Original Article

ISSN 1984-3038

Rev bras ecocardiogr imagem cardiovasc. 2013;26(3):189-195

E / e' ratio in the Prediction of Left Ventricular Remodeling after Myocardial Infarction

Relación E/e' en la Predicción de la Remodelación del Ventrículo Izquierdo Después de Infarto Agudo del Miocardio

Silvio Henrique Barberato[1], Admar Moraes de Souza[2], Costantino Ortiz Costantini[3], Costantino Roberto Frack Costantini[4]

[1] Medical Researcher NUPEC - Costantini Cardiology Hospital [2] Medical Supervisor of Echocardiography - Costantini Cardiology Hospital [3] Scientific Director of the Costantini Cardilogy Hospital [4] General Director of the Costantini Cardiology Hospital

SUMMARY

Background: Left ventricular (LV) dilation after acute myocardial infarction (AMI) is an important determinant of prognosis. The ratio of early mitral inflow velocity (E) and peak early diastolic annular velocity (e') provides the best single index for noninvasive detection of acute elevation of LV filling pressure. **Objective:** To assess whether E/e' ratio predicts LV remodeling after properly treated AMI compared with traditional clinical, laboratory and echocardiographic data. **Methods:** Comprehensive echocardiograms were performed in a series of consecutive patients with first AMI successfully treated with primary percutaneous transluminal angioplasty (PTCA), both 48 hours after intervention and 60 days later. Average E/e' was determined from four sites of mitral annulus. LV remodeling was defined as more than 15% increase in end-systolic volume estimated by Simpson method. Statistical analysis included Student t test, receiver-operator curves (ROC) and multivariate logistic regression (all significant with "p" less than 0.05). **Results:** Fifty-five patients were included, with mean age 58 ± 11 years, 43 men. The group of patients who underwent LV remodeling (n=13) had higher baseline E/e' than those without (13 ± 4 versus 8.5 ± 2, p <0.001). The ROC curve showed E/e' > 15 as a predictor of remodeling (AUC=0.81, p=0.001). In addition, regression analysis (comprising clinical, laboratory and echocardiographic variables along with AMI site) confirmed the independent value of E/e' in the prediction of LV remodeling (odds ratio 1.42, p=0.01). **Conclusion:** The E/e' ratio is an useful predictor for LV remodeling after AMI, indicating patients with increased cardiovascular risk.

Descriptors: Myocardial Infarction; Ventricular Remodeling; Echocardiography; Stroke Volume

RESUMEN

Fundamentos: La dilatación del ventrículo izquierdo (VI), después de infarto agudo del miocardio, (IAM) es un importante determinante del diagnóstico. La razón entre la velocidad diastólica E del flujo mitral y la velocidad diastólica e' del anillo mitral (relación E/e'), es el mejor índice no invasivo para detectar elevación aguda de la presión de llenado del VI. La hipótesis de este estudio es E/e' sea capaz de predecir remodelación del VI, después de IAM tratado. **Objetivo:** Evaluar si E/e' predice remodelación ventricular después de IAM, en comparación a los datos clínicos, de laboratorio y ecocardiográficos tradicionales. **Método:** Ecocardiogramas fueron realizados en pacientes consecutivos con primer IAM, después de angioplastia transluminal coronaria (ATC), seguida de recanalización efectiva, 48 horas y 60 días después del evento. E/e' fue calculada por el promedio de cuatro sitios del anillo mitral. Remodelación del VI fue definida como aumento ≥ 15% del volumen sistólico final al método de Simpson. Análisis estadísticos incluyeron test t de *Student*, curvas receptor-operador (ROC) y regresión logística multivariada, con p significante < 0,05. **Resultados:** Estudiados 55 pacientes, con edad 58±11 años, 43 hombres, se observó E/e' mayor (13±4 *versus* 8,5±2; p< 0,001) en el grupo con remodelación (n= 13) con relación al grupo sin remodelación (n= 42). La curva ROC

Institute: Costantini Cardiology Hospital. Curitiba-PR - Brazil-BR
Mailing Address: Pedro Collere Street, No. 89 - Vila Isabel 80320-320 - Curitiba-PR - Brazil-BR
Phone / Fax: (41) 3013-9000
silviohb@cardiol.br
Received: 27/08/2012 **Accepted:** 23/11/2012

indicó E/e' como predictor de remodelación (área bajo la curva= 0,81, p= 0,001). Análisis de regresión conteniendo variables clínicas, de laboratorio y dopplerecocardiográficas confirmaron E/e' como predictor independiente de la remodelación (*odds ratio* 1,42; p= 0,01). **Conclusión:** La relación E/e' es un predictor útil de remodelación del VI después de IAM, indicando pacientes con mayor riesgo cardiovascular.
Descriptores: Infarto del Miocardio, Remodelación Ventricular, Ecocardiografía, Volumen Sistólico

INTRODUCTION

The dilatation of the left ventricle (LV) after acute myocardial infarction (AMI) may occur even with transluminal coronary angioplasty (PTA) with good results. Previous studies have observed significant LV dilatation in approximately one third of patients, despite the patency of the artery related to the AMI [1,2.] The increase in the left ventricular cavity in response to aggression is often accompanied by change in the geometry and decreased overall performance of the chamber, which is conventionally called remodeling. Such LV dilatation after AMI is an important determinant of prognosis, increasing the risk of heart failure and sudden death [3.] Several indexes derived from Doppler echocardiography have been used to predict outcomes in patients after AMI. The presence of restrictive mitral flow, which is characterized by a short deceleration time (DT) of the E wave of mitral flow, was associated with increased risk of LV dilatation after AMI [4,5.] Elevated filling pressures, as suggested by DT <130 to 140ms, usually indicate larger infarcts with marked systolic dysfunction and special predisposition for remodeling [6.]

However, the mitral flow rate and DT are of limited value in patients with preserved LV systolic function [7.] Fortunately, the desirable early reperfusion obtained by recent advances in the techniques of PTA has resulted in better clinical outcomes and higher recovery of left ventricular function [8.] On the other hand, the ratio of early diastolic speed of mitral flow by conventional pulsed Doppler (E) and the early diastolic speed of the mitral annulus by tissue Doppler (e'), known as the E/e', correlated well with the LV filling pressure[7.] even in patients with ejection fraction (EF) preserved.

Our hypothesis was that the increased E/e' ratio (noninvasive marker of elevated LV filling pressures) is associated with higher incidence of LV dilatation in patients with successful reperfusion after AMI. Therefore, the aim of this study was to determine whether the E/e' predicts remodeling of the infarcted LV and adds information to the clinical, laboratorial, and echocardiographic traditional approach.

METHOD

Population

Consecutive patients admitted to the coronary care unit of our institution, with a diagnosis of first AMI, were evaluated for inclusion in the study. The diagnosis of AMI was defined by the recommendations of the *European and American College of Cardiology / American Heart Association guidelines* [9.] The inclusion criteria were the following: 1) coronary cineangiography after PTA showing patent AMI-related artery with TIMI flow grade III [10,] 2) echocardiogram showing akinesia in the wall related to compromised arterial region. The exclusion criteria were the following: 1) need for hemodynamic support with intra-aortic balloon; 2) sustained arrhythmia, precluding the measurement of Doppler echocardiographic indexes; 3) inadequate chest acoustic window; 4) Failure to agree to participate in the study.

The study was approved by the Ethics Committee and the patients were included after signing the free and clarified consent form.

Echocardiography

Complete echocardiographic evaluation was performed in a consecutive series of patients with first AMI at two times: 48 hours after PCI with successful rechanneling of the culprit vessel, and approximately 60 days after the AMI. At our institution, all patients are directly treated with primary PCI and non-thrombolysis. Therefore, the value of E/e' for the outcome researched was tested under these circumstances for all study subjects. Echocardiograms were performed by the same examiner by using *Philips* IE33 echocardiographer *(Philips Medical Systems,* USA) equipped with 2.5-4MHz transducer. The views were performed to allow a complete study by the techniques of M mode, two-dimensional, and Doppler (pulsed, continuous, color, and tissue).

In accordance with the recommendations of the *American Society of Echocardiography* (ASE) [11,] the following parameters were determined: interventricular septum thickness and LV inferolateral wall thickness in diastole, systolic and diastolic dimensions of the LV. The parietal motility score (PMS) was calculated taking into account the standard model of 16 segments and graduated in 4-point scale: 1 = normal, 2 = hypokinetic, 3 = akinetic, 4 = dyskinetic. The LV mass was calculated by using the formula of ASE and indexed by body surface area (DuBois and DuBois method). The volumes and EF were calculated by the Simpson's biplane method. LV remodeling was defined prospectively as ≥ 15% increase in end-systolic volume [12.]

The mitral flow rates were measured by pulsed Doppler in the apical 4-chamber view with the sample volume positioned between the tips of the mitral valve leaflets, and the patient was instructed to hold his breath whenever possible. The early diastolic speed (E) and the atrial contraction speed (A), as well as the E / A ratio and the DT were determined. The early diastolic annular speed (e') and atrial speed (a') were recorded by tissue Doppler in the apical 4- and 2-chamber view with sample volumes of 1 to 2 mm placed at the junction of the LV wall with four sites of the mitral annulus (septal, lateral, anterior, and inferior). The average speeds of the four sites represented and the e' and a' waves used for analysis in the study, as well as the E/e' ratio. All measurements represent the average of three cardiac cycles.

The LV diastolic function was graded according to the combined interpretation of the indexes derived from conventional pulsed Doppler of the mitral flow and tissue Doppler. Abnormal relaxation (diastolic dysfunction grade 1) was diagnosed with the presence of E/A ratio <0.9 and e' <10cm / s; and restrictive flow (diastolic dysfunction grade 3) was determined with E/A ratio >2, DT <140ms, and e' <8 cm/s[13]. In THE differentiation between normal and pseudonormal pattern (diastolic dysfunction grade 2), the presence of e' <8cm/s e E/e' ≥ 15 was used [13]. The indexed left atrial volume (iLAV) was measured by using the Simpson's biplane technique followed by indexation by body surface area.

Baseline clinical data and follow-up

Demographics and clinical data were obtained by detailed review of medical records. The following parameters were record: age, gender, weight, height, body mass index (BMI), history of diabetes, arterial hypertension, dyslipidemia, smoking, drugs in use, and prior PTA. The elapsed time from onset of symptoms to rechanneling of the culprit vessel, the location (LV wall compromised), Killip classification, blood pressure on admission, and enzyme peaks for creatine kinase-MB isoenzyme (CK-MB) and troponin were also noted. During and after the completion of the PTA, all patients were treated with the recommended doses of aspirin, clopidogrel, unfractionated heparin and abciximab [9]. Drug treatment after the event was conducted by the patient's physician, recommending the administration of ACE inhibitors (or angiotensin II receptor blockers), beta-blockers and diuretics, according to current guidelines [9]. The primary endpoint was LV remodeling 60 days after the AMI.

Statistical Analysis

The estimated calculation of the sample was 51 patients, taking into account an incidence of remodeling of approximately 30% [1], statistical power of 90%, and a significance level of 5%. Data are presented as mean plus standard deviation (continuous variables) and percentages (categorical variables). The differences between the groups with and without remodeling were determined by the Student's t test (continuous variables with normal distribution), Mann-Whitney test (continuous non-normally distributed) and chi-square (categorical).

The correlations between the Doppler echocardiographic indexes and changes in end-systolic volume were analyzed by using Pearson's correlation coefficient. Receiver-operator curve (ROC) was constructed to determine the E/e' as a predictor for remodeling, as well as sensitivity and specificity. Finally, multivariate logistic regression analysis was used to identify the independent value of E/e' in relation to several traditional variables. Statistical significance was defined as $p < 0.05$. Analyses were processed by the statistical program SPSS 13.0 for Windows (SPSS Inc., Chicago, Illinois).

RESULTS

We included 55 patients, 58 ± 11 years-old, 43 men, being detected remodeling (group I) in 13 subjects (24%), which were compared with the group without remodeling (group II), consisting of 42 individuals.

The demographic, clinical, and laboratorial characteristics of the study population (and their subgroups) are arranged in Table 1. Group I had a higher percentage of previous history of arterial hypertension (60% versus 38%, $p = 0.02$) and higher peaks of troponin (20 ± 12 *versus* 7 ± 8 ng / ml, $p = 0.005$) compared to group II. There was also a trend to higher peaks of CK-MB ($p = 0.06$) and time from symptom to vessel rechanneling ($p = 0.08$) in group I. No statistically significant difference was observed between the groups regarding age, gender, BMI, diabetes, dyslipidemia, smoking, previous use of angiotensin converting enzyme inhibitors / angiotensin II receptor blockers, previous PTA, infarction located in anterior wall, Killip II on admission, blood pressure on admission, and serum hemoglobin, glucose, and creatinine levels (all $p>0.05$).

Table 2 shows the main characteristics of the Doppler echocardiography of the study sample. Group I had larger LV systolic dimension ($p = 0.02$), lower EF ($p = 0.01$) higher EMP ($p < 0.001$), and lower e' ($p = 0.02$) and a' ($p = 0.03$), and higher E/e' ratio ($p<0.001$). No differences were observed in LV diastolic dimension, LVMI, E/A ratio, DT, and iLAV (all $p > 0.05$) between groups.

Correlation was observed between the variation in end-systolic volume after 60 days ($r = 0.26$, $p = 0.03$) and E/e', but not with the other variables. The ROC curve (Figure 1) indicated E/e' as a predictor of remodeling (area under the curve = 0.81, 95% confidence interval 0.68-0.94, $p = 0.001$). The cutoff value for E/e' > 15 showed a sensitivity of 70% and specificity of 98% for $>15\%$ increase of LV end-systolic volume.

Table 1: Main demographic, clinical, and laboratory characteristics of the study population and its subgroups: group I - with remodeling, group II - without remodeling

Variable	Total (n = 55)	Group I (n = 13)	Group II (n = 42)	p
Age (years)	58 ± 11	59 ± 13	58 ± 11	0.8
Male (%)	78 (43)		78	0.9
BMI (kg / m²)	27 ± 4	28 ± 4	27 ± 4	0.6
AH (%)	47 (26)	69	38	0.02
DM (%)	20	15	21	0.7
DL (%)	49	61	45	0.2
Smoking (%)	36	38	36	0.7
ACEI / ARB (%)	84	100	72	0.8
Previous PTA (%)	7	15	5	0.2
Previous AMI (%)	53	69	48	0.2
Time (hours)	5 ± 6	7 ± 8	4.5 ± 6	0.08
Killip II (%)	13	30	9.5	0.2
SBP (mmHg)	126 ± 21	131 ± 25	125 ± 20	0.5
DBP (mmHg)	75 ± 14	76 ± 19	75 ± 12	1.0
HR (beats. / Min.)	74 ± 13	70 ± 18	75 ± 12	0.5
CK-MB (U / L)	128 ± 118	194 ± 136	99 ± 103	0.06 *
Troponin I (ng / ml)	10 ± 11	20 ± 12	7 ± 8	0,005 *
Hemoglobin (g / dl)	13 ± 2	13 ± 2	13 ± 2	0.8
Glucose (mg / dl)	126 ± 50	129 ± 29	126 ± 55	0.9
Creatinine ()	1.07 ± 0.2	1.06 ± 0.2	1.07 ± 0.2	0.9

BMI - body mass index; AH - arterial hypertension, DM - diabetes mellitus, DL - dyslipidemia; ACEI / ARB - angiotensin converting enzyme inhibitors / angiotensin receptor blockers; PTA - percutaneous transluminal angioplasty, AMI - acute myocardial infarction; SBP - systolic blood pressure, DBP - diastolic blood pressure, HR - heart rate, CK-MB, creatine kinase-MB isoenzyme. - Used the Mann-Whitney test. Other continuous variables were compared by Student's t test.*

Multivariate regression analyses containing clinical variables (history of arterial hypertension, duration of symptoms), laboratory variables (troponin and CK-MB), and Doppler echocardiographic variables (LV systolic dimension, EF, EMP, a', E/e', and location of IAM) confirmed E/e' as the only independent predictor of remodeling (*odds ratio* 1.42, 95% confidence interval 1.1-1.9, p = 0.01), above and beyond all other parameters. Speculative analyses forcing the model to other input variables traditionally used, such as age, gender, DT, and location of AMI of the anterior wall did not change the independent predictive value of E/e'.

DISCUSSION

The main finding of this study was that E/e' seems to be an independent predictor of left ventricular remodeling after acute myocardial infarction treated with successful reperfusion by PTA. In particular, echocardiographic evidence of elevation of LV filling pressures, provided by E/e > 15, was strongly associated with LV dilatation, with values higher than clinical, laboratory, and echocardiographic parameters previously established. Considerable amount of evidence has shown that the presence of restrictive mitral flow (short DT) is a strong prognostic predictor after AMI, since in general it is associated with a larger area of the LV wall akinesia and increased end-diastolic pressure [4-6.] However, the DT has limitations known in individuals with preserved systolic function [7,] a situation increasingly common after the advances obtained by ready percutaneous intervention in AMI therapy. In parallel, it was demonstrated that E/e' ratio was the best indicator of the presence of increased end-diastolic pressure in the comparison between multiple echocardiographic parameters and the pressure measured by hemodynamic catheter [7,14.]

The present study indicates that E/e' is greater than DT to predict remodeling when evaluating a patient population by EF; relatively preserved (overall sample with mean EF percentage of 55 ± 12). Another intriguing finding was that E/e', representative

Table 2: **Main Doppler echocardiographic characteristics of the study population and its subgroups: group I - with remodeling, group II - without remodeling**

Variable	Total (n = 55)	Group I (n = 13)	Group II (n = 42)	p
LVDD (mm)	50 ± 4	51 ± 5	50 ± 4	0.2
LVSD (mm)	34 ± 7	38 ± 6	32 ± 7	0.02
LVEDV (mm)	90 ± 29	84 ± 19	91 ± 31	0.4
LVESV (mm)	41 ± 17	44 ± 16	40 ± 18	0.5
EF %	55 ± 12	47 ± 11	56 ± 12	0,01
PMS	1.3 ± 0.2	1.51 ± 0.2	1.27 ± 0.2	<0.001
LVMI (g / m^2)	101 ± 17	108 ± 18	99 ± 17	0.08
iLAV (ml / m^2)	25 ± 5	26 ± 5	24 ± 5	0.5
E (cm / s)	77 ± 19	84 ± 19	75 ± 18	0.1
A (cm / s)	70 ± 24	69 ± 27	70 ± 23	0.9
E / A	1.2 ± 0.5	1.4 ± 0.6	1.2 ± 0.4	0.1
DT (ms)	186 ± 31	172 ± 21	190 ± 33	0.2
e' (cm / s)	8.1 ± 2	6.9 ± 2	8.5 ± 2	0.02
a' (cm / s)	8.9 ± 2	7.7 ± 3	9.4 ± 2	0.03
E/e'	10 ± 3	13 ± 4	8.5 ± 2	<0.001

LVEDD - left ventricular diastolic dimension; LVESD - left ventricular systolic dimension; LVEDV - end-diastolic volume of the left ventricle; LVEST - end-systolic volume of the left ventricle; EF - ejection fraction; PMS - parietal motility score; LVMI - mass index of the left ventricle; E - early diastolic speed of mitral flow, A - atrial contraction speed of mitral flow, DT - deceleration time; e' - early annular diastolic speed; a' - annular atrial contraction speed.

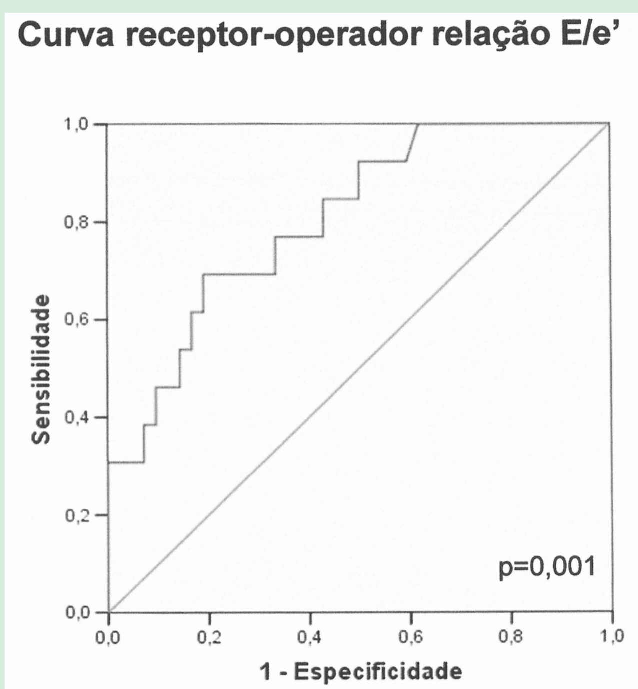

Figure 1: *Receiver-operator curve of E/e' ratio in the prediction of left ventricular remodeling after acute myocardial infarction treated.*

of the acute effects of elevated LV filling pressures, performed better to predict remodeling after AMI than an index traditionally associated with chronic elevation of filling pressures, the iLAV. Although iLAV is a clear predictor of mortality after AMI [15], its impact on remodeling was not observed in our study.

It is possible that patients with chronic increase of iLAV have already suffered prior to AMI some degree of left ventricular remodeling, thus mitigating the effects generated by the latest ischemic injury. Therefore, the impact of increased iLAV on LV remodeling would not be apparent to a relatively small cohort and a short follow-up duration like ours. Alternatively, one may speculate that the relationship between LV remodeling and acute increase in filling pressure is more important than between remodeling and chronic increase.

In the context of myocardial ischemia and infarction, tissue Doppler (from which derives the e' speed and, ultimately, the E/e' ratio) shows lower systolic and diastolic speeds in the mitral annulus [16]. These speeds decrease with regional hypoperfusion, recover with reperfusion, and differentiate between transmural and non-transmural infarction [17].

After AMI, the acute effects of ischemia and necrosis cause loss of myocytes integrity and disarray of LV geometry, leading to decreased overall performance and increased end-diastolic pressure of the LV. LV dilatation / remodeling emerges from this process as a compensatory mechanism to (try to) restore the filling pressure to a normal level (or near normal). This could explain why a substitute marker of acute measure of LV filling pressure works best in predicting remodeling.

In addition to estimate the cardiac function and filling pressures, some authors have investigated the prognostic value of E/e' ratio in AMI. In 250 patients followed-up for median period of 13 months after AMI, Hillis et al. showed that [18] E/e' >15 was a strong predictor of poor survival, with incremental value to clinical and traditional echocardiographic indexes of systolic and diastolic function. Certainly left ventricular remodeling plays an important role in the pathophysiology of the phenomena involved in the decreased survival in this group. The same group also published a study in the same investigational line, showing that E/e' >15 identify individuals with increased risk for LV dilatation after AMI [19].

However, there are several methodological differences between said report and the present study that must be highlighted. First, the population studied by Hillis et al. was composed of 47 [18] subjects, only 22 patients (47%) being treated with primary PCI, and 25 (53%) treated with thrombolysis [19]. In contrast, all patients in our group underwent percutaneous intervention, which is known to provide better evolution [8]. In addition, the criteria for defining LV remodeling were different: increase of ≥ 15% in LV end-systolic volume in our study, in contrast to increase of ≥ 15% in end-diastolic volume in said article. The option by using the variation in end-systolic volume for diagnosing remodeling was due to prior evidence that such parameter is superior to end-diastolic volume and ejection fraction itself as primary predictor of prognosis after AMI [12].

There is no consensus in the literature whether the variation in end-systolic or end-diastolic volume of the LV should be used in the diagnosis of remodeling, and other authors have also used our choice as reference [12]. Finally, it is important highlight that in the study by Hillis et al. [18], the E/e' ratio was obtained from the measurement of e' speed performed exclusively on the septal side of the mitral annulus, while in our study we used the average of 4 sides of the mitral annulus (septal, lateral, anterior and inferior). Such conduct is fundamental to reduce discrepancies in the presence of regional myocardial dysfunction [13].

Our approach has some limitations. It is known that tissue Doppler speeds are affected by the translation, traction, and tethering of adjacent myocardial segments [20] and, therefore, it is highly dependent on the angle. New imaging methods such as speckle tracking echocardiography and magnetic resonance imaging [21 22], without this limitation, has demonstrated extraordinary value to predict remodeling after AMI. However, its clinical application is still quite restricted for various reasons, including the availability, which makes the E/e' ratio the best choice in terms of cost-effective at the present moment.

Thus, the E/e' ratio can be a useful predictor in the setting of LV remodeling after AMI, indicating patients with increased cardiovascular risk and enabling early intervention.

References

1. Bolognese L, Neskovic AN, Parodi G, Cerisano G, Buonamici P, Santoro GM, et al. Left ventricular remodeling after primary coronary angioplasty: patterns of left ventricular dilation and long-term prognostic implications. *Circulation.* 2002;106(18):2351-7.
2. Cerisano G, Pucci PD, Valenti R, Boddi V, Migliorini A, Tommasi MS, et al. Comparison of the usefulness of Doppler-derived deceleration time versus plasma brain natriuretic peptide to predict left ventricular remodeling after mechanical revascularization in patients with ST-elevation acute myocardial infarction and left ventricular systolic dysfunction. *Am J Cardiol.* 2005;95(8):930-4.
3. St John Sutton M, Pfeffer MA, Moye L, Plappert T, Rouleau JL, Lamas G, et al. Cardiovascular death and left ventricular remodeling two years after myocardial infarction: baseline predictors and impact of long-term use of captopril: information from the Survival and Ventricular Enlargement (SAVE) trial. *Circulation.* 1997;96(10):3294-9.

4. Cerisano G, Bolognese L, Carrabba N, Buonamici P, Santoro GM, Antoniucci D, et al. Doppler-derived mitral deceleration time: an early strong predictor of left ventricular remodeling after reperfused anterior acute myocardial infarction. *Circulation* .1999;99(2):230-6.
5. Temporelli PL, Giannuzzi P, Nicolosi GL, Latini R, Franzosi MG, Gentile F, et al. Doppler-derived mitral deceleration time as a strong prognostic marker of left ventricular remodeling and survival after acute myocardial infarction: results of the GISSI-3 echo substudy. *J Am Coll Cardiol* .2004;43(9):1646-53.
6. Nijland F, Kamp O, Karreman AJ, van Eenige MJ, Visser CA. Prognostic implications of restrictive left ventricular filling in acute myocardial infarction: a serial Doppler echocardiographic study. *J Am Coll Cardiol* .1997;30(7):1618-24.
7. Ommen SR, Nishimura RA, Appleton CP, Miller FA, Oh JK, Redfield MM, et al. Clinical utility of Doppler echocardiography and tissue Doppler imaging in the estimation of left ventricular filling pressures: A comparative simultaneous Doppler-catheterization study. *Circulation.* 2000;102(15):1788-94.
8. Brodie BR, Stone GW, Cox DA, Stuckey TD, Turco M, Tcheng JE, et al. Impact of treatment delays on outcomes of primary percutaneous coronary intervention for acute myocardial infarction: analysis from the CADILLAC trial. *Am Heart J* .2006;151(6):1231-8.
9. Antman EM, Hand M, Armstrong PW, Bates ER, Green LA, Halasyamani LK, et al. 2007 focused update of the ACC/AHA 2004 guidelines for the management of patients with ST-elevation myocardial infarction: a report of the American College of Cardiology/ American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol* .2008;51(2):210-47.
10. Simes RJ, Topol EJ, Holmes DR Jr., White HD, Rutsch WR, Vahanian A, et al. Link between the angiographic substudy and mortality outcomes in a large randomized trial of myocardial reperfusion. Importance of early and complete infarct artery reperfusion. GUSTO-I Investigators. *Circulation* .1995;91(7):1923-8.
11. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, et al. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr* 2005;18(12):1440-63.
12. Mollema SA, Nucifora G, Bax JJ. Prognostic value of echocardiography after acute myocardial infarction. Heart 2009; 95(21): 1732-45.
13. Nagueh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA, et al. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. *J Am Soc Echocardiogr.* 2009;22(2):107-33.
14. Dokainish H, Zoghbi WA, Lakkis NM, Al-Bakshy F, Dhir M, Quinones MA, et al. Optimal noninvasive assessment of left ventricular filling pressures: a comparison of tissue Doppler echocardiography and B-type natriuretic peptide in patients with pulmonary artery catheters. *Circulation.* 2004;109(20):2432-9.
15. Moller JE, Hillis GS, Oh JK, Seward JB, Reeder GS, Wright RS, et al. Left atrial volume: a powerful predictor of survival after acute myocardial infarction. *Circulation.* 2003;107(17):2207-12.
16. Alam M, Wardell J, Andersson E, Samad BA, Nordlander R. Effects of first myocardial infarction on left ventricular systolic and diastolic function with the use of mitral annular velocity determined by pulsed wave doppler tissue imaging. *J Am Soc Echocardiogr* .2000;13(5):343-52.
17. Derumeaux G, Loufoua J, Pontier G, Cribier A, Ovize M. Tissue Doppler imaging differentiates transmural from nontransmural acute myocardial infarction after reperfusion therapy. *Circulation.* 2001;103(4):589-96.
18. Hillis GS, Moller JE, Pellikka PA, Gersh BJ, Wright RS, Ommen SR et al. Noninvasive estimation of left ventricular filling pressure by E/e' is a powerful predictor of survival after acute myocardial infarction. *J Am Coll Cardiol.* 2004;43(3):360-7.
19. Hillis GS, Ujino K, Mulvagh SL, Hagen ME, Oh JK. Echocardiographic indices of increased left ventricular filling pressure and dilation after acute myocardial infarction. *J Am Soc Echocardiogr.* 2006;19(4):450-6.
20. Abraham TP, Dimaano VL, Liang HY. Role of tissue Doppler and strain echocardiography in current clinical practice. *Circulation.* 2007;116(22):2597-609.
21. Park YH, Kang SJ, Song JK, Lee EY, Song JM, Kang DH, et al. Prognostic value of longitudinal strain after primary reperfusion therapy in patients with anterior-wall acute myocardial infarction. J Am Soc Echocardiogr. 2008; 21(3):262-7.
22. Lund GK, Stork A, Muellerleile K, Barmeyer AA, Bansmann MP, Knefel M, et al. Prediction of left ventricular remodeling and analysis of infarct resorption in patients with reperfused myocardial infarcts by using contrast-enhanced MR imaging. Radiology. 2007; 245(1):95-102.