at end-systole is no longer in the middle of LV wall, since it shows a relative shifting towards the epicardium. As a result, LV midwall diameter at end systole can be set equal to $LVID_s + 2\alpha$, where α is the end-systolic distance (greater than $T_s/2$) between the midwall and the subendocardium. Thus, mFS is obtained as

$$mFS = \frac{\text{End-diastolic midwall diameter}-\text{End-systolic midwall diamter}}{\text{End-diastolic midwall diamter}} = \frac{(LVID_d + T_d)-(LVID_s + 2\alpha)}{(LVID_d + T_d)}$$

The problem of calculating mFS therefore reduces to that of estimating α, which is the only unknown variable in the equation. Two different geometrical models, which assume a spherical or cylindrical shape for the left ventricle, were previously developed for this estimation. In these models, the left ventricle is considered as the union of two concentric shells, with a regular spherical or cylindrical shape, separated by the midwall layer. The value of α is obtained by equalizing the volume of the inner shell (or its ratio with total LV myocardial volume) at end diastole and end systole, under the assumption of constant shell volume, and solving the resulting equation. Details on the two models and the corresponding formulas for the calculation of α have been previously published [11, 12].

2.2.3. TE model

We developed a new method for the calculation of mFS, based on an alternative geometrical model for the estimation of α, where the left