Slope in Preload Recruitable Stroke Work Relationship Predicts Survival after Left Ventriculoplasty and Mitral Repair in Patients with Idiopathic Cardiomyopathy

Yasushige Shingu, MD, PhD, Suguru Kubota, MD, PhD, Satoru Wakasa, MD, PhD,

Tomonori Ooka, MD, PhD, Hiroki Kato, MD, PhD, Tsuyoshi Tachibana, MD, PhD,

and Yoshiro Matsui, MD, PhD

Department of Cardiovascular and Thoracic Surgery,

Hokkaido University Graduate School of Medicine, Sapporo, Japan

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Address for correspondence:

Prof. Yoshiro Matsui
Department of Cardiovascular and Thoracic Surgery
Hokkaido University Graduate School of Medicine
Kita 14, Nishi 7, Kitaku
Sapporo, 060-8648
Japan
Tel: +81-11-716-1161(6041)
Fax: +81-11-706-7612
Email: ymatsui@med.hokudai.ac.jp

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Abstract

Background: Left ventriculoplasty (LVP) and mitral valve plasty (MVP) are sometimes effective for patients with idiopathic dilated cardiomyopathy (DCM) who are not eligible for heart transplantation. Strict patient selection is warrented for these controversial procedures.

Methods and Results: The subjects were 18 patients with idiopathic DCM and mitral regurgitation who had not been indicated for heart transplantation due to either older age or patient refusal, and underwent LVP and MVP. Their mean age was 57±14 years and 50% were dependent on catecholamine infusion. The preload recruitable stroke work (PRSW) relationship and its slope (Mw) were estimated by a single-beat technique using transthoracic echocardiography. There were one 30-day mortality and six (33%) hospital deaths due to heart failure. The one-year survival rate was 50%. Left ventricular end-diastolic dimension (LVDd) decreased from 77±11 to 68±11 mm (p = .001) whereas the ejection fraction (LVEF) did not change. Preoperative Mw was significantly higher in one-year survivors than that in non-survivors (54±17 vs. 31±10, erg・cm^{-3}・10^3, p = .005). Preoperative LVDd was not different between the groups. The cut-off value of 42 erg・cm^{-3}・10^3 for Mw predicted one-year survival with high sensitivity (100%) and specificity (77%).

Conclusions: Mw**,** the slope in the PRSW relationship, may predict survival after LVP and MVP in patients with idiopathic DCM.

Words: 218

Introduction

The surgical strategy for patients with idiopathic dilated cardiomyopathy (DCM) and severe mitral regurgitation (MR) is still controversial[1]. MR has a negative impact on the prognosis of patients with heart failure and a very low ejection fraction[2, 3]. Mitral valve plasty (MVP) for patients with secondary severe MR and a low ejection fraction (< 30%) is recommended in the AHA guideline (class IIb)[4]. However, early recurrence of significant MR and heart failure symptoms within six months have been reported recently in patients with severely dilated left ventricle (LV) after down-sized mitral annuloplasty alone[5]. Thus, procedures in addition to mitral annuloplasty seem to be necessary for the large LV.

To eliminate recurrence of MR and heart failure symptoms in such high-risk patients some groups, including ours, have developed several submitral procedures as left ventriculoplasty (LVP) and reported acceptable midterm results[6-15]. Thus far, however, there exist no guidelines that recommend LVP concomitant with MVP, and Batista-type LVP is even a class III recommendation in the AHA guidelines[16]. We have performed LV plasty for extremely large heart in 55 cases from 2004 to 2013, and one year survival rate was 58%. From our experience, we believe this operation has a role in selected patients. Although strict patient selection is important for these controversial procedures, we still do not have any reliable LV functional parameters for the prediction of responders to LVP and MVP that we can easily use in clinical practice[17].

We reasoned that load-independent contractile functional parameters would correlate to survival after operation. We demonstrate here that preload recruitable stroke work relationship is useful to predict survival after LVP and MVP in end-stage heart failure patients with idiopathic DCM and severe MR.

Methods

Patients' characteristics

Tables 1 and 2 show the patients' preoperative characteristics. The 23 consecutive cases included 18 idiopathic DCM patients with end-stage heart failure who underwent LVP and MVP from 2006 to 2013 (mean age, 57±14 years; 27 to 77 years). Five patients were excluded from the study due to lack of sufficient echocardiographic data. The diagnosis of DCM was based on the absence of significant coronary artery disease or primary valvular heart disease. The pathological findings of the LV muscle specimens obtained during surgery were also consistent with DCM in all cases. They all had NYHA class III or IV. Nine (50%) patients were dependent on catecholamine infusion just before operation. Intraaortic balloon pumping (IABP) and percutaneous cardiopulmonary support (PCPS) were needed just before operation due to hemodynamic instability in two patients and one, respectively. While most patients used beta blockers preoperatively, the use of angiotensin-converting enzyme inhibitors and angiotensin receptor blockers was relatively rare due to low blood pressure and renal dysfunction. None of the patients had been registered for heart transplantation due to their age being over 60 years, which was the limited age in Japan at that time, in 11 cases and the patients' refusal in seven. The university ethics committee approved the research protocol and informed consent was obtained from the subjects.

Surgical procedures

To reshape the severely remodeled LV, we performed overlapping left ventriculoplasty without a patch as previously reported[10]. Briefly, we used a 72ml silicone sizer to remodel the LV to a more ellipsoidal shape and to not reduce the LV cavity too much. The lateral wall was sutured continuously on the deep septal wall using 3-0 polypropylene sutures with specially designed large curved needles. After aortic declamping, the medial wall was then overlapped on the lateral wall using interrupted 4-0 polypropylene sutures. When myocardial fibrosis was evident only in the posterior part of the LV, we employed a Batista-type operation.

We performed MVP as part of our original mitral complex reconstruction[14]. Briefly, papillary muscle approximation is a surgical method to join the entire papillary muscles side-by-side from the bases to the heads by three pledgeted mattress sutures of 3-0 polypropylene. We placed a subvalvular CV-4 ePTFE suture between the site of the chordal attachment of the approximated papillary muscles and the anterior mitral annulus. This suture was passed through the true-sized semi-rigid total annuloplasty ring[14].

Assessment of cardiac function by echocardiography

We used a Sonos 5500 ultrasound system (Philips Medical Systems, Andover, Massachusetts, USA) with a 3S transducer (3-5 MHz), a Vivid Seven system (GE/Vingmed, Milwaukee, Wis, USA) with an M3S (2.5-3.5 MHz) transducer, or an Aplio system (Toshiba Medical Systems, Tokyo, Japan) with a 2.5 MHz transducer. These were operated by experienced examiners who were blinded for the study. The following basic variables were measured from the parasternal long axis view: LV end-diastolic (LVDd) and end-systolic dimensions (LVDs) (mm), left atrial dimension (LAD) (mm), interventricular septal thickness (IVST), and LV posterior wall thickness (LVPWT) (mm). On an apical long-axis image, the pulsed Doppler sample volume was located at the tip of the mitral valve leaflets to obtain the deceleration time (DcT) (ms) of the early transmitral flow velocity. The LV end-diastolic volume (EDV), end-systolic volume (ESV), and LV ejection fraction (LVEF) were measured using the modified Simpson method. The MR grade was determined by the proximal isovelocity surface area (PISA) method or color Doppler images. In four cases, echocardiography was performed under dobutamine infusion (4-5 mg/kg/min). These four cases were not excluded because of very low Mw even with dobutamine. All values were averaged using three consecutive measurements.

Estimation of preload recuitable stroke work relationship

Stroke work in the heart with MR was calculated as we previously reported: *(total stroke volume) x (SBP - LAP) (ml ・mmHg)*, where SBP and LAP indicate systolic blood pressure and left atrial pressure, respectively[18]. Total stroke volume was calculated using the time velocity integral of pulsed Doppler at the LV outflow tract and mitral annulus level as follows: *(forward stroke volume) + (regurgitation volume) (ml)*. LAP was estimated by continuous wave Doppler of the MR jet as follows: *(systolic blood pressure) – (peak pressure gradient of the wave) (mmHg)*[19].

The preload recruitable stroke work (PRSW) relationship and its slope (Mw), which is recognized as a load-insensitive index of contractile function, were estimated by a single-beat technique according to a report by Lee et al[20]. Briefly, “Mw” was calculated as follows: *(total stroke work) / [EDV – k x EDV + (1 – k) x LV wall] (erg ・ cm^{-3} ・10^3)*. EDV was derived from the total stroke volume and LVEF. LV wall was estimated by the echocardiography-derived LV mass. Constant *k* was estimated by an equation: $k = 0.0004 \times LV\ mass + 0.6408$. This single-beat technique for Mw has been reported to be well correlated to that by the invasive catheter method for different LV sizes, LV mass, and the presence of regional wall motion abnormalities.

Validation of total stroke work by echocardiography alone using MR model in rat

To validate the key non-invasive parameter of total stroke work, we performed a pilot experiment using two male Sprague Dawley rats (body weight, 300g) obtained from Sankyo Labo Survice Corporation (Tokyo, Japan). The use of animals was consistent with the Guide for the Care and Use of Laboratory Animals published by the US National Institutes of Health (NIH publication No. 85-23, revised 1996) and the experimental protocols were approved by the local Animal Welfare Committee of the Hokkaido University, Japan. MR was created by damaging the mitral valve using 24G needles as previously reported[21]. Severe MR was confirmed by color Doppler. Four weeks after the procedure, animals were anesthetized with intramusclular ketamine and xylazine injection (45 and 4.5 mg/kg, respectively). The rats were examined in supine position by a Sonos 5500 ultrasound system (Philips Medical Systems, Andover, Massachusetts) with a 12-MHz phased array transducer and a 1.4F Millar catheter inserted through the right carotid artery and advanced into the LV. Signals of LV pressure and volume assessed by aqoustic quantification (AQ) mode in standard apical four-chamber view were simultaneously displayed in real-time mode in the monitor of the computer using a multichannel 16-bit analog-to-digital converter (PowerLab) and a data acquisition software (LabChart). External total stroke work was automatically measured from the area of pressure-volume loops (TSW-loop) on the software at baseline and after bolus saline infusion of 2, 4, 6, 8, and 10 ml. The values from 10 consecutive cycles were averaged at each volume loading. At each loading condition, total stroke work by echocardiography alone (TSW-echo) was separately measured by the above mentioned formula: *(total stroke volume) x (SBP - LAP) (ml •mmHg)* based on an assumption that pressure-volume loop is a square. These two different methods, TSW-loop and TSW-echo, were compared at each loading condition.

Statistical analysis

All the data are given as mean ± standard deviation. Statistical analysis was performed with SPSS version 17.0 software (SPSS Inc. Chicago, Ill). Categorical data were compared by Fisher's exact test. The Mann-Whitney U test was used to compare the continuous variables between the groups and the Wilcoxon test to compare the preoperative and postoperative values. The receiver operating characteristic (ROC) curve was used to analyze the sensitivity and specificity of the parameters for detecting one-year survival. We selected the cut-off values that maximize sensitivity plus specificity. The area under the curve (AUC) was used to compare predictive parameters. The survival rate was analyzed by the Kaplan-Meier method and log-rank test. In the animal study, the Bland-Altman test was used to assess the limits of agreement and confidence intervals between the two methods, TSW-loop and TSW-echo. A p value < .05 was considered statistically significant.

Results

Pilot experimental data

Mean total stroke work of different volume loading conditions was 8.6 ± 3.2 and 9.8 ± 4.6 ml・mmHg by TSW-echo and TSW-loop, respectively. Linear regression analysis demonstrated significant correlation between the two methods: y = 1.28 x – 1.25, r = 0.898, $p < 0.001$. Figure 1A shows representative consecutive 10 cycles of pressure-volume loop. Figure 1B shows the Bland-Altman spots which also indicated good correlation between the two methods, with only one of the 14 measurements being over 1.96 SD. This indicates that TSW-echo in which the pressure-volume loop is assumed to be a square (Figure 1A, dashed line) would be approximated to TSW-loop. We used TSW-echo for the calculation of Mw formula, *TSW / [EDV – k x EDV + (1 – k) x LV wall]*, proposed by Lee et al. in which constant *k* was derived from human clinical data[20].

Operative data

All patients underwent mitral complex reconstruction including mitral annuloplasty and papillary muscle approximation as a part of LVP. There was no conversion to mitral valve replacement. Thirteen (72%) patients underwent LVP by overlapping and two patients (11%) by a Batista-type procedure. Tricuspid valve ring annuloplasy was performed in all cases and the MAZE procedure was conducted in five (28%). Cardiopulmonary bypass and aortic cross clamp times were 235 ± 61 and 114 ± 24 minutes, respectively.

Comparison between one-year-survivor and non-survivor groups

There was one (6%) operative mortality within 30 days. There were six (33%) hospital deaths due to heart failure. The overall survival rates were 61% after six months and 50% one year after operation (one-year survivors, n=9; non-survivors, n=9).

Table 2 shows the differences in patients' preoperative characteristics between the one-year-survivor and non-survivor groups. Renal dysfunction (serum creatinine >2.0 mg/dl) was more common in non-survivors than in one-year survivors. Age and preoperative medication were comparable between the groups.

Table 3 shows the differences in preoperative cardiac functional parameters between one-year survivors and non-survivors. In one-year survivors, the heart rate was significantly lower and DcT was significantly longer, which indicates lower LV filling pressure than in non-survivors. The preoperative LVEF, regurgitation, and forward stroke volumes were significantly larger in one-year survivors than in non-survivors. LVDd and LV volumes were not significantly different between the groups.

Table 4 shows changes in cardiac functional parameters in one-year-survivor and non-survivor groups. The postoperative echocardiographic parameters were not applicable due to poor recording in three cases. The postoperative MR grade was mild or less in all cases. There was no reoperation due to recurrent MR during the follow-up (median, 11 months). In total, LVDd significantly decreased from 77 ± 11 to 68 ± 11 mm (p = .001), although LVEF did not significantly change even with the elimination of significant MR (from 25 ± 8% to 23 ± 5%, p = .51), possibly because of concomitant

LV volume reduction surgery. LVEF and forward stroke volume were significantly smaller in non-survivor than in one-year-survivor group both before and after surgery. LVESV did not significantly decrease after surgery and reduction rates were relatively low in the non-survivor group even though there was no statistical significance.

Figure 2 shows preoperative Mw in PRSW, a load-insensitive index of contractile function in one-year-survivor and non-survivor groups. Mw was significantly higher in one-year survivors than in non-survivors (54±17 vs. 31±10, erg・cm^{-3}・10^3, p = .005).

In the ROC curve analysis for prediction of one-year survival after surgery, AUC were 0.982 (p = .002), 0.929 (p = .005), 0.884 (p = .013), and 0.804 (p = .049) for preoperative Mw, LVEF, MR volume and deceleration time, respectively. The preoperative Mw was the best parameter to predict one-year survival after surgery. Mw-cut-off value of 42 erg・cm^{-3}・10^3 predicted one-year survival with sensitivity and specificity of 100% and 77%, respectively.

Figure 3 shows survival curves determined by Kaplan-Meier analysis in those with "higher Mw" (≥ 42 erg・cm^{-3}・10^3, n=8) and "lower Mw" (< 42 erg・cm^{-3}・10^3, n=10). The patients with higher Mw tended to have a better survival rate than those with lower Mw (log-rank p = .005). All but one patient with higher Mw survived with NYHA class of less than II (maximum survival, five years after surgery). On the other hand, in the group with lower Mw, more than half of the patients died of heart failure within six months after operation. There was no difference in preoperative characteristics except for LVEF in the higher and lower Mw group (Table 5).

Discussion

We demonstrated that preoperative Mw, a load-insensitive index of contractile function, was a good predictor of one-year survival after LVP and MVP in patients with idiopathic DCM and MR, whereas LV size was not. This preliminary study will contribute to the decision-making for the indication and timing of LVP and MVP for patients with end-stage heart failure who are not eligible for heart transplantation.

Some groups, including ours, have been trying to develop submitral procedures and LVP in order to eliminate recurrence of MR and heart failure symptoms in high-risk patients[6-15]. A group from the Cleveland clinic reported midterm results of mitral valve surgery and LV volume reduction surgery (Batista operation) for patients with idiopathic DCM and end-stage heart failure[6]. The early mortality was 4% and one-year survival was 82%. They suggested that older age (> 40 years) was the only predictive parameter for mortality, and that other functional parameters, including LV size and LVEF, did not correlate to survival after surgery. Suma et al. recently reported midterm results of mitral valve surgery in combination with selected LVP (Batista or septal anterior ventricular exclusion) for 95 patients with idiopathic DCM[22]. The three-year survival rates were 37% and 74% in patients with and without inotropic support before surgery, respectively. They suggested that preoperative inotropic dependency was the only contributing factor for mortality. Nonetheless, they did not find any cardiac functional parameters that predicted survival after operation. Thus far, therefore, there is no reliable functional parameter that we can easily assess in daily clinical practice to predict survival after LVP and MVP. In addition, there exists no demonstrable surgical strategy for patients with end-stage heart failure and significant MR.

The PRSW relationship and its slope, Mw, were estimated by a single-beat technique according to a report by Lee et al[20]. This single-beat technique for Mw has been reported to be correlated well with that by the invasive catheter method for different LV sizes, LV mass, and the presence of regional wall motion abnormalities. A flat slope, low Mw, indicates that increased preload produces relatively little increase in stroke work because of reduced contractility. The relationship takes both preload and afterload into account and is applicable in a wide variety of cardiac diseases. In the current study, the preoperative Mw was the best parameter to predict one-year survival after surgery. Although LVEF was also a good parameter, we consider that PRSW would be more suitable for predicting prognosis of patients than LVEF because PRSW considers LV developed pressure as well as stroke volume, which would reflect intrinsic LV capacity to pump. Though we need more evidence of efficacy in these preliminary procedures, we might consider LVP and MVP for idiopathic DCM patients with refractory heart failure before assist device implantation or heart transplantation when their Mw is greater than 42 erg・cm^{-3}・10^3.

In this calculation of Mw, we need to determine total stroke work in the heart with MR. We recently reported a noninvasive method for estimation of total stroke work using transthoracic echocardiography, which is based on an assumption that the LV pressure-volume loop is approximated to a square[18]. Total stroke work was calculated as follows: *total stroke work = (forward stroke volume + MR volume) x (LVSP-LVDP),* which was further approximated to *"(forward stroke volume + MR volume) x (SBP-LAP)"*, where LVSP and LVDP indicate LV systolic and diastolic pressure, respectively. This formula is different from that reported by Chow et al: (*forward stroke volume x SBP) + (MR volume x LAP)*[23]. It is conceivable that regurgitant stroke work in MR should be calculated using LV pressure, but not LAP as LV stroke work is always derived from "LV" pressure. In aortic valve stenosis, for example, we estimate LV stroke work from stroke volume multiplied by higher "LV" pressure, but not lower "aortic" pressure. Furthermore, we do not need the values of aortic and MR impedances for estimating LV stroke work. Aortic and MR impedances directly influence the forward and backward stroke volumes, respectively. The effect of different impedance is included in LV stroke work which is derived from LV stroke volumes.

Limitations

The major limitation of this study is small number of subjects. Second, the results in the current study are applicable only for MVP concomitant with LVP. Further study is necessary to examine the usefulness of Mw in PRSW for isolated MVP. Third, this study does not answer the question of whether volume reduction surgery in addition to MVP has any beneficial effect on LV function and improves survival and functional status. A randomized trial with more subjects is necessary to determine this.

Conclusions

Mw, the slope in the preload recruitable stroke work relationship, may predict survival after LVP and MVP in patients with idiopathic DCM and refractory end-stage heart failure, although further study is necessary to validate its use.

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Legends to figures

Figure 1. (A) Representative consecutive 10 cycles of pressure-volume loop (TSW-loop) and an assumed square for TSW-echo (dashed line). (B) Bland-Altman spots to assess the limits of agreement and confidence intervals between the two methods, TSW-loop and TSW-echo. MR, mitral regurgitation; TSW, total stroke work.

Figure 2. Preoperative Mw, the slope in the preload recruitable stroke work relationship, which is a load-insensitive index of contractile function, in one-year survivors and non-survivors who underwent left ventriculoplasty and mitral valve plasty.

Figure 3. Survival curves by Kaplan-Meier analysis in those with higher Mw ($\geq$ 42 erg・cm^{-3}・10^{3}) and lower Mw (< 42 erg・cm^{-3}・10^{3}). LVP, left ventriculoplasty; MVP, mitral valve plasty; Mw, the slope in preload recruitable stroke work relationship.

Table 1. Patients' clinical and echocardiographic characteristics of all 18 idiopathic DCM cases

age	gender	NYHA class	CA dependent	RF (Cr>2.0)	AF	Echocardiographic data LVDd (mm)	LVDs (mm)	LVEF (%)	DcT (ms)	MR grade	Mw ($erg \cdot cm^{-3} \cdot 10^3$)
one-year survivors											
55	male	3	yes	no	yes	88	81	34	135	4	56
67	male	4	yes	no	yes	73	68	23	136	4	28
64	male	3	no	no	no	80	70	24	144	4	46
60	female	3	no	no	yes	82	67	33	212	4	59
37	male	3	no	no	no	69	54	31	231	4	43
52	male	3	no	no	yes	83	79	21	125	4	41
63	male	4	yes	no	no	72	66	28	350	4	67
36	male	3	yes	no	no	89	76	40	244	4	88
27	female	3	no	no	no	57	52	31	108	4	59
non-survivors											
36	male	4	yes	yes	no	94	87	10	100	3	21
69	male	3	no	yes	no	72	69	21	130	4	41
61	male	4	yes	no	no	88	85	17	82	4	17
59	male	4	yes	yes	yes	85	74	32	NA	4	44
55	male	4	yes	no	no	80	74	24	115	4	33
67	male	3	yes	no	yes	69	59	23	150	4	33
71	male	4	yes	yes	no	62	58	14	120	4	18
77	female	3	no	yes	no	74	69	21	158	4	31
64	male	3	no	no	yes	73	70	27	96	3	37

DcT, deceleration time; NYHA, New York Heart Association; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; Mw, the slope in the preload recruitable stroke work relationship; NA, not applicable.

Table 2. Preoperative characteristics in DCM patients

Variables	Total (n=18)	One-year survivors (n=9)	Non-survivors (n=9)	P value
Age	57±14	51±14	62±12	.08
Male gender	15 (83%)	7	8	1.00
Atrial fibrillation	7 (39%)	4	3	1.00
Diabetes mellitus	5 (28%)	2	3	.62
Renal dysfunction (serum creatinine >2.0 mg/dl)	5 (28%)	0	5	.026
NYHA class III/IV	10/8	6/3	4/5	.64
CRT-D implantation	7 (39%)	2	5	.15
Cathecholamine dependent	9 (50%)	3	6	.35
Intraaortic balloon pumping	2 (11%)	0	2	.47
Percutenous cardiopulmonary support	1 (6%)	0	1	1.00
Medications				
amiodarone	11 (61%)	6	5	1.00
beta blockers	16 (89%)	7	9	.47
angiotensin-converting enzime inhibitors	5 (28%)	2	3	1.00
angiotensin receptor blockers	7 (39%)	5	2	.34

Values ± standard deviation. CRT-D, cardiac resynchronization therapy-defibrillators; NYHA, New York Heart Association.

Table 3. Preoperative cardiac functional parameters in DCM patients

Variables	Total (n=18)	One-year survivors (n=9)	Non-survivors (n=9)	P value
Heart rate, bpm	73±14	67±11	79±15	.042
Systolic blood pressure, mmHg	88±10	88±11	89±10	.76
Diastolic blood pressure, mmHg	53±10	50±9	56±10	.12
BNP, pg/ml	1346±1041	1066±716	1628±1271	.35
Cardiac catheter data				
Cardiac index, L/min/m^2	2.0±0.4	2.1±0.5	1.9±0.3	.32
sPA, mmHg	48±17	40±18	55±14	.07
PCWP, mmHg	23±10	22±12	26±8	.86
Echocardiographic data				
LVDd, mm	77±10	77±10	77±10	1.00
LVDs, mm	70±10	68±10	72±10	.43
IVST, mm	9.3±1.0	9.7±0.9	9.0±1.1	.14
LVPWT, mm	8.4±1.2	8.4±1.2	8.3±1.2	.85
LVEF, %	25±8	29±6	21±7	.019
LAD, mm	57±12	58±12	57±12	.70
DcT, ms	155±68	187±79	119±26	.034
MR grade	3.9±0.3	4.0±0.0	3.8±0.4	.15
Regurgitation volume, ml	49±21	61±20	34±11	.011
Forward stroke volume, ml	43±20	53±23	33±12	.040
Estimated LAP, mmHg	24±14	18±7	30±17	.11
LVEDV, ml	291±105	285±82	297±129	.97
LVESV, ml	218±91	197±57	238±116	.83

Values ± standard deviation. BNP, brain natriuretic peptide; DcT, deceleration time; IVST, interventricular septal thickness; LAD, left atrial dimension; LAP, left atrial pressure; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end-systolic volume; LVPWT, left ventricular posterior wall thickness; MR, mitral regurgitation; PCWP, pulmonary capillary wedge pressure; sPA, systolic pulmonary artery pressure.

Table 4. Changes in cardiac functional parameters in DCM patients

Variables	Total (n=15)		One-year survivors (n=9)		Non-survivors (n=6)	
	PreOP	PostOP	PreOP	PostOP	PreOP	PostOP
Heart rate, bpm	74±15	84±13*	67±11	80±13*	83±14$^{\#}$	90±12
SBP, mmHg	89±11	87±10	88±11	89±6	90±12	83±14
DBP, mmHg	53±10	55±7	50±9	57±4	58±11	53±10
Echocardiography						
LVDd, mm	77±11	68±11**	77±10	67±9**	77±12	69±10*
LVDs, mm	69±11	61±9**	68±10	59±7**	71±12	64±10*
LVEF, %	25±8	23±5	29±6	26±4	18±5$^{\#\#}$	19±5$^{\#\#}$
MR grade	3.9±0.3	0.4±0.5**	4.0±0.0	0.2±0.4**	3.8±0.5	0.5±0.5*
Forward stroke volume, ml	43±21	47±17	53±23	57±15	30±8$^{\#}$	35±12$^{\#}$
SPECT						
LVEDV, ml	351±118	243±81**	361±80	250±71*	337±170	231±102*
LVESV, ml	271±118	188±74**	265±62	182±49*	292±183	198±115
reduction rate (LVEDV), %	-	29±13	-	34±14	-	23±8
reduction rate (LVESV), %	-	28±16	-	33±17	-	20±13

Values ± standard deviation. DBP, diastolic blood pressure; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, left ventricular end-systolic volume; MR, mitral regurgitation; SBP, systolic blood pressure. *P< .05 and **P< .01 vs. preOP values; $^{\#}$P< .05 and $^{\#\#}$P< .01 vs. one-year survivors.

Table 5. Preoperative characteristics of patients with higher and lower Mw

Variables	higher Mw ($\geq$ 42) (n=8)	lower Mw (< 42) (n=10)	P value
Age	50±14	62±12	.06
Male gender	6	9	.56
Atrial fibrillation	3	4	1.00
Diabetes mellitus	2	3	1.00
Renal dysfunction (serum creatinine >2.0 mg/dl)	1	4	.31
NYHA class III/IV	5/3	5/5	.66
CRT-D implantation	1	6	.05
Cathecholamine dependent	3	6	.64
Intraaortic balloon pumping	1	1	1.00
Percutenous cardiopulmonary support	1	0	.44
Medications			
amiodarone	6	5	.37
beta blockers	6	10	.18
angiotensin-converting enzime inhibitors	1	4	.31
angiotensin receptor blockers	4	3	.63
Echocardiographic data			
LVDd, mm	78±11	77±9	.83
LVDs, mm	68±10	72±10	.46
LVEF, %	32±5	20±5	< .001

Values ± standard deviation. CRT-D, cardiac resynchronization therapy-defibrillators; LVDd, left ventricular end-diastolic dimension; LVDs, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction; NYHA, New York Heart Association.

Figure 1

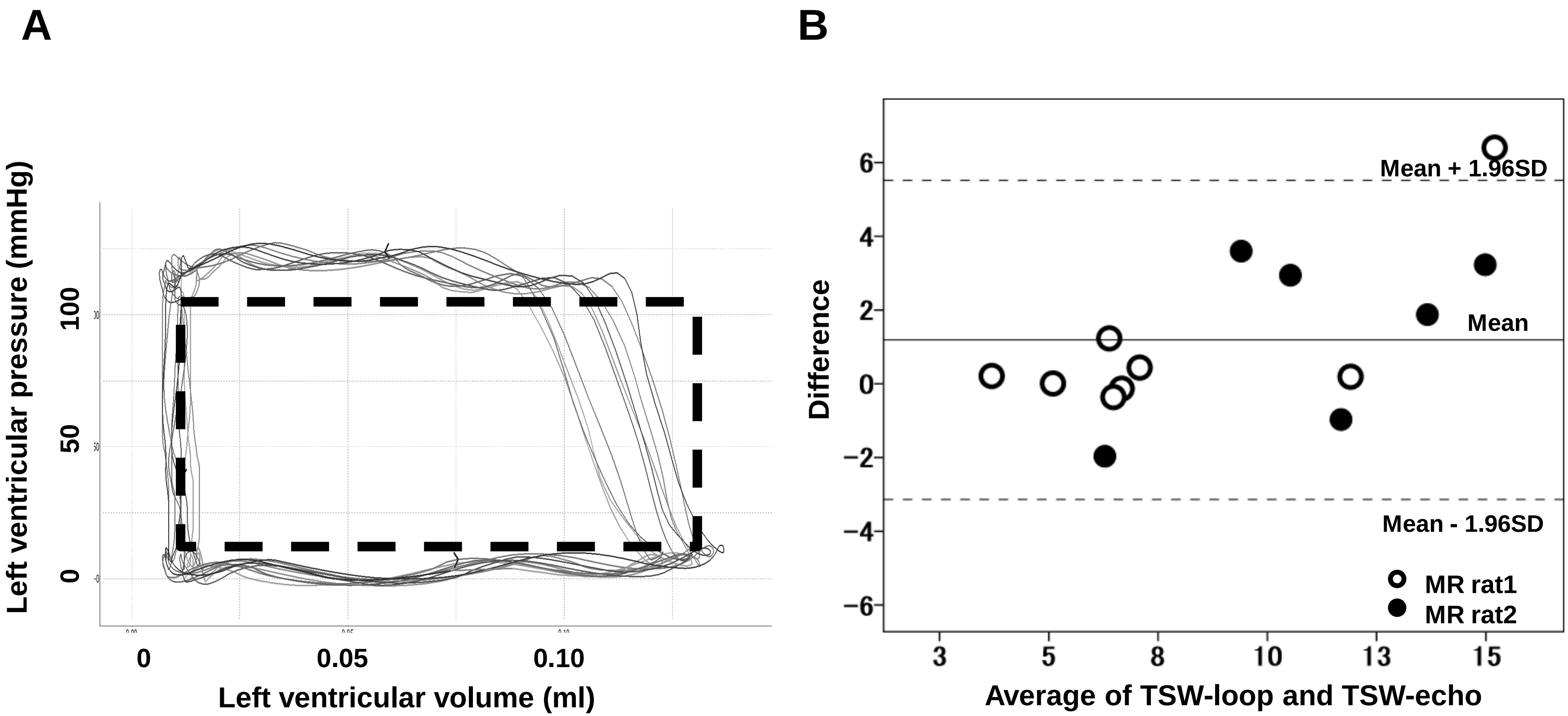
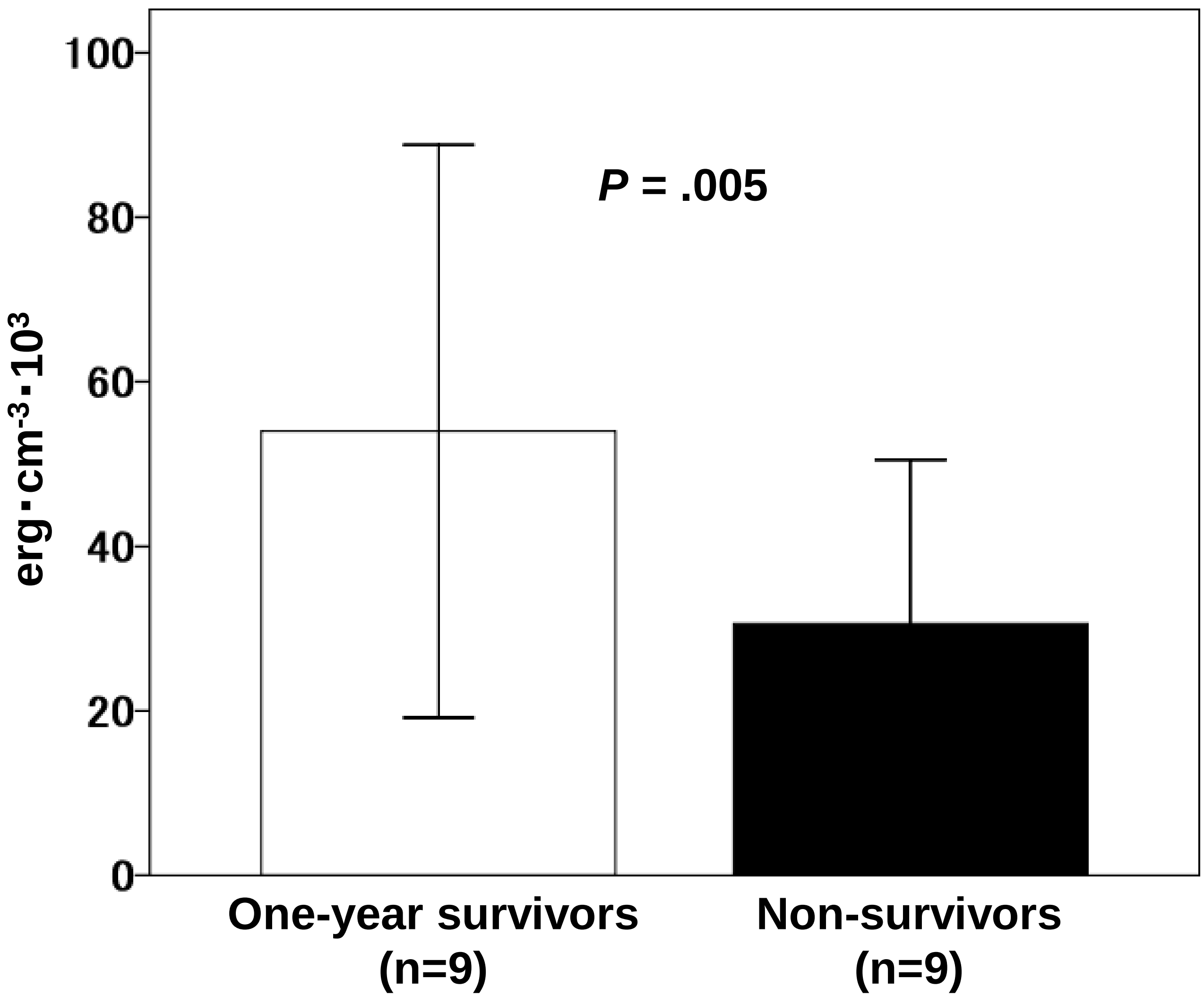
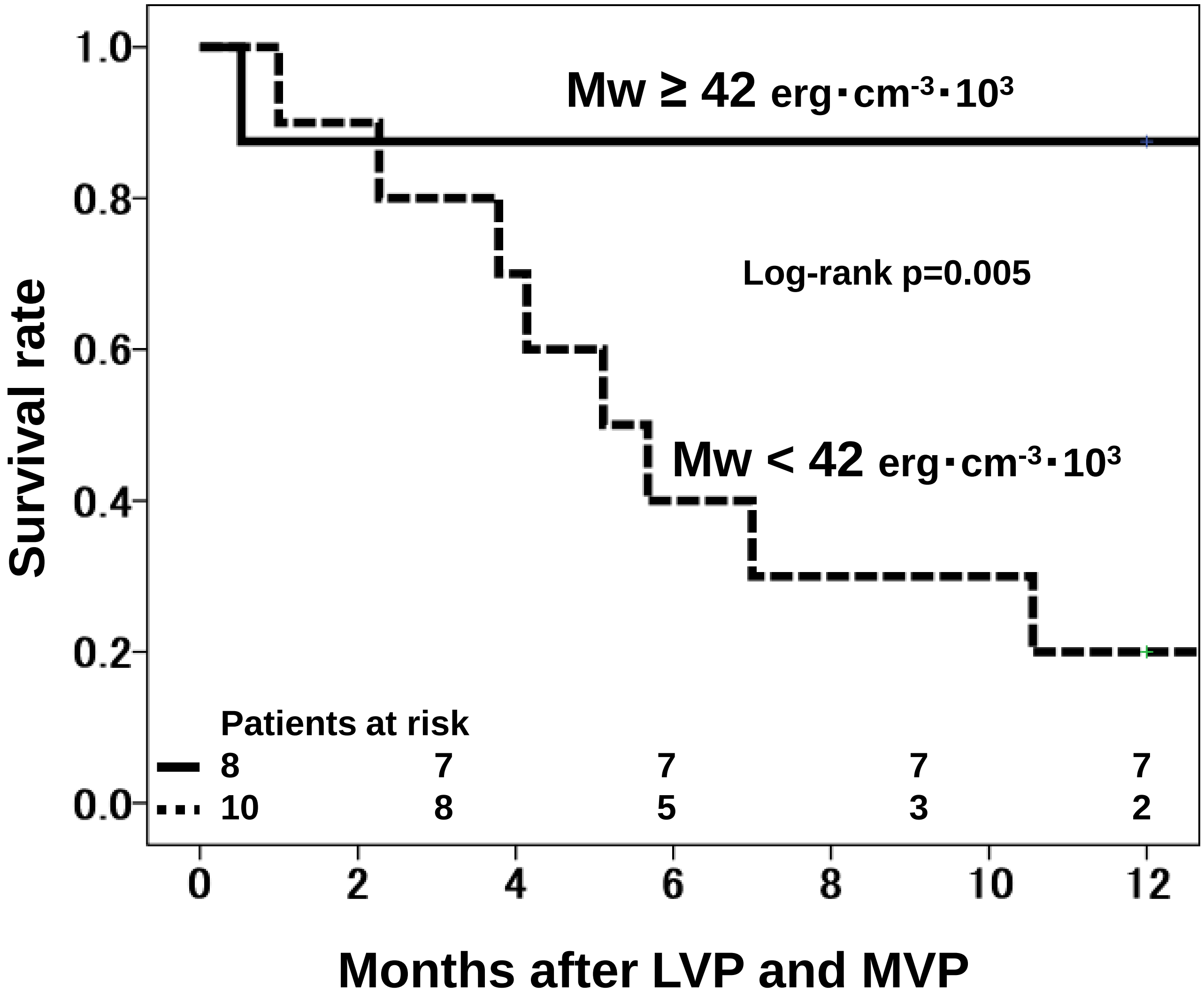

A
B
Left ventricular pressure (mmHg)
0
50
100
0
0.05
0.10
Left ventricular volume (ml)
Difference
6
4
2
0
−2
−4
−6
Mean + 1.96SD
Mean
Mean - 1.96SD
MR rat1
MR rat2
3
5
8
10
13
15
Average of TSW-loop and TSW-echo

Figure 2



100
80
60
40
20
0
erg·cm⁻³·10³
P = .005
One-year survivors
(n=9)
Non-survivors
(n=9)

Figure 3



Mw ≥ 42 erg·cm-3·103
Log-rank p=0.005
Mw < 42 erg·cm-3·103
Survival rate
1.0
0.8
0.6
0.4
0.2
0.0
Patients at risk
8 7 7 7 7
10 8 5 3 2
0
2
4
6
8
10
12
Months after LVP and MVP