Noninvasive estimation of left ventricular filling pressures in patients with heart failure after surgical ventricular restoration and restrictive mitral annuloplasty

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Objective: Doppler echocardiography, including tissue Doppler imaging, is widely applied to assess diastolic left ventricular function using early transmitral flow velocity combined with mitral annular velocity as a noninvasive estimate of left ventricular filling pressures. However, the accuracy of early transmitral flow velocity/mitral annular velocity in patients with heart failure, particularly after extensive cardiac surgery, is debated. Global diastolic strain rate during isovolumic relaxation obtained with 2-dimensional speckle-tracking analysis was recently proposed as an alternative approach to estimate left ventricular filling pressures.

Methods: We analyzed diastolic function in patients with heart failure after surgical ventricular restoration and/or restrictive mitral annuloplasty. Echocardiography, including tissue Doppler imaging and speckle-tracking analysis, was performed to determine early transmitral flow velocity/atrial transmitral flow velocity, isovolumetric relaxation time, deceleration time, early transmitral flow velocity/mean mitral annular velocity, strain rate during isovolumic relaxation, and early transmitral flow velocity/strain rate during isovolumic relaxation. These noninvasive indices were correlated with relaxation time constant Tau, peak rate of pressure decline, and left ventricular end-diastolic pressure obtained in the catheterization room using high-fidelity pressure catheters.

Results: Twenty-three patients were analyzed 6 months after restrictive mitral annuloplasty (n = 8), surgical ventricular restoration (n = 4), or a combined procedure (n = 11). The strongest correlation with invasive indices, in particular left ventricular end-diastolic pressure, was found for strain rate during isovolumic relaxation ($r = -0.76$, $P < .001$). Early transmitral flow velocity/mean mitral annular velocity did not correlate significantly with any of the invasive indices. Strain rate during isovolumic relaxation (cutoff value $< 0.38\ s^{-1}$) accurately predicted left ventricular end-diastolic pressure of 16 mm Hg or more with 100% sensitivity and 93% specificity.

Conclusions: In a group of patients with heart failure who were investigated 6 months after cardiac surgery, early transmitral flow velocity/mean mitral annular velocity correlated poorly with invasively obtained diastolic indexes. Global strain rate during isovolumic relaxation, however, correlated well with left ventricular end-diastolic pressure and peak rate of pressure decline. Our data suggest that global strain rate during isovolumic relaxation is a promising noninvasive index to assess left ventricular filling pressures in patients with heart failure after extensive cardiac surgery, including restrictive mitral annuloplasty and surgical ventricular restoration. (J Thorac Cardiovasc Surg 2010;140:807-15)

Noninvasive assessment of left ventricular (LV) diastolic function is of growing importance in view of the increasing number of patients with diastolic heart failure diagnoses.[1,2] In addition, the impact of surgical interventions in patients with heart failure, such as surgical ventricular restoration (SVR) and restrictive mitral annuloplasty (RMA), remains debated particularly with regard to a potential negative effect on diastolic function.[3] Elevated filling pressures are a hallmark in heart failure and represent the main physiologic consequence of diastolic dysfunction.[4] This methodological study was designed to investigate which echocardiographic indices are the most promising to assess elevated filling pressures in patients after extensive cardiac surgery. Several echocardiographic indices have been proposed to assess LV filling pressures noninvasively. In particular, early transmitral flow velocity (E) combined with mitral annular velocity (E′) derived from tissue Doppler imaging (ie, mitral E/E′ ratio) is widely used as an estimate of LV filling pressures.[5] Recently, however, the validity of this index, particularly

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Abbreviations and Acronyms

A	= atrial transmitral flow velocity
AUC	= area under the curve
CABG	= coronary artery bypass grafting
dP/dt_{MIN}	= peak rate of pressure decline
DT	= deceleration time
E/E′	= early transmitral flow velocity/mitral annular velocity
IVRT	= isovolumetric relaxation time
LV	= left ventricular
LVEDP	= left ventricular end-diastolic pressure
RMA	= restrictive mitral annuloplasty
SR_{IVR}	= strain rate during isovolumic relaxation
SVR	= surgical ventricular restoration

when applied in patients with heart failure, has been questioned.[6,7] Moreover, a number of potential limitations that may affect its accuracy in patients investigated after cardiac surgery, including RMA and SVR, should be considered. The underlying assumption is that E′ is a preload-independent index of LV relaxation and that correcting E for the influence of myocardial relaxation (ie, using E/E′) improves its relation with filling pressures. However, whether mitral annular velocity adequately represents global LV relaxation in the presence of an RMA ring is unknown. Similarly, altered LV geometry and insertion of a patch during SVR may induce abnormal mitral annulus dynamics. Global diastolic strain rate during isovolumic relaxation (SR_{IVR}) obtained with 2-dimensional speckle-tracking analysis was recently proposed as an alternative approach.[7] SR_{IVR} measures diastolic strain rate from all LV segments during the isovolumetric relaxation period when the mitral valve is still closed. SR_{IVR} represents the performance of all myocardial segments, is load independent, and accounts for the initial LV size. Therefore, SR_{IVR} could be of interest in the evaluation of filling pressures in patients after RMA and/or SVR. Consequently, we measured LV pressures during catheterization in a group of patients with heart failure 6 months after cardiac surgery and compared invasive diastolic indices with the proposed echocardiographic indices of diastolic function.

MATERIALS AND METHODS

Study Population

The study group consisted of 23 patients (mean age, 64 ± 12 years; 16 men) with dilated cardiomyopathy, New York Heart Association class III/IV, and LV ejection fraction less than 35% who underwent cardiac surgery, including coronary artery bypass grafting (CABG), RMA, and SVR. The patients underwent echocardiography and subsequent right and left-sided heart catheterization on the same day at approximately 6 months after cardiac surgery. Measurements were not performed simultaneously. The protocol was approved by the Leiden University Medical Center committee, and all patients gave informed consent. All patients received medical therapy for chronic heart failure. Patient characteristics are summarized in Table 1.

TABLE 1. Patient characteristics at 6 months follow-up after surgery

	N = 23
Age, y	64 ± 12
Men, %	70
NYHA class	1.5 ± 0.6
Quality of life score	16 ± 12
6-min hall walk test, m	442 ± 95
Ischemic cause, %	87
Medical treatment	
Diuretics, %	78%
β-blockers, %	57%
ACEIs, AT antagonists, %	74%
Statins, %	74%
Anticoagulants, %	74%
Surgical data	
Ring size RMA	25.4 ± 1.2
Residual mitral regurgitation	0.9 ± 0.9
CPB time, min	188 ± 55
Aortic crossclamp time, min	128 ± 41
ICU stay, d	6 ± 11
Hospital stay, d	17 ± 12
Inotropics ICU (>24 h), %	57

NYHA, New York Heart Association; *ACEI,* angiotensin-converting enzyme inhibitor; *AT,* angiotensin; *RMA,* restrictive mitral annuloplasty; *CPB,* cardiopulmonary bypass; *ICU,* intensive care unit.

Surgical Procedures

Surgical procedures were performed using normothermic cardiopulmonary bypass with intermittent antegrade warm-blood cardioplegia. CABG, SVR, and RMA were performed when indicated as described previously.[8] After median sternotomy, patients underwent conventional CABG using internal thoracic arteries when possible. SVR was performed by means of an endoventricular circular patch plasty as previously described by Dor and colleagues.[9] Briefly, the LV was opened through the infarcted area. An endocardial encircling suture (Fontan stitch) was placed at the transitional zone between scarred and normal tissue. To define the target volume, a balloon containing 55 mL of saline per meters squared of body surface area was

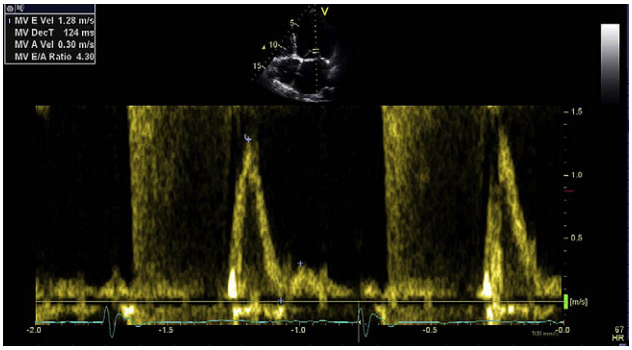

FIGURE 1. Assessment of mitral inflow pattern. Peak E/A and E-wave DT were obtained using spectral Doppler velocities by placing a sample volume at the mitral leaflet tips from the apical 4-chamber view. *MV,* Mitral valve; *E/A,* early transmitral flow velocity/atrial transmitral flow velocity; *DecT,* deceleration time.

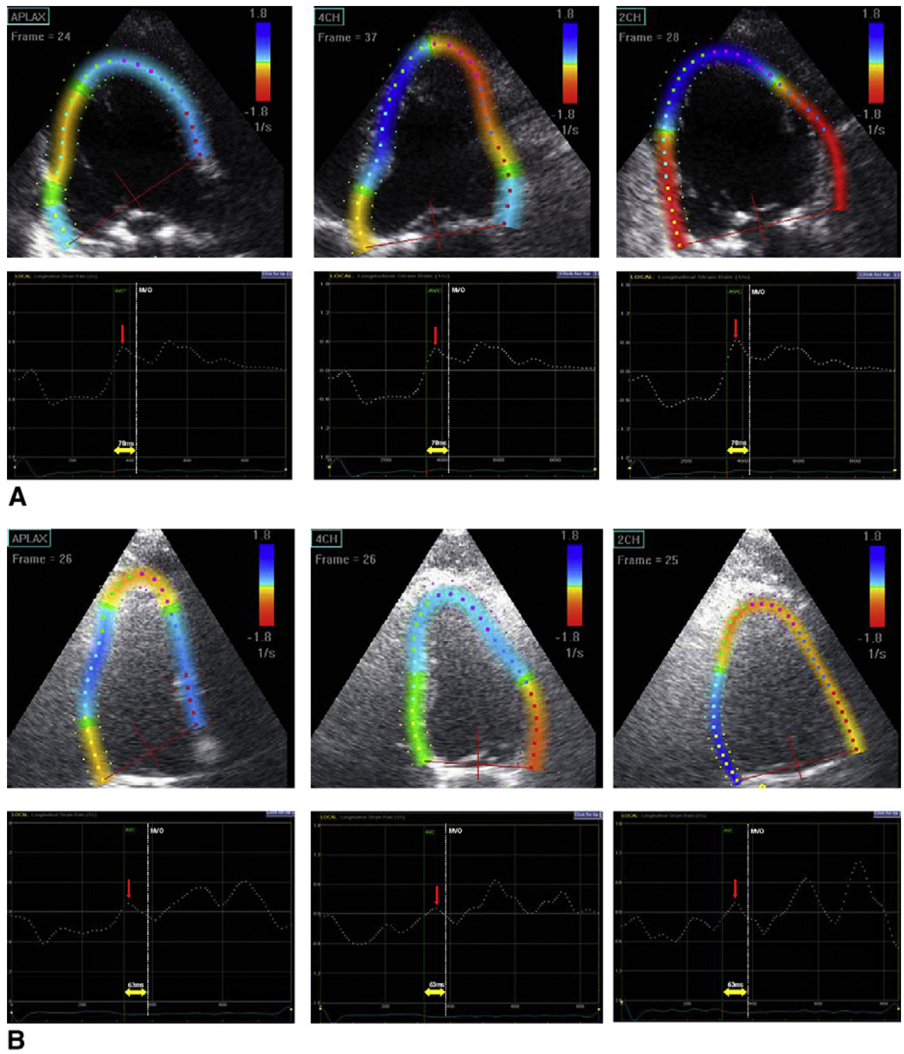

FIGURE 2. A, Assessment of peak global longitudinal SR_{IVR} in a patient with LVEDP $\leq$ 16 mm Hg. In the upper panels from left to right: 3-, 4-, and 2-chamber apical views in which speckle-tracking analysis was applied. In the lower panels, strain rate curves are shown for each apical view. Aortic valve closure was identified on pulsed-wave Doppler tracings obtained from the LV outflow tract. Mitral valve opening (MVO) was calculated by adding isovolumic relaxation time to aortic valve closure (*yellow arrow*). Peak global SR_{IVR} (*red arrow*) was 0.50/sec. B, Assessment of peak global SR_{IVR} in a patient with LVEDP > 16 mm Hg. Methods and figure layout are the same as in A. Peak global SR_{IVR} (*red arrow*) was 0.14/sec.

temporarily placed into the left ventricle. The Fontan stitch was tightened to approximate the ventricular wall to the balloon. A tailored oval Dacron patch was used to close the residual orifice. The excluded scar tissue was closed over the patch to ensure hemostasis. RMA was performed stringently with a ring size 2 sizes smaller than the measured size. A Carpentier Edwards Physio ring (Edwards Lifesciences, Irvine, Calif) was placed by means of an atrial transseptal approach.

Invasive Measurements

Hemodynamic data were obtained during routine right and left-sided heart catheterization at 6.5 $\pm$ 0.8 months follow-up after cardiac surgery, including thermodilution cardiac output, left ventriculography, and coronary angiography. LV pressure was measured using a high-fidelity, solid-state pressure-tip catheter (Sentron; Roden, The Netherlands). LV function was quantified by the heart rate, cardiac output, end-systolic pressure, end-diastolic pressure, minimal rate of LV pressure change ($-dP/dt_{MIN}$), and time constant of relaxation (τ).[10]

Echocardiography

All patients were imaged in the left lateral decubitus position with a commercially available system (Vingmed Vivid 7, General Electric-Medical Systems, Milwaukee, Wis) equipped with a 3.5-MHz transducer. Standard 2-dimensional images and Doppler and color-Doppler data acquired from the parasternal and apical views (2-, 3-, and 4-chamber) were digitally stored in cine-loop format; analyses were subsequently performed offline using EchoPAC version 7.0.0 (General Electric-Medical Systems). LV end-diastolic volume and end-systolic volume were measured according to Simpson's biplane method, and LV ejection fraction was calculated as [(end-diastolic volume $-$ end-systolic volume)/end-diastolic volume] $\times$ 100%.[11] Spectral Doppler velocities were measured from the apical 4-chamber view using a 2-mm sample volume positioned at the mitral leaflet tips. Peak transmitral early (E-wave) and atrial (A-wave) transmitral flow velocities, and the E-wave deceleration time (DT) were obtained (Figure 1). Continuous-wave Doppler echocardiography simultaneously recording aortic and mitral flow was used to measure isovolumetric relaxation time

TABLE 2. Hemodynamic and echocardiographic measurements

	All patients	LVEDP < 16mm Hg	LVEDP ≥ 16mm Hg	*P* value
	N = 23	N = 8	N = 15	
Age, y	64 ± 12	65 ± 12	64 ± 12	.58
Male, %	69.6	62.5	73.3	.59
Heart rate, beats/min	69 ± 13	63 ± 12	72 ± 13	.22
CO, L/min	5.1 ± 1.2	4.8 ± 1.0	5.3 ± 1.3	.52
CI, L/min/m^2	3.2 ± 0.8	3.1 ± 0.6	3.2 ± 0.9	.70
LVESP, mm Hg	120 ± 24	114 ± 14	123 ± 28	.40
LVEDP, mm Hg	17.8 ± 6.1	11.2 ± 2.9	21.4 ± 4.0	<.001
$-dP/dt_{MIN}$, mm Hg/s	1112 ± 246	1154 ± 273	1089 ± 237	.75
τ, ms	79 ± 16	71 ± 17	84 ± 15	.06
EF, %	33 ± 7	36 ± 6	31 ± 8	.09
ESV, mL	111 ± 43	98 ± 23	119 ± 50	.42
ESVI, mL/m^2	58 ± 20	55 ± 11	60 ± 24	.92
EDV, mL	165 ± 56	155 ± 41	171 ± 63	.68
EDVI, mL/m^2	87 ± 26	87 ± 20	87 ± 29	.87
E, cm/s	145 ± 30	154 ± 22	140 ± 33	.25
A, cm/s	76 ± 36	100 ± 39	63 ± 27	.01
E/A	2.2 ± 0.8	1.8 ± 0.7	2.4 ± 0.7	.03
IVRT, ms	88 ± 31	96 ± 12	83 ± 37	.38
DT, ms	217 ± 76	245 ± 76	203 ± 74	.18
E'_{SEPTAL}, cm/s	2.7 ± 0.8	2.8 ± 0.6	2.6 ± 0.2	.75
$E'_{LATERAL}$, cm/s	5.0 ± 1.6	4.9 ± 1.3	5.1 ± 1.7	.90
E'_{MEAN}, cm/s	3.9 ± 1.0	3.8 ± 0.8	3.9 ± 1.2	.97
E/E'_{SEPTAL}	62 ± 31	58 ± 16	64 ± 37	.70
$E/E'_{LATERAL}$	32 ± 13	34 ± 11	31 ± 14	.52
E/E'_{MEAN}	41 ± 15	42 ± 12	40 ± 17	.70
SR_{IVR}, s^{-1}	0.33 ± 0.13	0.45 ± 0.06	0.27 ± 0.10	.001
E/SR_{IVR}, cm	499 ± 211	345 ± 65	582 ± 216	.01

CO, Cardiac output; *CI,* cardiac index; *LVESP,* left ventricular end-systolic pressure; *LVEDP,* left ventricular end-diastolic pressure; τ, isovolumic relaxation time constant; *EF,* ejection fraction; *ESV,* end-systolic volume; *ESVI,* end-systolic volume index; *EDV,* end-diastolic volume; *EDVI,* end-diastolic volume index; *E,* early transmitral flow velocity; *A,* atrial transmitral flow velocity; *IVRT,* isovolumic relaxation time; *DT,* deceleration time; *E′,* mitral annular velocity; *SR_{IVR},* strain rate during isovolumic relaxation.

(IVRT).[1] Doppler tracings were obtained in accordance to the recommendations of the American Society of Echocardiography.[12]

Tissue Doppler Imaging

Color-coded tissue Doppler images of the LV obtained in the apical 4-chamber view were acquired at high frame rates (>100 frames/s) during end expiration. Early diastolic myocardial velocities (E′) were determined at the septal and lateral sides of the mitral annulus (E'_{SEPTAL}, $E'_{LATERAL}$). E'_{MEAN} was calculated as $(E'_{SEPTAL} + E'_{LATERAL})/2$.[5,13] The studies were stored digitally for subsequent offline analysis.

Speckle-Tracking Analysis

Speckle-tracking analysis is based on tracking of natural acoustic markers, or speckles, on standard 2-dimensional grayscale images. This technique is independent of insonation angle and permits evaluation of myocardial contraction/relaxation along the circumferential, longitudinal, and radial directions.[14,15] In the present study, speckle-tracking analysis was applied to the LV in apical 2-, 3-, and 4-chamber views. The frame rate ranged from 80 to 100 frames/s, and 3 cardiac cycles for each apical view were stored in cine-loop format for the offline analysis. During analysis, the endocardial border was manually traced and the region of interest width was adjusted to include the entire myocardium. The software package (EchoPac version 7.0.0) then automatically tracks and accepts segments of good tracking quality and rejects poorly tracked segments, while allowing the observer to manually override its decisions on the basis of visual assessments of tracking quality. Global longitudinal strain and strain rate were obtained automatically from each apical view, and mean global strain and strain rate were manually averaged. Peak global longitudinal strain rate during the isovolumic relaxation (SR_{IVR}) was determined as an index of diastolic function.[7] Typical examples for a patient with normal and elevated filling pressures are shown in Figure 2, *A, B*.

Reproducibility

To assess the reproducibility of SR_{IVR}, 5 patients were randomly selected: Bland–Altman analysis was performed to evaluate the intra- and interobserver agreement by repeating the analysis 1 week later by the same observer and a second independent observer. Bland–Altman analysis demonstrated good intra- and interobserver agreement, with small bias not significantly different from zero. Mean differences ± 2 standard deviations were 0.02 ± 0.07 s^{-1} and 0.02 ± 0.08 s^{-1}, for intra- and interobserver agreement, respectively.

Statistical Analysis

Continuous variables are expressed as mean value ± standard deviation. Variables were compared between groups (normal, LV end-diastolic pressure [LVEDP] < 16 mm Hg; elevated filling pressures, LVEDP ≥ 16 mm Hg) using the Mann–Whitney *U* test for continuous variables and the chi-square test for categoric variables. Pearson correlation coefficients were computed to assess the relationship between invasive indexes and echocardiographic indexes. The optimal cutoff value for each echocardiographic index to predict LVEDP of 16 mm Hg or greater was determined by receiver operating characteristic curve analysis. The optimal cutoff value was defined as the value for which

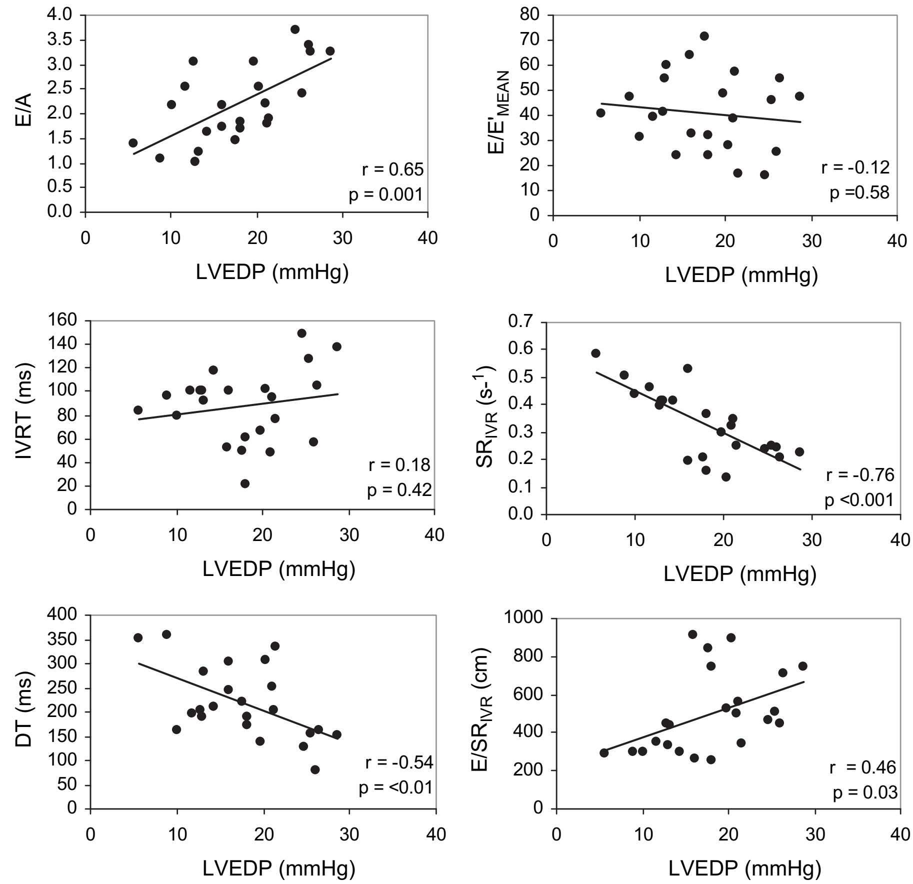

FIGURE 3. Relations between LVEDP and echocardiographic diastolic indices: E/A, IVRT, DT, E/E'_{MEAN}, SR_{IVR}, and E/SR_{IVR}. *LVEDP,* Left ventricular end-diastolic pressure; *IVRT,* isovolumetric relaxation time; *DT,* deceleration time; *E/A,* early transmitral flow velocity/atrial transmitral flow velocity; *E/E'_{MEAN},* early transmitral flow velocity/mean mitral annular velocity; *SR_{IVR},* strain rate during isovolumic relaxation.

the sum of sensitivity and specificity was maximized. Analyses were performed using the statistical software programs SPSS 16.0 (SPSS Inc, Chicago, Ill) and Graphpad 4.02 (GraphPad Software, Inc., San Diego, Calif). A 2-sided *P* value < .05 was considered statistically significant.

RESULTS

Patient Characteristics

Twenty-three patients with heart failure were analyzed 6.5 ± 0.8 months after cardiac surgery. Nineteen patients underwent RMA, of whom 11 obtained a combined RMA/SVR procedure. In 4 patients, SVR without RMA was performed. Additional tricuspid valve annuloplasty was performed in 10 patients, and additional CABG was performed in 19 patients. Patients had an average age of 64 ± 12 years, and 70% were men. At approximately 6 months follow-up, patients were classified as mean New York Heart Association class 1.5 ± 0.6 with a mean LV ejection fraction of 33% ± 7%, a mean quality of life score of 16 ± 12, and a mean 6-minute hall walk test of 442 ± 95 m. Fifteen patients (65%) had elevated LV filling pressures (LVEDP ≥ 16 mm Hg). Patient characteristics are presented in Table 1.

Invasive Hemodynamic and Echocardiographic Measurements

Adequate invasive and echocardiographic measurements were obtained in all patients. Table 2 presents the hemodynamic and echocardiographic follow-up data, including stratification according to normal (LVEDP < 16 mm Hg) and elevated LV filling pressures (LVEDP ≥ 16 mm Hg). Mean LVEDP was 11.2 ± 2.9 mm Hg in the normal group and 21.4 ± 4.0 mm Hg in the patients with elevated filling pressure ($P < .001$). The patients with elevated filling pressure showed a tendency for having a higher heart rate, increased relaxation time, and lower ejection fraction, but none of these differences reached statistical significance. Conventional Doppler and tissue-Doppler indices showed reduced A velocity (63 ± 27 cm/s vs 100 ± 39 cm/s, $P = .01$) and increased E/A (2.4 ± 0.7 vs 1.8 ± 0.7, $P = .03$) in the patients with elevated filling pressure, but no differences between groups were found for E, E′, or E/E′. However, speckle-tracking analysis showed that SR_{IVR} was significantly lower in patients with elevated filling pressure (0.27 ± 0.10 s^{-1} vs 0.45 ± 0.06 s^{-1}, $P = .001$), and

TABLE 3. Correlation (r) of invasive indices of diastolic function with mitral flow Doppler, tissue Doppler, and speckle-tracking indices

	τ	$-dP/dt_{MIN}$	LVEDP
Mitral flow Doppler			
E/A			
r	0.38	–0.43	0.65
P value	0.07	0.04	0.001
IVRT			
r	0.33	–0.29	0.18
P value	0.12	0.18	0.42
DT			
r	–0.08	0.35	–0.54
P value	0.70	0.10	0.01
Tissue Doppler			
E/E'_{MEAN}			
r	–0.07	0.08	–0.12
P value	0.76	0.71	0.58
Speckle tracking			
SR_{IVR}			
r	–0.39	0.46	–0.76
P value	0.07	0.03	<0.001
E/SR_{IVR}			
r	0.47	–0.36	0.46
P value	0.02	0.09	0.03

E, Early transmitral flow velocity; *A*, atrial transmitral flow velocity; *IVRT*, isovolumic relaxation time; *DT*, deceleration time; E'_{MEAN}, mean mitral annular velocity; SR_{IVR}, strain rate during isovolumic relaxation; τ, isovolumic relaxation time constant; dP/dt_{MIN}, peak rate of pressure decline; *LVEDP*, left ventricular end-diastolic pressure.

consequently E/SR_{IVR} was significantly higher (582 ± 216 cm vs 345 ± 65 cm, $P = .01$).

Correlation between Echocardiographic and Invasive Diastolic Indices

Relationships of echocardiographic indices (E/A, IVRT, DT, E/E'_{MEAN}, SR_{IVR}, and E/SR_{IVR}) with invasive LVEDP are shown in Figure 3. E/A, DT, SR_{IVR}, and E/SR_{IVR} yielded significant correlations with the highest correlation for SR_{IVR}; however, IVRT and E/E′ did not correlate with LVEDP. Table 3 shows that E/A and SR_{IVR} also correlated significantly with dP/dt_{MIN}, whereas E/SR_{IVR} correlated with τ. On the other hand, IVRT and E/E′ did not correlate with any of the invasive diastolic indices. To investigate whether IVRT and E/E′ showed better correlation with mean diastolic pressure, we determined the pressure at the onset of atrial contraction located on the electrocardiogram (pre-A pressure). However, neither IVRT ($r = 0.18$, $P = .42$) nor E/E′ ($r = -0.26$, $P = .23$) showed a significant correlation with pre-A pressure.

Diagnostic Accuracy of Noninvasive Estimates of Elevated Filling Pressure

To further investigate the value of echocardiographic indices to predict an elevated filling pressure, we performed receiver operating characteristic curve analyses. Area under the curve (AUC), optimal cutoff values, and corresponding

TABLE 4. Receiver operating characteristic analysis of echocardiographic parameters to predict left ventricular end-diastolic pressure ≥ 16 mm Hg

	Cutoff value	Sensitivity (95% CI) (%)	Specificity (95% CI) (%)	AUC
Mitral flow Doppler				
E/A	>1.7	93.3 (68.1–99.8)	62.5 (24.5–91.5)	0.78
IVRT	<95.5 ms	60.0 (32.3–83.7)	62.5 (24.5–91.5)	0.61
DT	<207 ms	60.0 (32.3–83.7)	50.0 (15.7–84.3)	0.68
Tissue Doppler				
E/E'_{MEAN}	<39.1	53.3 (26.6–78.7)	75.0 (34.9–96.8)	0.55
Speckle tracking				
SR_{IVR}	$<0.38\ s^{-1}$	93.3 (68.1–99.8)	100 (63.0–100)	0.94
E/SR_{IVR}	>444 cm	80.0 (51.9–95.7)	87.5 (47.4–99.7)	0.83

E, Early transmitral flow velocity; *A*, atrial transmitral flow velocity; *AUC*, area under the curve; *CI*, confidence interval; *IVRT*, isovolumic relaxation time; *DT*, deceleration time; E'_{MEAN}, mitral annular velocity (mean); SR_{IVR}, strain rate during isovolumic relaxation.

sensitivities and specificities to predict LVEDP 16 mm Hg or greater[4] are presented in Table 4. SR_{IVR} showed the highest diagnostic accuracy (AUC = 0.94) and excellent sensitivity and specificity of 93% and 100%, respectively, to predict elevated filling pressure using a cutoff value less than 0.38 s^{-1}. E/SR_{IVR} was also accurate with an AUC of 0.83 and sensitivity and specificity of 80.0 and 87.5%, respectively, at a cutoff value of greater than 444 cm. Other indices, in particular E/E'_{MEAN}, showed limited diagnostic accuracy (Figure 4).

DISCUSSION

E/E′ was introduced by Nagueh and colleagues[5] for noninvasive assessment of filling pressure. The rationale for using this ratio was that E′ reflects LV relaxation and is relatively independent of left atrial pressure, and thus E/E′ should correct for the influence of myocardial relaxation on the mitral E velocity and relate more closely to filling pressure. Subsequently, E/E′ was shown to be a clinically useful index in different groups of patients.[5,16-20] However, less favorable results were reported recently, particularly in patients with heart failure. Mullens and colleagues[21] reported limitations in the use of E/E′ ratio in patients with decompensated heart failure. The authors found no correlation between E/E′ and filling pressures. A study by Bruch and colleagues[22] indicated an absence of correlation with E/E′ in patients with primary mitral regurgitation, and a report by Diwan and colleagues[6] indicated decreased correlation with E/E′ in the presence of mitral regurgitation or mitral stenosis. We anticipated that validity of E/E′ might also be limited in patients after RMA or SVR because of altered mitral annulus dynamics and a different recoil mechanism. Therefore, we examined patients with heart failure 6

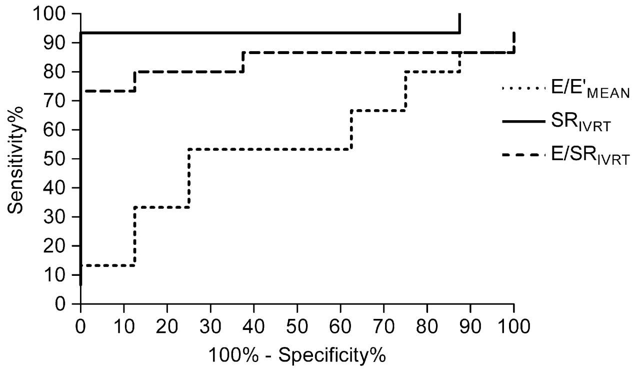

FIGURE 4. Receiver operating characteristic curve analysis to define accuracy and optimal cutoff values of echocardiographic indices E/E'_{MEAN}, SR_{IVR}, and E/SR_{IVR} for predicting elevated filling pressure (LVEDP ≥ 16 mm Hg). *E/E′MEAN*, Early transmitral flow velocity/mean mitral annular velocity; *SRIVRT*, strain rate during isovolumic relaxation time; *E/SRIVRT*, early transmitral flow velocity/strain rate during isovolumic relaxation time.

months after surgery using diastolic indices from invasive LV pressures as the gold standard reference.

An alternative echocardiographic parameter, SR_{IVR}, was recently proposed as a possible noninvasive index to estimate LV filling pressure.[7] This global index represents the performance of all myocardial segments and thus may better account for the combined effects of regional wall motion abnormalities, and it is also load independent. Good correlations were found for filling pressures in patients with normal ejection fraction and regional dysfunction.[7] This new noninvasive index to estimate LV filling pressures was also correlated with invasively obtained LV pressure.

The current findings indicate that in this particular group of patients with heart failure, E/E'_{MEAN} did not correlate with any of the invasively obtained diastolic indices. Measurements at the septal and lateral annulus were also tested separately, but no correlation with any of the invasive indices was detected; however, SR_{IVR} showed a good correlation with LVEDP (r = –0.76, P < .001) and dP/dt_{MIN} ($r = 0.46$, $P = .03$) (Table 3). Notably, E/A and DT time also correlated significantly with LVEDP, although the correlation was less strong. These indices are clinically useful but are known to be influenced by many factors, such as loading conditions, mitral valve disease, tachycardia, aging, and atrial fibrillation.[1] The lack of correlation between E/E′ and LVEDP in our study is probably due to abnormal LV relaxation and LV stiffness that affect mitral inflow velocity and DT differently than expected, invalidating the E/E′ approach. In our study, mitral E velocity (mean value, 145 ± 30 cm/s) was relatively high compared with other studies, observing mitral E velocities in the range of 81 to 96 cm/s in patients with decompensated heart failure, hypertrophic cardiomyopathy, or heart failure with normal ejection fraction.[17,21,23] Bruch and colleagues,[22] however, reported a higher mitral E velocity (116 ± 0.33 cm/s) comparable to our study in patients with primary mitral regurgitation.[22] Furthermore, we noted a lower mean value for E′ (3.9 ± 1.0 cm/s) compared with most other studies. Reported values range from 5.1 to 12.4 cm/s for the septal side and from 5.3 to 8.5 cm/s for the lateral side.[6,17,19,21-23] Given the relatively high E, which is presumably due to the use of an undersized mitral annuloplasty creating a smaller mitral valve orifice and concomitant higher mitral inflow velocities, and low E′, the mean E/E′ (41 ± 15) in our study exceeded values reported in most studies and suggested filling pressures higher then actually measured. Diwan and colleagues,[6] however, found similar values (38 ± 16) for E/E′ ratio in patients with mitral stenosis. Presumably, the presence of a restrictive mitral ring or inserted patch resulted in abnormal inflow and recoil mechanisms, explaining the current observations. The superior correlation of filling pressure with SR_{IVR} could be due to the fact that speckle-tracking measurements are directly obtained from the myocardium at a time point when the tricuspid and mitral valves are closed, circumventing problems related to annular and valvular abnormalities.[6,22] To further analyze the outcome, we retrospectively stratified the patients in 2 groups according to normal or elevated diastolic pressures.[4] We observed that E/A, A, SR_{IVR}, and E/SR_{IVR} showed significant differences when comparing these subgroups (Table 2; Figure 5). SR_{IVR} demonstrated the highest diagnostic accuracy (AUC of 0.94) and excellent sensitivity and specificity of 93% and 100%, respectively, to predict elevated filling pressure using a cutoff value less than 0.38 s^{-1} (Table 4; Figure 4). Receiver operating characteristic curve analysis indicated that by using a cutoff value of 0.38 s^{-1}, only 1 patient in the group of elevated LVEDP was misdiagnosed. E/SR_{IVR} also showed a significant difference between groups but was associated with a lower sensitivity (80%) and specificity (87.5%; AUC = 0.83). Transmitral inflow velocity E apparently did not provide additional information for predicting elevated filling pressure in this patient group. E/A ratio was significantly higher in the patients with elevated filling pressure, but diagnostic accuracy of this index (AUC = 0.78; sensitivity, 93.3%; specificity = 62.5%) was relatively poor. As also demonstrated by the box-plots, substantial overlap between the subgroups, which was present for this index. Clearly, the other noninvasive indices, particularly E/E’, were unable to adequately predict elevated filling pressure.

Limitations

This study shows initial results regarding the use of the proposed echocardiography parameter (SR_{IVR}) obtained by speckle-tracking analysis to predict elevated filing pressures in patients with heart failure after cardiac surgery. Further research is necessary to validate this parameter in a prospective cohort. Furthermore, the purpose of this study was to evaluate different echocardiographic parameters regarding prediction of diastolic pressure after cardiac surgery in its full

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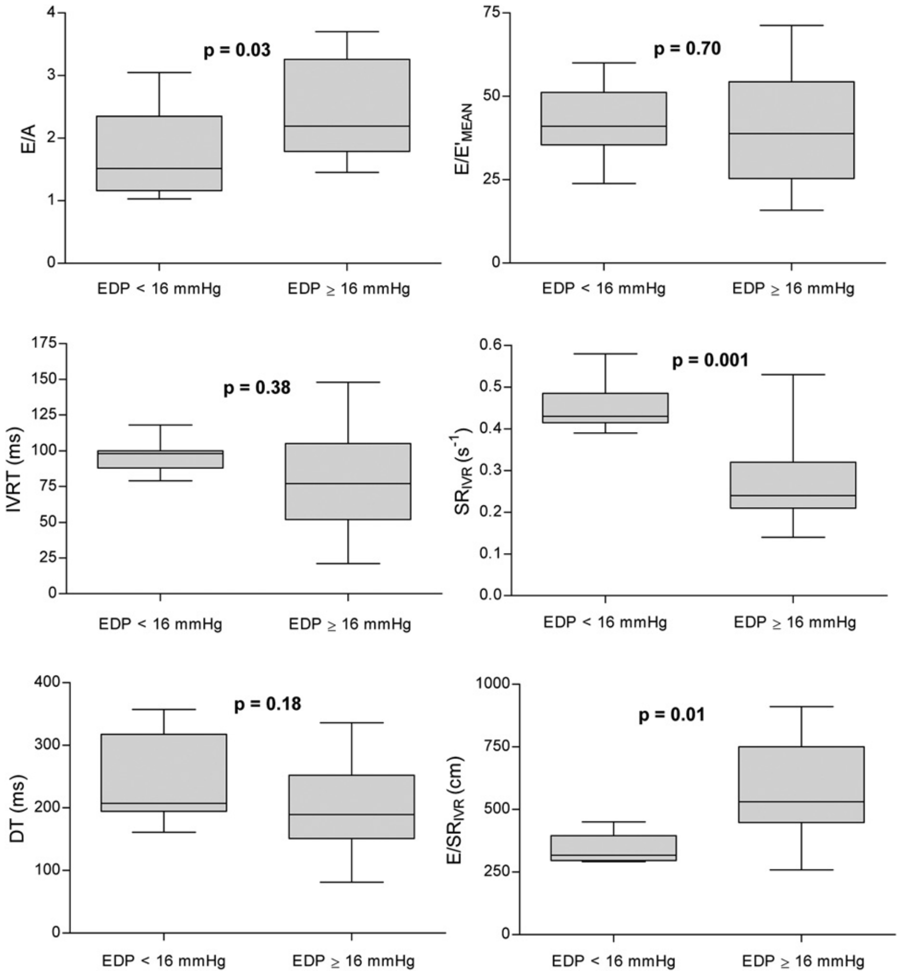

FIGURE 5. Box plots for echo indices (E/A, IVRT, DT, E/E'_{MEAN}, SR_{IVR}, and E/SR_{IVR}) comparing patient groups with normal (LVEDP < 16 mm Hg) and elevated filling pressure (LVEDP ≥ 16 mm Hg). Error bars indicate the full data range; box indicates lower quartile (Q1), median value, and upper quartile (Q3). *IVRT,* Isovolumetric relaxation time; *EDP,* end-diastolic pressure; *DT,* deceleration time; E/SR_{IVR}, early transmitral flow velocity/strain rate during isovolumic relaxation; SR_{IVR}, strain rate during isovolumic relaxation; *E/A,* early transmitral flow velocity/atrial transmitral flow velocity; E/E'_{MEAN}, early transmitral velocity/mean mitral annular velocity.

complexity as it is applied in our patients during clinical practice. Extrapolation to patients treated with SVR or RMA alone has to be done with caution.

CONCLUSIONS

Our data indicate that E/E'_{MEAN} may not be a useful index to estimate filling pressures in patients after extensive cardiac surgery, including SVR and RMA. However, global SR_{IVR} is a promising noninvasive index to assess LV filling pressures in this specific patient group.

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