Original Article

# Correlation of Right Ventricular dP/dt with Functional Capacity and RV Function in Patients with Mitral Stenosis

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**Background**: Evaluation of right ventricular (RV) contractility and systolic function in patients with right sided heart disease is an essential component of clinical management. The aim of this study was to assess RV systolic function by qualitative and quantitative methods and compare it to rate of ventricular pressure change during the isovolumic contraction period (dP/dt) as RV contractility index in patients with rheumatic mitral stenosis.
**Patients and Methods:** In 56 consecutive patients with moderate to severe mitral stenosis, RV systolic function, RV dP/dt and dP/dt/Pmax, were calculated and compared.
**Results:** There was significant correlation between RV dP/dt and RV function ($P<0.001$) and between RV dP/dt and New York Heart Association (NYHA) functional capacity ($P<.001$). The mean of dP/dt was decreased with increasing severity of RV dysfunction (mean dP/dt was 648±159 for normal RV function, 592± 126 for mild RV dysfunction, 319±146 for moderate RV dysfunction and 166±150 for severe RV dysfunction) Severity of tricuspid regurgitation and pulmonary hypertension had no significant effect on RV dP/dt and RV function.
RV dP/dt/Pmax had also significant relationship with RV function and functional capacity ($P <0.001$).
**Conclusion:** Measurements of dP/dt and dP/dt/Pmax, are practical methods for estimating RV contractility and results have a good correlation with RV systolic function and functional capacity.

**Keywords:** Right ventricles, contractility, mitral stenosis

## Introduction

Echocardiographic assessment of right ventricular (RV) systolic function is challenging. Although originally RV was not considered much more than a conduit and reservoir, its importance in both acquired as well as congenital heart disease has become increasingly clear. RV function has an important role in determining cardiac output and functional capacity,[1-8] and estimation of right ventricular function is helpful to predict prognosis in various clinical situations such as primary pulmonary hypertension and dilated cardiomyopathy.[9-13] A qualitative assessment of the right ventricle is a routine part of echocardiography,[1-3] but visual assessment of RV function is suboptimal, and the complex shape of the right ventricle greatly complicates volume quantification and quantitative assessments such as ejection fraction and other indices that are used for the left ventricle. There are few clinically applicable quantitative methods to assess RV function and most of them depend on loading conditions.[2] The rate of ventricular pressure change during the isovolumic

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contraction period, dP/dt, is a well- established index of myocardial contractility, and is among the most widely used measurements of left ventricular (LV) contractility. Little data is available for RV dP/dt, and it had not been used routinely in clinical practice. Some authors suggested that RV dP/dt is a more accurate measurement of RV contractility, but no study has compared it to other RV systolic function indices such as tricuspid annular plane systolic excursion (TAPSE) or RV tissue Doppler imaging (TDI) S velocity.[15-16]

The aim of this study was to evaluate the correlation of RV dP/dt (as a contractility index) and RV systolic function (by qualitative and quantitative measurements) in patients with moderate to severe mitral stenosis (MS).

## Patieents and Methods

### Population

We enrolled 56 consecutive patients with moderate to severe MS (by definition MV area<1.5cm2) who had a detectable tricuspid regurgitation (TR) jet and were referred to our center for percutaneous mitral commissurotomy. Patients with concomitant coronary artery disease, congenital heart disease, and severe rheumatic involvement of the aortic or tricuspid valves were excluded.

### Echocardiographic evaluation

All patient underwent a clinical assessment and comprehensive two dimensional and Doppler echocardiography study with a commercially available ultrasound system (Vivid 3, GE ultrasound), equipped with a 2.5-MHz transducer. LV size and function was graded based on the American Society of Echocardiography guidelines.[17] TR severity was visually assessed from multiple views. Jet area (percentage of right atrium area) and PISA radius with aliasing velocity of 28 cm/s were obtained for determining TR severity, which was graded as mild, moderate and severe according to the American Society of Echocardiography guidelines.[18]

TR velocity was recorded by Continuous wave (CW) Doppler echocardiography, with the aid of color Doppler echocardiography, to obtain the highest jet velocity of adequate quality and was recorded on a strip chart recorder at a paper speed of 100 mm/s. RV dP/dt was calculated from the interval between 1 m/s and 2 m/s velocity spectrum on the TR ( Fig. 1), therefore RV dP/dt =12000/ time (in millisecond) was obtained by averaging 3 cycles in sinus rhythm and 5 cycles in atrial fibrilation. RV systolic function was graded as mild, moderate and severe by visual assessment and two other quantitative methods: tricuspid annular plane systolic excursion (TAPSE) and tissue Doppler imaging (TDI) tricuspid annulus S velocity. Given a reference value of 20 mm for TAPSE and 12 cm/sec for TDI, the RV was considered mildly impaired when TAPSE was between 15-20 mm and severely impaired when TAPSE was less than 10 mm.[19-20] The RV pressure was calculated from the sum of the TR pressure gradient and estimated RA pressure based on inferior vena caval (IVC) diameter.

Patient symptoms were classified according to the New York Heart Association (NYHA) functional classes(FC) I-IV.

To decrease variability of the echocardiographic measurements, all measurements were prospectively performed by a cardiologist with

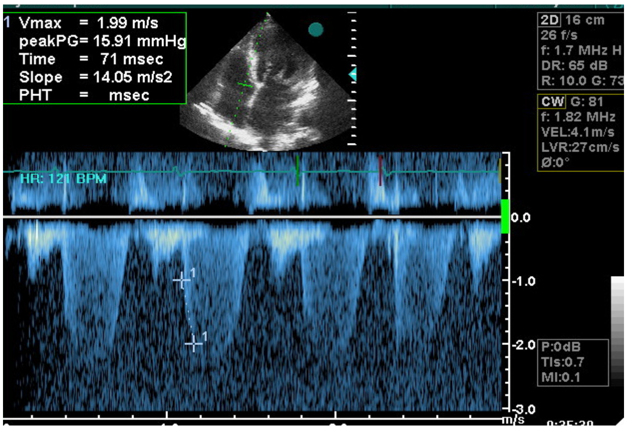



**Figure 1**: RV dP/dt showing calculation of the interval between 1 m/s and 2 m/s velocity on the TR spectrum.

a level III training in echocardiography, and RV systolic function was assessed by another echocardiologist who was blinded to other measurements.

### Statistical Analysis

Interval data was expressed as means (SD) and categorical data was expressed as count (relative frequency). Statistical analysis was performed by using one-way analysis of variance (ANOVA) and its non-parametric equivalent, Kruskal-Wallis tests. Independent sample t and Chi-square tests were also used. P value less than 0.05 was considered significant.

Multiple analysis was performed, using ordinal logistic regression models between RV function and dP/dt and also RV function and dP/dt/ $P_{max}$ , adjusted for TR severity, Pulmonary artery hypertension (PAH), FC and LV ejection fraction (EF).SPSS 15 for Windows (SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis.

### Reliability

Intra-observer variability was measured by random selection of 20 echocardiographic records and reassessment dP/dt index. No significant difference was observed between two measurements (paired t test, p = 0.06). Pearson's correlation coefficient *r* was 0.79, which suggest a good correlation among data. Bland-Altman plot showed that only one out of 20 (0.05) measurement was beyond the mean ±1.96 SD range. This meant that there was a good agreement between two set of observations and therefore, acceptable intra-observer reliability.

## Results

### Baseline characteristics

56 patients (28 women), with a mean (SD) age of 54 (13.5) years (range 22 to 88 years) participated in the study. 48 cases (0.85) had sinus rhythm, 7 (0.13) had atrial fibrillation and 1 patient (0.02) had atrial flutter.

Estimated mean (SD) for left ventricular ejection fraction (LVEF) was 43.6 (9) percent. Mean heart rate (SD) was 76 (14.7) beat/min. LV size was in normal range mean (SD) of diastolic dimension was 5.1 (1) cm. We observed 2 patients (0.04) in NYHA functional class (FC) I, 28 (0.50) in FC II, 24 (0.42) in FC III and 2 (0.04) in FC IV.

Right ventricle (RV) function was normal in 10 (0.18), mild dysfunction in 12 (0.21), moderate dysfunction in 24 (0.43) and severe dysfunction in 10 (0.18) patients. Mean (SD) RV dP/dt was 408 (220) mmHg/s (range 94 to 1000 mmHg/s); also, RV dP/dt/$P_{max}$ was estimated with a mean (SD) of 11.7(7.8) /s (range 1.81 to 31.96 /s)

Severity of tricuspid valve regurgitation (TR) was mild in 32(0.57), moderate in 14(0.25) and severe in 10 (0.18) patients. Mean (SD) of pulmonary artery pressure (PAP) was 47.75 (21.04) mmHg. Twenty-five (0.45) patients had mild, 22 (0.39) moderate and 9 (0.16) severe pulmonary arterial hypertension (PAH).

**Relationships between RV function, dp/dt and dp/dt/$p_{max}$**

A statistically significant negative association was found between the state of RV function (as ordinal data) and dP/dt (P<0.001). Bonferroni post-hoc test revealed a statistically significant difference in mean of dP/dt in any subgroup of RV function, except the mean in normal RV function and mild RV dysfunction subgroups (Fig. 2-a). The mean of dP/dt decreased with increasing RV dysfunction.

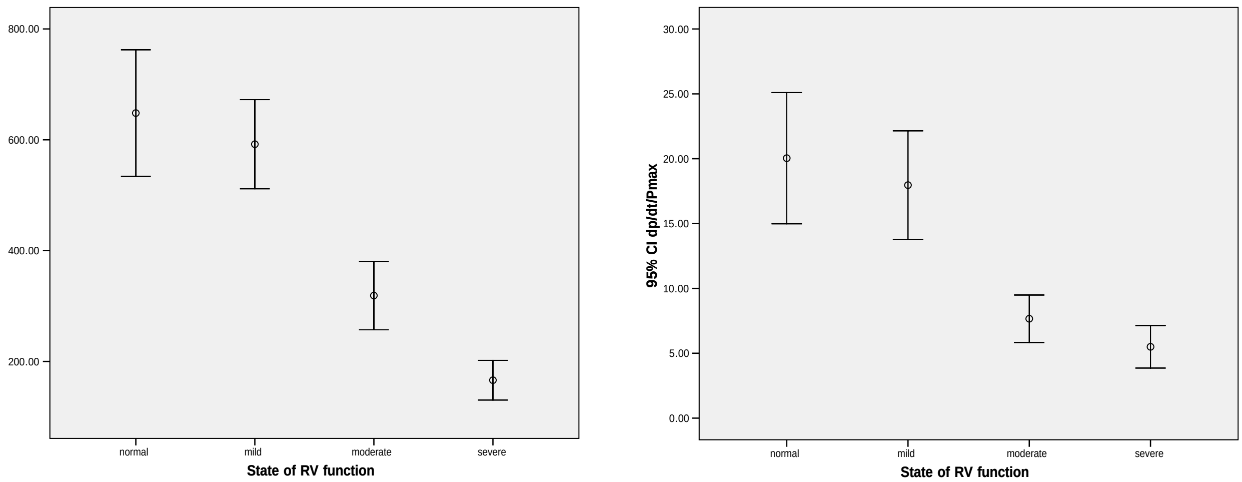
RV dP/dt ranged from 94 to 1000 mmHg/s; mean 408±220 mmHg/s. In normal RV function, mean dP/dt was 648(±159), in mild RV dysfunction, mean dP/dt was 592(± 126 ), in moderate RV dysfunction, mean dP/dt was 319(±146) and in severe RV dysfunction, mean dP/dt was 166 (±150). There were significant correlation between RV dp/dt and RV function (P<0.001) and between RV dP/dt and NYHA functional capacity (P<0.001).

There was a significant difference between RV function and dP/dt/$P_{max}$ (P< 0.001) and the results of Bonferroni post-hoc test was in agreement with those of dp/dt (Table 1, Fig. 2-b); RV dP/dt/Pmax showed significant relationship with RV function and functional capacity (P <0.001).

**Table 1.** Associations between the state of right ventricle function and other variables

| | State of RV Function | | | | P value |
|---|---|---|---|---|---|
| | Severe Dysfunction (n=10) | Moderate Dysfunction (n=24) | Mild Dysfunction (n=12) | Normal Function (n=10) | |
| **dP/dt mmHg/s** * | 648 (159.7) | 592 (126.6) | 319 (146.3) | 166 (150.1) | < 0.001 |
| **dP/dt/$P_{max}$ /s** * | 20 (7.1) | 18 (6.6) | 8 (4.3) | 5 (2.3) | < 0.001 |
| **LVEF percent** * | 48 (10.2) | 50 (4.9) | 40 (8.8) | 38 (7.8) | 0.001 |
| **FC** † | | | | | |
| **Class I** | 2 (0.20) | 0 | 0 | 0 | |
| **Class II** | 7 (0.70) | 9 (0.67) | 10 (0.42) | 2 (0.20) | 0.002 |
| **Class III** | 1 (0.10) | 3 (0.33) | 12 (0.50) | 8 (0.80) | |
| **Class IV** | 0 | 0 | 2 (0.08) | 0 | |
| **PAH**† | | | | | |
| **Mild** | 5 (0.50) | 8 (0.67) | 6 (0.25) | 6 (0.60) | |
| **Moderate** | 5 (0.50) | 3 (0.25) | 11 (0.46) | 3 (0.30) | 0.038 |
| **Severe** | 0 | 1 (0.08) | 7 (0.29) | 1 (0.10) | |
| TR Severity † | | | | | |
| Mild | 8 (0.80) | 9 (0.75) | 11 (0.46) | 4 (0.40) | 0.080 |
| Moderate | 2 (0.20) | 2 (0.17) | 7 (0.29) | 3 (0.30) | |
| Severe | 0 | 1 (0.8) | 6 (0.25) | 3 (0.30) | |

RV: right ventricle; LVEF: left ventricle ejection fraction; FC: NYHA functional class; PAH: pulmonary artery hypertension; TR: tricuspid regurgitation. * Numbers in the parentheses represent standard deviations. † Numbers in the parentheses represent relative frequency in each RV function subgroup.




(A) (B)

**Figure 2**: Error bars show the relationship between the state of RV function and A) dp/dt; B) dp/dt/$p_{max}$

### Relationships between RV function and other determinants

Bivariate associations between the state of RV function (as ordinal data) and TR severity, PAH (as ordinal data), FC and LVEF are shown in Table 1. LVEF had a significant association with the state of RV function (P=0.001). There were significant differences between the mean values of LVEF in the subgroup with mild degrees of RV dysfunction and moderate and severe RV dysfunction (P< 0.01). There was significant association between FC (P= 0.002) and PAH (P= 0.038) and RV function. No significant result was observed regarding TR severity (p= 0.08). Also, age and gender did not have significant difference among subgroups (P= 0.91).

**Table 2**. Associations between the state of right ventricle function and dP/dt, adjusted for other determinants.

| | Odds Ratio [CI 95%] | P value* |
|---|---|---|
| **dP/dt** | 0.988 [0.983 - 0.993] | < 0.001 |
| **LVEF** | 0.94 [0.87 - 1.01] | 0.110 |
| **FC** | 1.84 [0.56 - 6.12] | 0.321 |
| **PAH** | 1.76 [0.76 - 4.07] | 0.187 |
| **TR Severity** | 0.85 [0.33 - 2.15] | 0.726 |

*LVEF: left ventricle ejection fraction; FC: NYHA functional class; PAH: pulmonary artery hypertension; TR: tricuspid regurgitation.*
** Based on Wald test; values < 0.05 considered significant.*

### Multiple analysis

Considering the state of RV function as an ordinal variable with 4 subgroups, we used two ordinal logistic regression models to determine the associations between RV function and dP/dt and also RV function and dP/dt/ $P_{max}$, adjusted for TR severity, PAH, FC, and LVEF. The results are presented in Table 2 and 3.

The first model showed a weak, reverse but statistically significant association between RV

[0.983 - 0.993]; P<0.001). No significant association remained among other variables (Table 2).

In the second model (Table 3), there was a reverse association between RV function and dP/dt/ $P_{max}$ (odds ratio= 0.73, CI 95%: 0.64 - 0.84); P< 0.001). Besides, FC and PAH had significant adjusted relationship with the state of RV function.

**Table 3.** Associations between the state of right ventricle function and $dp/dt/p_{max}$ , adjusted for other determinants.

| | Odds Ratio [CI 95%] | P value* |
|---|---|---|
| $dp/dt/p_{max}$ | 0.73 [0.64 - 0.84] | < 0.001 |
| LVEF | 0.94 [0.88 - 1.02] | 0.127 |
| FC | 4.08 [1.27 - 13.16] | 0.018 |
| PAH | 0.31 [0.12 - 0.78] | 0.014 |
| TR Severity | 0.67 [0.28 - 1.61] | 0.369 |

*LVEF: left ventricle ejection fraction; FC: NYHA functional class; PAH: pulmonary artery hypertension; TR: tricuspid regurgitation.*
** Based on Wald test; values < 0.05 considered significant.*

## Discussion

The evaluation of right ventricular (RV) systolic function is important for its clinical and prognostic value but difficult to obtain due to complex RV geometry. The instantaneous pressure-volume relationship of the RV may provide a more accurate measurement of RV contractility,[21-24] however, it is too invasive and is not suitable for a routine assessment. RV dP/dt which is a well-validated index of ventricular systolic performance is not dependent on RV geometry and can be easily estimated in any patient with TR jet. We selected RV dP/dt and RV $dP/dt/P_{max}$ as RV contractility indices in patients with significant MS who had a detectable TR jet.

In this study we calculated RV dP/dt and RV $dP/dt/P_{max}$ using Doppler echocardiography and demonstrated that these indices have a good correlation with both qualitative and quantitative assessment of RV function and the patient's functional capacity.

It has been suggested that RV dP/dt is less dependent on afterload[4,21,25] but dependent on preload; in contrast, $dP/dt/P_{max}$ is considered to be relatively insensitive to both preload and afterload, both theoretically and experimentally[4]. Using RV TDI S velocity and TAPSE for assessment RV systolic function, Saxena et al have demonstrated that RV systolic function had an excellent correlation with RV fractional area change regardless of the degree of PAH.[26] In our study we found no significant difference between patients with different TR severity and PAH when we adjusted them for evaluating associations between RV function and dP/dt and $dP/dt/P_{max}$. We therefore concluded that TR severity and PAH are not major confounding factors, and that RV dP/dt and $dP/dt/P_{max}$ were relatively after load and pre-load independent.

We found a significant association between the state of RV function and LVEF, and other authors have suggested that there is a good correlation between TAPSE and LV systolic function.[27]

We also found a significant association between FC and PAH.

Kanzaki et al, found only a weak correlation between RV dP/dt and NYHA functional capacity.[2] Their study population was patients with dominant RV failure and they concluded that RV $dP/dt/P_{max}$, but not RV dP/dt, was a clinically useful index, whereas in our patients, both indices correlated significantly with NYHA FC. This difference might be due to the patient population selection. Our patients were in the entire spectrum of RV dysfunction, but they had only selected patients with severe RV dysfunction.

Our study showed a mean value of RV dP/dt for the spectrum of RV function (Table 1), although we could not find a significant difference between normal RV function and mild RV dysfunction.

To our knowledge there is no documented normal value for RV dP/dt, and we demonstrated that there is some overlap between RV dP/dt value in patients with normal RV function and mild RV dysfunction. This could be due to a relatively small sample selection of these patients. Although we found a significant difference between moderate and severe RV dysfunction, more studies are needed to substantiate these values.

RV dP/dt and RV dP/dt/$P_{max}$ are contractility indices of the isovolumic contraction time, and in the presence of TR there is no actual isovolumic time. It has been shown that MR per se had little effect on LV dP/dt,[3, 4] and although there is no similar data available, we hypothesize that TR also has little effect on RV dP/dt.

Although magnetic resonance imaging (MRI) is considered as the gold standard for quantization of ventricular volumes and systolic function, subjective assessment, eyeballing, by echocardiography is the modality most often used for the RV.[14] We selected quantitative methods that are clinically applicable and have a high specificity and negative predictive value for detecting abnormal RV systolic function.[19]

Measurements of RV dP/dt, and dP/dt/$P_{max}$, are practical methods for estimating RV contractility and have a good correlation with RV systolic function and functional capacity.

**Conflicts of Interest** no declare.

**References**

1 Baker BJ, Wilen MM, Boyd CM, et al. Relation of right ventricular ejection fraction to exercise capacity of patients with chronic left ventricular failure. *AM J Cardiol* 1984; **54**:596-9.

2 Kanzaki H, Nakatani S, Kawada T, et al. Right ventricular dp/dt /pmax , not dp/dt max , noninvasively derived from tricuspid regurgitation velocity is a useful index of right ventricular contractility. *J Am Sco Echocardiog* 2002; **15**:136-42.

3 Imanishi T, Nakatani S, Yamada S, et al. Validation of continuous wave Doppler-determined right ventricular peak positive and negative dp/dt : effect of right atrial pressure on measurement. *J Am Coll Cardiol* 1994; **23**:1638-43.

4 Mason DT. Usefulness and limitations of the rate of rise of intraventricular pressure (dp/dt) in the evaluation of myocardial contractility in man. *Am J Cardiol* 1962; **23**:516-27.

5 Roberson DA, Cui W, Lawn O. Right ventricular Tei index in children : effect of method, age, body surface area , and heart rate. *J Am Soc Echocardiogr* 2007; **20**:764-70.

6 Tei C, Nishimura RA, Seward JB, et al. Noninvasive Doppler-derived myocardial performance index: correlation with simultaneous measurements of cardiac catheterization measurements. *J Am Soc Echocardiogr* 1997; **10**:169-78.

7 Tei C, Dujardin KS, Hodge DO, et al. Doppler echocardiographic index for assessment of global right ventricular function. *J Am Soc Echocaardiogr* 1996; **9**:838-47.

8 Tayyareci Y, Yilmaz N, Berrin U, et al. Early detection of right ventricular systolic dysfunction by using myocardial acceleration during isovolumic contraction in patients with mitral stenosis. *Eur J Echocardiogr* 2008; **9**:516-21.

9 Lee KS, Abbas AE, Khandheria BK, et al. Echocardiographic assessment of right heart hemodynamic parameters. *J Am Soc Echocardiogr* 2007; **20**:773-82

10 Chung T, Emmett L, Mansberg R, et al. Natural history of right ventricular dysfunction after acute pulmonary embolism. *J Am Soc. Echocardiogr* 2007; **20**:885-94.

11 Kjaergaard J, Schaadt BK, Lund JO, et al. Quantitative measures of right ventricular dysfunction by echocardiography in the diagnosis of acute nonmassive pulmonary embolism. *J Am Soc Echocardiogr* 2006; **19**:1267-71.

12 Kjaergaard J ,Sogaard P, Hassager C. Quantitative echocardiographic analysis of the right ventricle in healthy individuals. *J Am Soc Echocardiogr* 2006; **19**:1365-72.

13 Haddad F, Denault AY, Couture P, et al. Right ventricular myocardial performance index predicts perioperative mortality or circulatory failure in high-risk valvular surgery. *J Am Soc Echocardiogr* 2007; **20**:1065-72.

14 Puchalski MD, Williams RV, Askovich B, et al. Assessment of right ventricular size and function: echo versus magnetic resonance imaging. *Congenit Heart Dis* 2007; **2**:27-31.

15 Bonow L, Zipes M. Braunwald's Heart Disease. 8th Ed. Saunders Elsevier. 2008l; p.572.

16 Koh J, Seward JB, Tajik AJ. The echo manual. 3th ed. Wolters Kluwer Lippincott Williams & Wilkins. 2006; p.77.

17 Lang RM, Bierig M, Devereux RB, et al. Recommendations for chamber quantification. *J Am Soc Echocardiogr* 2005; **18**:1440-63.

18 Zoghbi WA, Enriquez-Sarano M, Foster E, et al. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler chocardiography. *J Am Soc Echocardiogr* 2003; **16**:777-802.

19 Miller D, Farah MG, Liner A, et al. The relation between quantitative right ventricular ejection fraction and indices of tricuspid annular motion and myocardial performance. J Am Soc Echocardiogr. 2004; **17**:443-7.

**20** Miller D, Farah MG, Liner A, et al.The relation between quantitative right ventricular ejection fraction and indices of tricuspid annular motion and myocardial performance. *J Am Soc Echocardiogr*. 2004; **17**:443-7.

**21** Tamborini G, Pepi M, Galli CA, et al.Feasibility and accuracy of a routine echocardiographic assessment of right ventricular function. *Int J Cardiol*. 2007 31; **115**:86-9.

**22** Kass DA, Maughan WL, Guo ZM, et al. Comparative influence of load versus inotropic states on indexes of ventricular contractility: experimental and theoretical analysis based on pressure-volume relationships. *Circulation*. 1987; **76**:1422-36.

**23** Gorcsan J, Murali S, Counihan PJ, et al. Right ventricular performance and contractile reserve in patients with severe heart failure: assessment by pressure-area relations and association with outcome. *Circulation*. 1996; **94**:3190-7.

**24** Brown KA, Ditchey RV. Human right ventricular end-systolic pressure-volume relation defined by maximal elastance. *Circulation*. 1988; **78**:81-91.

**25** Oe M, Gorcsan J, Mandarino WA, et al. Automated echocardiographic measures of right ventricular area as an index of volume and end-systolic pressurearea relations to assess right ventricular function. *Circulation*. 1995; **92**:1026-33.

**26** Dubin AM, Feinstein JA, Reddy VM, et al. Van Hare and David N. Rosenthal. Electrical Resynchronization: A Novel Therapy for the Failing Right Ventricle. *Circulation* 2003; **107**:2287-9.

**27** 26- Saxena N, Rajagopalan N, Edelman K, et al.Tricuspid annular systolic velocity: a useful measurement in determining right ventricular systolic function regardless of pulmonary artery pressures. *Echocardiography*.2006; **23**:750-5.

**28** 27- Ghio S, Recusani F, Klersy C, et al. Prognostic usefulness of the tricuspid annular plane systolic excursion in patients with congestive heart failure secondary to idiopathic or ischemic dilated cardiomyopathy. *Am J Cardiol*. 2000; **85**:837-42.