

Right ventricular dysfunction in chronic heart failure patients

Lenka Špinarová*, Jaroslav Meluzín, Jiří Toman, Petr Hude, Jan Krejčí, Jiří Vítovec

1st Cardio-angiologic Department, University Hospital, Pekařská 53, 656 91 Brno, Czech Republic

Received 8 October 2003; received in revised form 20 January 2004; accepted 9 July 2004

Available online 19 March 2005

Abstract

Aim: To evaluate any differences in haemodynamic and echocardiographic parameters in patients with both left (LV) and right ventricular (RV) systolic dysfunction and in patients with isolated LV systolic dysfunction.

Study group: One hundred patients with RV systolic dysfunction defined as peak velocity of tricuspid annular motion in systole (Sa) < 11.5 cm/s, and 55 patients without RV systolic dysfunction Sa > 11.5 cm/s. All patients had LV systolic dysfunction, LV ejection fraction (EF) below 40%, NYHA II–IV.

Methods: LV diameters, volumes and EF were measured by echocardiography. Patients underwent tissue Doppler imaging (TDI) of tricuspid annular motion with measurement of peak systolic velocity (Sa), peak early (Ea) and peak late (Aa) diastolic velocities. Right heart catheterization was also performed.

Results: Patients with RV systolic dysfunction did not differ from those without RV systolic dysfunction in terms of LV function. Patients with RV systolic dysfunction had larger RV dimension 30.6 ± 5.8 vs. 33.9 ± 6.7 mm, $p < 0.002$. The patients with RV systolic dysfunction had higher values on right heart catheterization: MPAP 29.6 ± 12.1 vs. 24.9 ± 11.4 mm Hg, $p < 0.02$, PCWP 20.8 ± 10.0 vs. 17.3 ± 9.3 mm Hg, $p < 0.03$, PVR 189.9 ± 123.3 vs. 137.7 ± 94.9 dyn s cm^{-5} , $p < 0.008$, CVP 7.7 ± 5.6 vs. 5.1 ± 3.9 mm Hg, $p < 0.002$. The patients with RV systolic dysfunction had more pronounced diastolic dysfunction measured by TDI: Ea 9.9 ± 2.3 vs. 11.4 ± 2.5 cm/s, $p < 0.0001$ and Aa 13.1 ± 4.0 vs. 16.5 ± 4.7 cm/s, $p < 0.000007$.

Conclusion: Patients with heart failure and both left and right ventricular systolic dysfunction showed more serious findings on central haemodynamics as well as more pronounced right ventricular diastolic dysfunction than those with isolated left ventricular systolic dysfunction.

© 2004 European Society of Cardiology. Published by Elsevier B.V. All rights reserved.

Keywords: Right ventricle; Doppler tissue imaging; Tricuspid annulus; Haemodynamics

1. Introduction

Chronic heart failure is a disease process characterized by impaired left ventricular function, increased peripheral and pulmonary vascular resistance and sodium and water retention [1,2].

The worse the failure, the worse the prognosis is [3]. Independent negative prognostic factors are: myocardial function damage (EF below 20%, high systemic arterial resistance, low cardiac output), low peak oxygen consumption (pVO_2 below 14 ml/kg/min), hyponatremia below 135 mmol/l, age, diagnosis of coronary artery disease and

increased cardiothoracic ratio [4]. Neurohumoral markers: high level of norepinephrine, atrial natriuretic peptide or its precursor N terminal fragment proANP, big endothelin and tumor necrosis factor alpha also have a high negative predictive value [5,6]. Di Salvo et al. [7] recently demonstrated the independent prognostic value of right ventricular ejection fraction in patients with advanced heart failure. The same result was obtained by de Groot for patients with moderate heart failure [8].

In our recent study, we showed that the evaluation of peak systolic tricuspid annular velocity using tissue Doppler imaging provides a simple, rapid and non-invasive tool for assessing right ventricular function in patients with chronic heart failure [9]. Using this methodology differences in haemodynamic and echocardiographic parameters between

* Corresponding author. Tel./fax: +420 54318 2212.

E-mail address: lenka.spinarova@fnusa.cz (L. Špinarová).

patients with isolated left ventricular systolic dysfunction and those with systolic dysfunction of both the left and right ventricle were investigated.

2. Methods

2.1. Study population

The study included 155 patients with left ventricular (LV) systolic dysfunction, defined as an ejection fraction (EF) below 40%. All patients had symptomatic chronic heart failure NYHA class II–IV. The inclusion criteria were as follows: (a) good quality echocardiographic imaging of tricuspid annular motion, (b) sinus rhythm at electrocardiography and (c) clinically stable. The etiology for heart failure was coronary artery disease (defined as 70% angiographically verified luminal narrowing in at least one major coronary artery or documented myocardial infarction) (86 patients) or dilated cardiomyopathy (69 patients). The diagnosis of dilated cardiomyopathy was made based on echocardiographic and clinical criteria. There were 129 men and 26 women, mean age 52 ± 9 years. Of 155 patients with chronic heart failure, 100 exhibited right ventricular (RV) systolic dysfunction defined as peak velocity of tricuspid annular motion in systole (Sa) < 11.5 cm/s (Group A), and 55 patients did not have RV systolic dysfunction $Sa > 11.5$ cm/s (Group B).

All patients gave their written consent to the investigations. The study complied with the Declaration of Helsinki and was approved by the institutional ethics committee.

2.2. Echocardiography

Standard and tissue Doppler echocardiograms were obtained in all the patients using SONOS 5500 (Hewlett Packard, Andover, MA, USA) equipment with a phased array transducer of 2.5 MHz and Doppler tissue imaging technology. A detailed description of this technique has been given previously [10]. Minimal gain was used to assure clear and well-defined pulsed Doppler tissue imaging borders. Doppler tissue measurements were acquired with subjects in the left lateral decubitus position during shallow respiration or end-expiratory apnoea.

Guided by two-dimensional four-chamber view, a sample volume with a fixed length of 0.52 cm was placed on the tricuspid annulus at the place of attachment of the anterior leaflet of the tricuspid valve. Care was taken to obtain an ultrasound beam parallel to the direction of the tricuspid annular motion. Peak systolic (Sa), peak early (Ea) and late (Aa) diastolic annular velocities, along with simultaneous electrocardiography, were recorded on a videotape at a speed of 50 mm s^{-1} for subsequent analysis. A systolic annular velocity $< 11.5 \text{ cm s}^{-1}$ predicted right ventricular dysfunction (ejection fraction $< 45\%$) with a sensitivity of 90% and specificity of 85% [9].

We used a cut off value of 45% for right ventricular dysfunction on the basis of the study by Tokgozoglul [11]. This study evaluated right ventricular function in healthy subjects with no cardiac disease, by echocardiography and radionuclide ventriculography. The lower limit for normal RV function was 45%. The same cut off was used in our previous study [9].

When evaluating peak systolic velocity, the initial peak occurring in the course of isometric contraction was ignored. All pulsed Doppler tissue imaging parameters were measured on three to five consecutive heart cycles. In addition to pulsed Doppler tissue imaging, conventional echocardiography was performed, including M-mode and two-dimensional echocardiography. The right ventricular and left ventricular diameters, and septal and posterior wall thickness were measured according to the recommendations of the American Society of Echocardiography, and left ventricular ejection fraction was calculated using the biplane method according to the modified Simpson's rule [12].

2.3. Right heart catheterization

Right heart catheterization was performed via the right subclavian vein. A 7F thermodilution catheter (model 131HF7, Barter Healthcare Corporation, Irvine, CA, USA) was inserted through the right cavities and the pulmonary artery into the pulmonary wedge position. The measurements of mean right atrial pressure, mean pulmonary artery pressure and mean pulmonary capillary wedge pressures were obtained with the patient in a supine position using a mechano-electrical transducer (model P23XL, Ohmeda Medical Devices Division, Oxnard, CA, USA) connected to a bedside monitor (model 90308, SpaceLabs, Redmond, WA, USA). Cardiac output was measured by the thermodilution technique. The thermodilution curve was recorded and calculated using a thermodilution module of the above-mentioned monitor. The cardiac index was calculated as follows: cardiac index ($\text{l min}^{-1} \text{ m}^{-2}$) = cardiac output (l min^{-1})/body surface area (m^2).

2.4. Statistical analysis

Clinical, echocardiographic and right heart catheterization data are expressed as mean \pm standard deviation. Comparison between Groups A and B was done using a two-tailed *t*-test.

A *p* value < 0.05 was regarded as statistically significant.

3. Results

3.1. Characteristics of the study group

The baseline clinical and demographic data are shown in Table 1. The groups were comparable for age, gender and etiology of heart failure.

Table 1
Baseline characteristics of the study population

	RV dysfunction (S<11.5 cm/s)—group A	No RV dysfunction (S >11.5 cm/s)—group B
CAD/DCMP	54/46	32/23
Males/females	86/14	43/12
Age (years)	51±9	53±8

CAD—coronary artery disease, DCMP—dilated cardiomyopathy, RV—right ventricle.

3.2. Echocardiography

Table 2 shows standard echocardiographic and pulsed Doppler tissue imaging measurements. There were no differences between the groups for left ventricular dimensions and volumes. However, patients with right ventricular systolic dysfunction had significantly different dimensions of the right ventricle.

Patients with right ventricular systolic dysfunction also showed lower peak early (Ea) and late (Aa) diastolic velocities of tricuspid annular motion.

3.3. Right heart catheterization

Patients with the right ventricular dysfunction had higher central venous pressure, pulmonary vascular resistance, mean pulmonary artery and wedge pressures as shown in Table 3.

4. Discussion

Tissue Doppler imaging has evolved to become a useful non-invasive method for the assessment of left and right myocardial velocities in a variety of clinical conditions. It can be used to assess global and regional systolic function and to identify abnormal relaxation [13].

Doppler tissue imaging has been shown to be very sensitive in the early detection of the right ventricular

Table 2
Echocardiographic data

	Group A (n=100)	Group B (n=55)	p value
LVDD (mm)	69.3±8.3	68.8±8.4	ns
LVDS (mm)	59.7±8.5	57.5±8.9	ns
RVDD (mm)	33.9±6.7	30.6±5.8	0.002
LVEF (%)	23.1±5.5	24.5±6.4	ns
LVEDVi (ml/m ²)	131.1±38.5	122.5±46.3	ns
LVESVi (ml/m ²)	100.5±32.3	93.3±39.5	ns
Ea (cm/s)	9.9±2.3	11.4±2.5	0.0001
Aa (cm/s)	13.1±4.0	16.5±4.7	0.000007

Data are expressed as mean±standard deviation. LVDD—left ventricular end-diastolic diameter, LVDS—left ventricular end-systolic diameter, RVDD—right ventricular end-diastolic diameter, LVEF—left ventricular ejection fraction, LVEDVi—left ventricular end-diastolic volume index, LVESVi—left ventricular endsystolic volume index, Ea—peak early diastolic tricuspid annular velocity, Aa—peak late diastolic tricuspid annular velocity.

Table 3
Right heart catheterization data

	Group A (n=100)	Group B (n=55)	p value
CVP (mm Hg)	7.7±5.6	5.1±3.9	0.002
MPAP (mm Hg)	29.6±12.1	24.9±11.4	0.02
PCWP (mm Hg)	20.8±10.0	17.3±9.3	0.03
PVR (dyn s cm ⁻⁵)	189.8±123.2	137.7±94.9	0.008

Data are expressed as mean±standard deviation. CVP—central venous pressure, MPAP—mean pulmonary artery pressure, PCWP—pulmonary capillary wedge pressure, PVR—pulmonary vascular resistance.

diastolic dysfunction in patients with Chagas' disease, in contrast to parameters of right inflow pulsed wave Doppler. Although the patients and controls showed normal right ventricular filling dynamics by conventional pulsed Doppler, 44% of the Chagas' disease group presented with an abnormal ratio: early diastolic myocardial velocity/late diastolic myocardial velocity (Em/Am) compared with only one of the control group [14].

The utility of Doppler tissue imaging of tricuspid annular motion for the non-invasive assessment of right ventricular systolic function was demonstrated in our previous study. The peak systolic tricuspid annular velocity significantly correlates with the right ventricular ejection fraction assessed by first-passed radionuclide ventriculography, and a value <11.5 cm/s predicts the presence of right ventricular systolic dysfunction (ejection fraction < 45%) with a sensitivity of 90% and specificity of 85%. Good quality recording can be obtained in more than 95% patients [9]. This method has been accepted as a convenient means of quantitatively evaluating right ventricular systolic function, and has been used as a diagnostic tool by a number of groups [15].

The method is quick, noninvasive, inexpensive and widely available. Based on this methodology, our patients were divided into those with and those without right ventricular systolic dysfunction.

In the trial by Alam et al. myocardial velocities of the mitral and tricuspid annulus were studied in chronic heart failure patients and compared with healthy controls. Patients with chronic heart failure had significantly decreased mitral and tricuspid systolic velocities compared with healthy controls. The early diastolic velocity was also reduced in patients compared with healthy controls for both, mitral and tricuspid annuli [16]. In our study we also found reduced peak early diastolic velocity of tricuspid annular motion in patients with concomitant RV systolic dysfunction compared to patients with normal RV systolic function.

Patients with right ventricular systolic dysfunction also had higher central venous pressure, pulmonary vascular resistance, mean pulmonary artery and wedge pressures.

In the study by di Salvo, the major finding was the importance of right ventricular function for predicting both overall and event-free survival in patients with advanced heart failure.

Preserved rest or exercise right ventricular ejection fraction was found to predict both overall and event-free survival better than peak VO_2 [7]. The same result was obtained by de Groote for patients with moderate heart failure [8].

The right ventricle is very sensitive to load and systolic pulmonary artery pressure is an important determinant of right ventricular function. A significant but weak correlation between right ventricular ejection fraction and systolic pulmonary artery pressure in patients with moderate heart failure was reported [8].

The presence of right ventricular dysfunction with pre-existing left ventricular dysfunction is also associated with higher plasma brain natriuretic peptide (BNP) levels, compared to patients with isolated left ventricular dysfunction. Among patients with a left ventricular ejection fraction below 40%, plasma BNP levels were significantly higher in patients with right ventricular ejection fraction below 40% ($p < 0.004$) [17].

All these findings support the idea that the presence of the right ventricular systolic dysfunction is connected with adverse haemodynamic and humoral response and survival. Therefore, it is highly important to evaluate right ventricular function in patients with chronic heart failure. The prognostic importance of tissue Doppler imaging of tricuspid annular motion was shown in our recently published paper [18]. Patients with lower S_a (< 10.8 cm/s) exhibited worse survival $p < 0.048$ and event free survival $p < 0.001$ compared with those having $S_a > 10.8$ cm/s. Risk values of $S_a < 10.8$ cm/s and left ventricular end-diastolic diameter (> 70 mm) were found to be additive, leading to a very poor prognosis. Taking into account the fact that an S_a value of 11.5 cm/s divides patients into those with normal or abnormal right ventricular systolic function, the cohort of patients with $S_a < 10.8$ cm/s represents those with moderate or severe right ventricular dysfunction.

4.1. Limitations of the study

The echocardiographic and haemodynamic parameters were not obtained simultaneously, but within a time interval of 20–24 h. However, in view of the stable condition of the patients, we do not think that this could significantly influence our results. Another limitation is the fact that patients were required to be in sinus rhythm for inclusion in the study.

4.2. Conclusion

This study demonstrates the utility of Doppler tissue imaging of tricuspid annular motion for the non-invasive evaluation of the right ventricular function.

Patients with heart failure and right ventricular systolic dysfunction showed more serious findings for central

haemodynamics and also more pronounced right ventricular diastolic dysfunction.

Acknowledgements

This work was supported by grant of Education of the Czech Republic (MSM No 14100004) and by grant of Ministry of Health of the Czech Republic (IGA No NA/7619-3).

References

- [1] Coats AJ. Controversies in the management of heart failure. Churchill Livingstone; 1997. p. 180.
- [2] Cowie MR, Mosterd A, Wood DA, et al. The epidemiology of heart failure. *Eur Heart J* 1997;18:208–25.
- [3] Ho KK, Anderson KM, Kannel WB, Grossman W, Levy D. Survival after the onset of congestive heart failure in Framingham Heart Study Subjects. *Circulation* 1993;88:107–15.
- [4] Špinar J, Vitovec J, Spac J, Špinarova L, Toman J, Štefja M. Non-invasive prognostic factors in chronic heart failure. One year survival of 300 patients with diagnosis of chronic heart failure due to ischemic heart disease or dilated cardiomyopathy. *Int J Cardiol* 1996;56:283–8.
- [5] Anand IS, Ferrari R, Kalra GS, et al. Edema of cardiac origin. Studies of body water and sodium, renal function, hemodynamic indexes, and plasma hormones in untreated congestive cardiac failure. *Circ* 1989;80:299–305.
- [6] Pacher R, Stanek B, Huelsman M, et al. Prognostic impact of big endothelin-1 plasma concentrations compared with invasive hemodynamic evaluation in severe heart failure. *J Am Coll Cardiol* 1996; 27(3):633–41.
- [7] Di Salvo TG, Mathier M, Semigran MJ, Dec GW. Preserved right ventricular ejection fraction predicts exercise capacity and survival in advanced heart failure. *J Am Coll Cardiol* 1995;25:1143–52.
- [8] De Groote P, Millaire A, Foucher-Hossein A, Nogue O, et al. Right ventricular ejection fraction is an independent predictor of survival of patients with moderate heart failure. *J Am Coll Cardiol* 1998; 32(4):948–54.
- [9] Meluzin J, Špinarová L, Bakala J, et al. Pulsed Doppler tissue imaging of the velocity of tricuspid annular systolic motion. A new, rapid, and non-invasive method for evaluating right ventricular systolic function. *Eur Heart J* 2001;22:340–8.
- [10] Miyake K, Yamagishi M, Tahala N, et al. New method for evaluating left ventricular wall motion by color-coded tissue Doppler imaging: In vitro and in vivo studies. *J Am Coll Cardiol* 1995;25:717–24.
- [11] Tokgozoglul SL, Caner B, Kabakci G, Kes S. Measurement of RV ejection fraction by contrast echocardiography. *IJC* 1997;59: 71–4.
- [12] Schiller NB, Shah PM, Crawford M, et al. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. *J Am Soc Echocardiogr* 1989;2:358–67.
- [13] Waggoner AD, Bierig M. Tissue Doppler Imaging: A useful echocardiographic method for the cardiac sonographer to assess systolic and diastolic ventricular function. *J Am Soc Echocardiogr* 2001;14:1143–52.
- [14] Barros MVL, Machado FS, Ribeiro ALP, de Costa Rocha MO. Detection of early right ventricular dysfunction in Chagas' disease using Doppler tissue imaging. *J Am Soc Echocardiogr* 2002;15: 1197–201.

- [15] Burgess MI, Bright-Thomas RJ, Ray SG. Echocardiographic evaluation of right ventricular function. *Eur J Echocardiog* 2002;3: 252–62.
- [16] Alam M, Wardell J, Andersson E, Nordlander R, Samad B. Assessment of left ventricular function using mitral annular velocities in patients with congestive heart failure with or without the presence of significant mitral regurgitation. *J Am Soc Echocardiogr* 2003;16: 240–5.
- [17] Mariano-Goulart D, Eberlé MC, Boudousq V, et al. Major increase in brain natriuretic peptide indicates right ventricular systolic dysfunction in patients with heart failure. *Eur Heart J* 2003;5:481–8.
- [18] Meluzín J, Špinarová L, Dušek L, et al. Prognostic importance of the right ventricular function assessed by Doppler tissue imaging. *Eur J Echocardiog* 2003;4:262–71.