Early Hemodynamic Improvement after Percutaneous Mitral Valve Repair Evaluated by Noninvasive Pressure-Volume Analysis

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Background: Mitral regurgitation represents a volume load on the left ventricle leading to congestion and symptoms of heart failure. The aim of this study was to characterize early hemodynamic adaptions after percutaneous mitral valve (MV) repair.

Methods: Forty-six consecutive patients with symptomatic high-grade MV insufficiency (mean age, 72 years; 54% men) were prospectively included in the study and examined before and after successful catheter-based clip implantation. Seventy percent of patients had secondary mitral regurgitation. Noninvasive pressure-volume loops were reconstructed from echocardiography with simultaneous blood pressure measurements.

Results: MV repair reduced left ventricular end-diastolic volume index from 87 ± 41 to 80 ± 40 mL/m^2 ($P < .0001$). End-systolic volume index was 55 ± 37 mL/m^2 before versus 54 ± 37 mL/m^2 after repair ($P = .52$). Hence, total stroke volume decreased from 60 ± 23 to 49 ± 16 mL ($P < .0001$), as did total ejection fraction (from 41 ± 14% to 37 ± 13%, $P = .002$) and global longitudinal strain (from −11 ± 4.9% to −9.1 ± 4.4%, $P = .0001$). Forward stroke volume, forward ejection fraction, and forward cardiac output remained constant (43 ± 12 mL vs 42 ± 11 mL, 33 ± 17% vs 35 ± 18%, and 3.2 ± 0.9 L/min vs 3.4 ± 0.8 L/min, respectively). Parameters of left ventricular contractility (end-systolic elastance and peak power index) and measurements of afterload (arterial elastance, end-systolic wall stress, and total peripheral resistance) were similar before and after MV repair. Forward ejection fraction correlated more strongly with end-systolic elastance ($r = 0.61$, $P < .0001$) than did total ejection fraction ($r = 0.35$, $P = .0007$) or global longitudinal strain ($r = −0.38$, $P = .0002$). Total mechanical energy (pressure-volume area) decreased from 10,903 ± 4,410 to 9,124 ± 2,968 mm Hg × mL ($P = .0007$) because of reduced stroke work (5,546 ± 2,241 mm Hg × mL vs 4,414 ± 1,412 mm Hg × mL, $P < .0001$). At 3 months, symptom status had improved (76% of patients in New York Heart Association classes I and II), and 97% of patients had mitral regurgitation grade ≤2+.

Conclusions: Left ventricular contractility and forward cardiac output remained unchanged after percutaneous MV repair despite decreases in total ejection fraction and global longitudinal strain. The left ventricle was unloaded through reduced end-diastolic volume. Thus, MV repair is associated with an improved hemodynamic state in noninvasive pressure-volume analysis. (J Am Soc Echocardiogr 2016;■:■-■.)

Keywords: Mitral regurgitation, Percutaneous mitral valve repair, Noninvasive pressure-volume analysis, Left ventricular contractility

Mitral regurgitation (MR) is the most common valve disease. MR is characterized by volume overload leading to left ventricular (LV) and left atrial dilatation.[1] MR predisposes to atrial fibrillation (AF), pulmonary hypertension, and congestive heart failure and increases mortality.[1,2] Primary MR is a disease of the mitral valve (MV) or the subvalvular apparatus that includes prolapse, flail leaflet, and degeneration.[3] Secondary MR results from LV dilatation and dysfunction (i.e., an imbalance between closing and tethering forces imposed on the valve, leading to MR).[4]

Surgical valve repair is the standard therapy for primary MR. In secondary MR, MV surgery is recommended only for patients who undergo coronary bypass surgery.[5] Many patients with symptomatic MR are treated medically because of comorbidities, LV dysfunction, or older age.[6] A percutaneous approach with a catheter-based clip

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Abbreviations

2D = Two-dimensional

AF = Atrial fibrillation

CO = Cardiac output

DBP = Diastolic blood pressure

Ea = Effective arterial elastance

Ees = End-systolic elastance

EF = Ejection fraction

ESMWS = End-systolic meridional wall stress

GLS = Global longitudinal peak systolic strain

HR = Heart rate

LV = Left ventricular

LVEDV = Left ventricular end-diastolic volume

LVEDVi = Indexed left ventricular end-diastolic volume

LVESVi = Indexed left ventricular end-systolisch volume

LVESV = Left ventricular end-systolic volume

MR = Mitral regurgitation

MV = Mitral valve

NYHA = New York Heart Association

Pes = Left ventricular end-systolic pressure

PPI = Peak power index

PVA = Pressure volume area

SBP = Systolic blood pressure

SR = Sinus rhythm

SV = Stroke volume

SW = Stroke work

TPR = Total peripheral resistance

V_0 = Volume-axis intercept of end-systolic pressure-volume relationship

implantation (MitraClip; Abbot Vascular, Santa Clara, CA) has been developed on the basis of Alfieri's edge-to-edge MV repair.[7] On the basis of promising early and 5-year results,[7,8] the procedure provides a treatment alternative for symptomatic patients with high risk for surgery, particularly those with chronic heart failure and secondary MR.[5,9,10]

Important questions regarding hemodynamic alterations after percutaneous MV repair remain. It is largely unknown how a failing left ventricle adapts to altered loading conditions after MV repair. There have been concerns about a possible impairment of LV performance after MV repair due to the elimination of the low-impedance flow into the left atrium that results in an increase in global LV afterload.[11] The pressure-volume relationship is the gold standard to assess contractility, but invasive hemodynamic measurements are not appropriate for serial examinations. Therefore, we used a noninvasive single-beat approach assessing LV contractility on the basis of comprehensive echocardiography[12,13] to investigate the early hemodynamic changes after successful percutaneous MV repair.

METHODS

Patient Population

Fifty consecutive patients with symptomatic MR underwent percutaneous MV repair at the Saarland University Hospital between January 2013 and May 2015. Four patients were excluded because of procedural failure with persistent MR ≥3+; the remaining 46 patients with successful valve repair were included in the final analysis. All patients gave written informed consent. The local ethics committee of Ärztekammer des Saarlandes approved the study (No. 08/13). Eligibility of the patients for percutaneous MV repair was based on the presence of symptoms, moderate to severe (3+) or severe (4+) MR, morphologic criteria of the MV on transesophageal echocardiography, and high-risk status for surgery according to current European Society of Cardiology guidelines.[5]

Percutaneous MV Repair

MV repair was performed with the MitraClip system and was executed under anesthesia with propofol and remifentanil. Catecholamines and fluids were administrated and dosed as necessary to maintain blood pressure. The procedure was guided by two-dimensional (2D) and three-dimensional transesophageal echocardiography and fluoroscopy.[7] Procedural success was defined as the implantation of at least one clip and reduction of MR ≤2+ at the end of the procedure.

Echocardiography

The same physician performed transthoracic echocardiography on the day before and 1 to 4 days after MV repair, with great care to perform all measurements in a clinically compensated condition at similar fluid status. Standard echocardiography encompassed 2D, Doppler, and Doppler tissue imaging according to current guidelines[14,15] using a Vivid E9 (GE Vingmed Ultrasound AS, Horten, Norway). Quantitative analysis was conducted offline with EchoPAC software (GE Vingmed Ultrasound AS). LV end-diastolic volume (LVEDV), LV end-systolic volume (LVESV), total stroke volume (SV), total ejection fraction (EF), and left atrial volume were calculated according to the 2D biplane method of disks.[15] Forward SV and cardiac output (CO) were determined from pulsed-wave Doppler and the diameter of the LV outflow tract, measured in the zoom mode to minimize miscalculations. Body surface area was estimated using the Dubois formula. Forward EF was calculated from forward SV divided by LVEDV and expressed as a percentage.[16,17] MR severity was graded in a multiparametric approach according to current guidelines, including qualitative, semiquantitative, and quantitative parameters.[18] MV morphology (i.e., leaflet tethering, MV annular diameter, leaflet prolapse or flail, color Doppler regurgitation flow, and the density of the continuous-wave Doppler regurgitant flow signal) served as qualitative parameters. The presence of systolic pulmonary vein flow reversal usually indicates severe MR. The vena contracta cross-sectional area and effective regurgitant orifice area according to the hemielliptic proximal isovelocity surface area method are quantitative parameters with thresholds for severe MR (4+) of effective regurgitant orifice area ≥40 mm^2 for primary and ≥20 mm^2 for secondary MR.[18] Global longitudinal peak systolic strain (GLS) was derived from the 16-segment model of the left ventricle from three apical views.[15,19] All segments were averaged to obtain the global strain value. Tricuspid annular peak systolic excursion was determined from the lateral tricuspid valve annulus.[20] Right ventricular systolic pressure was estimated from tricuspid valve regurgitation peak systolic velocity using the simplified Bernoulli equation.[18] Right atrial pressures were estimated from a subcostal view evaluating the inferior vena cava diameter and respiratory variability according to American Society of Echocardiography guidelines.[21] In AF, quantitative measurements are mean values of five beats,[15] and similar cardiac cycle lengths in the apical views for cardiac chamber quantification were used.

Noninvasive Pressure-Volume Analysis

Arm-cuff blood pressure was measured after 10 min of rest in a left lateral position, simultaneously with LV outflow tract Doppler measurements for the calculation of contractility parameters. LV end-systolic elastance (Ees) is the slope of the end-systolic pressure-volume relationship and represents LV contractility (Figure 1). Traditionally, Ees is derived from invasive catheter-based pressure-volume analysis.