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Relationship between Mean Right Atrial Pressure and Doppler Parameters in Patients with Right Ventricular Infarction

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Summary

Background: The incidence of an inferior left ventricular infarction involving the right ventricle is very high, ranging from 14 to 84%. Isolated right ventricular infarction accounts for < 3% of all cases of infarction.

Hypothesis: The aim of the present study was to assess the relationship between Doppler parameters of hepatic vein and tricuspid inflow, as well as mean right atrial (RA) pressure in patients with right ventricular infarction.

Methods: In all, 59 consecutive patients with inferior left ventricular infarction involving the right ventricle were selected for the study. All patients underwent Doppler echocardiographic evaluation of tricuspid and hepatic vein parameters and catheterization of the right side of the heart. Patients were divided into two groups according to the presence or absence of severe tricuspid regurgitation.

Results: In patients with severe tricuspid regurgitation, a significant correlation ($r = 0.64$; $p < 0.001$) between RA maximal volume and mean right atrial pressure (RAP) was found, and the sensitivity of RA maximal volume in identifying mean RAP > 7 mmHg was 64% with a specificity of 78%. In patients without severe tricuspid regurgitation, the most significant relationship was observed between mean RAP and inferior vena cava collapse index. Significant correlations between maximal and minimal diameters of the inferior vena cava were also observed.

Conclusions: Echocardiographic and Doppler parameters may be useful for evaluating mean RAP in patients with right ventricular infarction. In patients with severe tricuspid regurgitation, the more important parameters are maximal and minimal RA volumes. In patients without severe tricuspid regurgitation together with right atrial volume, the important parameters are acceleration and deceleration time of the tricuspid inflow peak E velocity and hepatic systolic and diastolic venous flow.

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Introduction

The incidence of an inferior left ventricular infarction involving the right ventricle is very high, ranging from 14 to 84%.[1,2] Isolated right ventricular infarction accounts for < 3% of all cases of infarction.[3] In the presence of a right ventricular infarction, it is necessary to increase atrial contractility to overcome the increased myocardial stiffness.[3] Any reduction in atrial function is likely to have significant adverse effects on hemodynamics in patients with a large right ventricular infarction.[4] Right atrial pressure (RAP) is highly sensitive and specific for identifying right ventricular infarction and is a reliable guide for therapy.[5,6] A comprehensive evaluation of the relationship between echocardiographic and Doppler parameters of right ventricular function, right atrial (RA) function, and inferior vena cava, and mean RAP (mRAP) in patients with right ventricular infarction has not been performed previously. This study was undertaken to assess the relationship between Doppler parameters of hepatic vein and tricuspid inflow and right ventricular and mRAP.

Methods

Patient Population

In all, 74 consecutive patients with inferior left ventricular infarction involving the right ventricle were screened for the study. Fifteen patients were excluded from the study because of an inadequate recording of Doppler tracings and/or inadequate recording of pressures. The remaining 59 patients (43 men and 16 women) had a mean age of 65 ± 8 years. All patients had indwelling central venous catheters or underwent catheterization of the right side of the heart, and were in the Intensive Care Unit of our University Hospital.

Simultaneous recordings of transthoracic echocardiography, mRAP, and standard upright posteroanterior chest x-ray film were obtained in all patients.

The transthoracic echocardiographic studies were independently examined by an observer blinded to the diagnosis of the patients. Exclusion criteria included inadequate recordings of pressures or Doppler tracings, or a chest x-ray inadequate for a quantitative evaluation of the width of the azygos vein. Patients with bundle-branch block, previous cardiac failure, or those admitted > 10 h after the onset of symptoms were excluded from the study.

The clinical data of the patients are presented in Table I.

TABLE I Hemodynamic and two-dimensional echocardiographic parameters on right-side cardiac structure and function in patients with and without severe tricuspid regurgitation

Hemodynamics	With severe TR	Without severe TR
Mean RAP (mmHg)	16.5 ± 6.8 (6–28)	17.2 ± 7.4 (8–28)
Heart rate (beats/min)	66 ± 9 (52–78)	69 ± 10 (56–74)
Systolic blood pressure (mmHg)	104 ± 10 (78–130)	106 ± 14 (72–128)
Diastolic blood pressure (mmHg)	88 ± 6 (74–84)	84 ± 8 (78–88)
Pulmonary artery systolic pressure (mmHg)	28 ± 12 (17–36)	31 ± 13 (13–35)
Pulmonary artery diastolic pressure (mmHg)	14 ± 6 (7–21)	12 ± 7 (5–19)
Pulmonary artery wedge pressure (mmHg)	7 ± 6 (6–15)	8 ± 6 (7–12)
Cardiac output (l/min)	2.3 ± 1.3 (1.6–4.3)	3.2 ± 1.5 (1.8–4.7)
Echocardiographic parameters		
RA vol max cm^3	49.7 ± 7.5 (38–60)	45.8 ± 6.7 (36–57)
RA vol min cm^3	44.5 ± 6.5 (32–54)	41.6 ± 6.2 (32–52)
IVC max cm	1.71 ± 0.8 (1.5–1.85)	1.61 ± 0.5 (1.5–1.7)
IVC min cm	1.69 ± 0.8 (1.4–1.84)	1.10 ± 0.4 (1–1.2)
IVC collapse (%)	31 ± 18 (9–98)	45 ± 23 (10–98)
RVEF (%)	38.4 ± 11 (16–58)	32.5 ± 12 (17–58)

Abbreviations: TR = tricuspid regurgitation, mean RAP = mean right atrial pressure, RA = right atrium, IVC = inferior vena cava, RVEF = right ventricular ejection fraction.

Study Protocol

Right ventricular infarction was diagnosed if patients fit at least three of the electrocardiographic, hemodynamic, angiographic, or echocardiographic criteria.[4,6–8]

In all patients, a standard 12-lead electrocardiogram (ECG) and right precordial leads (V_3–V_{6R}) were recorded within 10 h from the onset of symptoms. ST-segment deviations were assessed 0.04 s after the J point in all 16 leads. A 1 mm ST-segment elevation and/or Q waves in V_4–V_{6R} leads were required to diagnose the presence of right ventricular infarction.[2,7] All patients had ECG signs of right ventricular involvement.

Radiographic and echocardiographic features of right ventricular infarction were evaluated as previously described in detail.[7,9,10]

The hemodynamic alterations that were considered highly indicative of a right ventricular infarction included significantly elevated RAP that exceeded the pulmonary-capillary wedge pressure.[2,4] Coronary angiography was considered indicative of right ventricular infarction if there was an occlusion of the right coronary artery proximal to the acute marginal branches.[8]

On the basis of this protocol, 59 patients were enrolled in this study. Thrombolytic therapy was used in all eligible patients; 54 patients were eligible while 4 patients had major contraindications.

The study protocol was approved by the Ethical Committee of the University, and all patients signed an informed consent form.

Echocardiographic and Doppler Evaluation

Echocardiographic studies were performed with patients in the supine position. Measurements were taken at end expiration. Standard echocardiographic imaging was obtained from the parasternal, apical, and subcostal windows for the evaluation of right and left ventricular function and for assessment of the size of the right atrium and inferior vena cava.[9] Color flow Doppler echocardiography was used to screen for the presence of valvular regurgitation. A pulsed Doppler recording of tricuspid inflow was obtained from the low parasternal and apical windows, with the sample volume positioned at the tips of the tricuspid valve. The flow velocity of the hepatic vein was obtained from the subcostal view. Ten cardiac cycles from each window were recorded and measured. Right ventricular function was quantified from the four-chamber view using modified Simpson's rule.[11]

Maximal right atrial volume preceding the opening of the tricuspid valve and minimal RA volume following atrial contraction were measured from the apical four-chamber view. Right atrial volumes were calculated with modified Simpson's rule.[11]

The inspiratory change was measured from the two-dimensional subcostal view, from which a percent collapse index was obtained. The inspiratory change, commonly referred to as a sniff test, was used frequently to estimate RAP.[12]

Tricuspid inflow measurements were performed from the window providing the highest overall velocities, allowing the best angulation with flow.

The following parameters were measured: peak early inflow velocity, peak late velocity, and the ratio of deceleration: acceleration time.

From the hepatic vein flow velocity, the parameters for peak velocity and time velocity integral of the systolic, diastolic, and atrial reversal waves were measured. The duration of the atrial reversal wave was measured from the beginning to the end of the atrial reversal wave. All measurements represented the average of five consecutive cycles. This approach allowed parameters to be almost identical to those obtained during end-espiratory apnea.[13]

Hemodynamic Recordings

All readings were referenced to the midaxillary line with the patients in the supine position. The position of the catheter was identified by chest radiograms. Pressure measurements

TABLE II Mean value of Doppler-derived parameters in patients with and without severe tricuspid regurgitation

Tricuspid flow	With severe TR	Without severe TR
Peak E velocity (cm/s)	68.28 ± 10.9 (55–96)	58.8 ± 16.9 (30–82)
Peak A velocity (cm/s)	76.30 ± 9.2 (54–91)	57.1 ± 14.1 (34–80)
E/A ratio	0.89 ± 0.12 (0.66–1.29)	1.08 ± 0.39 (0.5–2.17)
AFF	0.27 ± 0.05 (0.26–0.36)	0.25 ± 0.03 (0.2–0.31)
% Deceleration time (ms)	218.6 ± 139 (64–465)	163.9 ± 46 (40–220)
Hepatic vein flow		
Diastolic velocity (cm/s)	39.1 ± 16 (18–70)	34.0 ± 12 (18–55)
Systolic velocity (cm/s)	−14.2 ± 10 [−7(−24)]	14.4 ± 5 (8–28)

Abbreviations: AFF = atrial filling fraction, TR = tricuspid regurgitation.

were determined at end expiration and an average of three to five cycles was obtained.

Statistical Analysis

Data are expressed as mean ± 1 standard deviation. An unpaired *t*-test was used to compare variables between groups of patients. To compare qualitative ventricular function assessment and mean RAP, the chi-square test was used. Correlations were performed with linear regression analysis. Stepwise multiple linear regression was subsequently performed. The difference was considered statistically significant when $p < 0.05$.

Results

Patients were divided into two groups according to the presence or absence of severe tricuspid regurgitation. Group 1 included 32 patients (23 men, 9 women, mean age 66 ± 8 years) with severe tricuspid regurgitation. Group 2 included 27 patients (20 men, 7 women, mean age 64 ± 9 years) without severe tricuspid regurgitation.

Doppler and Echocardiographic Features of Patients with Severe Tricuspid Regurgitation

Table I shows the hemodynamic and echocardiographic parameters of patients in Group 1. Right ventricular ejection fraction averaged 34 ± 11% (range 16–58%). Right atrial maximal volume averaged 49 ± 7 cm3 (range 38–60 cm^3), and minimal volume averaged 44 ± 6 cm3 (range 32–54 cm^3). The maximal diameter of the inferior vena cava averaged 1.71 ± 0.1 cm (range 1.5–1.8 cm) with a minimal diameter after inspiratory effort of 1.69 ± 0.8 cm (range 1.4–1.8 cm) and a percent collapse of 31 ± 18% (range 9–98%).

Doppler-derived parameters in patients with severe tricuspid regurgitation are listed in Table II.

Relation of Echocardiographic Measurements to Mean Right Atrial Pressure

Table III shows the correlation between echocardiographic parameters and mean RAP. A significant correlation was present for deceleration time ($r = 0.47$; $p < 0.006$) (Fig. 1). A relationship was observed between RA maximal volume and mean RAP ($r = 0.64$; $p < 0.001$) (Fig. 2), and the sensitivity of RA maximal volume in identifying mean RAP > 7 mmHg was 64% with a specificity of 78%.

A strong inverse relationship was observed between mean RAP and right ventricular ejection fraction. Correlations between maximal and minimal diameters and the collapse index of the inferior vena cava were weak and not significant. The strongest relationship between Doppler parameters and mRAP was seen with the deceleration and acceleration time of the tricuspid inflow.

Doppler and Echocardiographic Features of Patients without Severe Tricuspid Regurgitation (Group 2)

Hemodynamics and Doppler echocardiographic parameters in patients without severe tricuspid regurgitation are presented in Tables II and III.

Right ventricular ejection fraction averaged 32.5 ± 12% (range 17–58%). Right atrial maximal volume averaged 45.8 ± 6.7 (range 36–57), and minimal volume averaged 41.6 ± 6.2 (range 32–52). The mean percent collapse of the inferior vena cava was 45 ± 20% (range 10–82%).

Relation of Echocardiographic Measurements to Mean Right Atrial Pressure in Patients without Severe Tricuspid Regurgitation

Table IV shows the correlation between echocardiographic parameters and mRAP. Among echocardiographic parameters, a significant relationship was observed between mRAP

TABLE III Correlation between Doppler-derived parameter and mean right atrial pressure in patients with severe tricuspid regurgitation

Tricuspid flow	r	p Value
Peak E velocity	0.11	0.5
Peak A velocity	0.28	0.1
E/A ratio	0.14	0.4
AFF	0.29	0.1
A-wave duration	0.06	0.7
Deceleration time	0.47	0.006
Acceleration time	0.42	0.01
Hepatic vein flow		
Diastolic velocity	0.012	0.09
Systolic velocity	0.25	0.16

Abbreviations as in Table II.

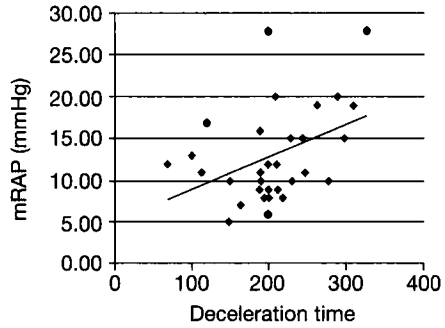

FIG. 1 Scatterplot showing the relation of tricuspid deceleration time with mean right atrial pressure (mRAP) in patients with severe tricuspid regurgitation. ◆ $r = 0.47$, $p < 0.01$.

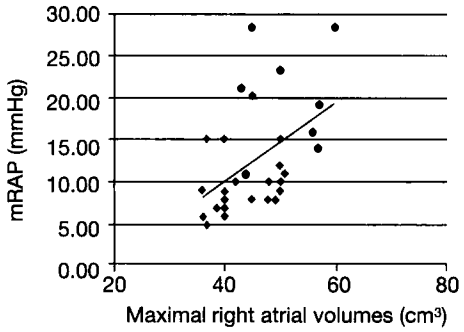

FIG. 2 Scatterplot showing the relation of maximal right atrial volume with mean right atrial pressure (mRAP) in patients with severe tricuspid regurgitation. ◆ $r = 0.64$, $p < 0.001$.

and maximal and minimal right atrial volumes. Larger atrial volumes at end systole and end diastole were found to be associated with higher mRAP. The sensitivity of this parameter in identifying mRAP > 7 mmHg was 74% and specificity was 87% (Table V).

The most significant relationship was observed between mRAP and the inferior vena cava collapse index. Significant correlations were observed between maximal and minimal diameters of the inferior vena cava. Table V shows the sensitivity and specificity of the best Doppler and two-dimensional variables for separating normal from elevated mRAP.

Discussion

The present study was undertaken to assess the relationship between Doppler echocardiographic parameters and mRAP in patients with right ventricular infarction. A previous paper by Nagueh *et al.* has demonstrated that Doppler parameters of hepatic vein flow, particularly those including the systolic filling wave, had the strongest relation with mRAP.[13] This feature is confirmed by the present paper in a patient population with acute right ventricular infarction.

The strongest relation was observed between systolic and diastolic hepatic vein flow velocities and mRAP. Tricuspid diastolic inflow reflects the effect of filling pressure, right ventricular relaxation, and net atrioventricular compliance.[13] The dependence of tricuspid filling dynamics on loading condition has been previously described.[14] Right ventricular infarction is characterized by elevated mRAP, resulting in a higher early velocity of tricuspid inflow.[9] In patients with right ventricular infarction and severe tricuspid regurgitation, there was a significant correlation between RA maximal volume and mRAP; this parameter had high sensitivity and specificity in identifying patients with mRAP > 7 mmHg. A larger atrial volume at the end of ventricular systole is probably due to several factors. The severity of the hemodynamic derangements associated with right ventricular infarction is related not only to the extent of right ventricular ischemia, and consequently right ventricular dysfunction, but also to the restraining effect of the pericardium and the resulting interaction between the ventricles.[15] The restraining effect of the pericardium induces a reduction in right ventricular systolic pressure in a patient with severe tricuspid regurgitation.

It was postulated that, as right ventricular systolic function diminishes, the atrial contraction becomes the driving force for pulmonary perfusion.[14, 16] The inverse relationship between mRAP and right ventricular ejection time is probably due to the active right ventricular systolic pressure wave caused by left ventricular contraction, which bulges in piston-like fashion into the right ventricle. This generates a systolic force sufficient for pulmonary perfusion and a simultaneous increase in tricuspid regurgitation.[17]

TABLE IV Correlation between Doppler-derived parameter and mean right atrial pressure in patients without severe tricuspid regurgitation

Tricuspid flow	r	p Value
Peak E velocity	0.13	0.5
Peak A velocity	0.41	0.03
E/A ratio	0.19	0.32
AFF	0.17	0.39
A-wave duration	0.52	0.005
Deceleration time	0.64	0.0003
Acceleration time	0.65	0.0002
Hepatic vein flow		
Diastolic velocity	0.47	0.01
Systolic velocity	0.73	0.001

Abbreviations as in Table II.

TABLE V Sensitivity and specificity of echocardiographic and Doppler parameters for mean right atrial pressure > 7mmHg in patients without severe tricuspid regurgitation

	Sensitivity	Specificity
RA volume max > 35 cm	74	87
Acceleration time < 65	65	80
Deceleration time < 200	76	79
Systolic velocity hepatic vein > 30	81	92
Diastolic velocity hepatic vein > 12	84	94

Abbreviation: RA = right atrial.

The behavior of acceleration time is probably due to right ventricular pressure tracing, which is often bifid in right ventricular infarction and characterized by a "dip-plateau" pattern in the diastolic pressure curve with a high early gradient between the right atrium and ventricle.[18] The correlation of mRAP with deceleration time is similar to that observed in patients with constrictive pericarditis.[19]

In patients without severe tricuspid regurgitation, larger volumes were found to be associated with a higher mRAP. There was also a strong sensitivity and specificity of the acceleration and deceleration time of the tricuspid E wave. Furthermore, these parameters correlated well with mRAP. In this group, there was also a "dip-plateau" in the right ventricular diastolic pressure curve that reflects a decrease in compliance as well as in pericardial constraining forces.[13, 19] Our findings in patients without severe tricuspid regurgitation were similar to those previously reported.[13]

The contribution of RA contraction to pulmonary perfusion explains the correlation between mRAP and hepatic venous flow. Determinants of the systolic forward flow include atrial relaxation, the descent of the tricuspid annular plane toward the ventricle apex, and, more important, the RAP. The higher the RAP, the lower the pressure gradient between the hepatic veins and the right atrium, and thus the lower the forward systolic flow.[4, 13] In the present study, systolic forward flow parameters correlated well with RAP, and the diastolic flow also showed a strong relationship with RAP. Goldstein *et al.* observed the right atrial wave form and demonstrated that the predominant atrial descent in diastole is blunted, reflecting an increase in resistance to diastolic filling which is proportional to mRAP.[17, 20]

Clinical Implication

A recent paper reported the reference values for right ventricular filling of normal persons,[21] suggesting the role of right-side Doppler parameters in the comprehensive evaluation of many diseases. The role of Doppler echocardiography in the Coronary Care Unit has been increasing over the years, and we need to get more information, not only about the extension of the ischemic disease but also to assess hemodynamics and function. The Doppler echocardiographic parameters we tested can be useful in identifying patients with right ventricular infarction and increased mRAP when invasive techniques are not immediately available.

Conclusions

The echocardiographic and Doppler parameters may be useful for evaluating mRAP in patients with right ventricular infarction. In patients with severe tricuspid regurgitation, the more important parameters are maximal and minimal RA volumes. The increase of RA volumes suggested an increased mRAP > 7 mmHg. In patients without severe tricuspid regurgitation together with right atrial volume, the important parameters are the acceleration and deceleration times of the tricuspid E wave and hepatic, systolic, and diastolic venous flow.

References

1. Isner JM, Roberts WC: Right ventricular infarction complicating left ventricular infarction secondary to coronary artery disease. *Am J Cardiol* 1978;42:885–894
2. Andersen HR, Nielsen D, Falk E: Right ventricular infarction: Diagnostic value of ST elevation in lead III exceeding that of lead II during inferior/posterior infarction. *Am Heart J* 1989;117:82–85
3. Cohn JN: Right ventricular infarction revisited. *Am J Cardiol* 1979;43:666–668
4. Dell'Italia LJ, Starling MR, Crawford MH, Boros BL, Chanduri TK, O'Rourke RA: Right ventricular infarction: Identification by hemodynamic measurements before and after volume loading and correlation with noninvasive techniques. *J Am Coll Cardiol* 1984; 4:931–939
5. Kazemi H, Parson EF, Valenca LM, Strieder DJ: Distribution of pulmonary blood flow after myocardial ischemia and infarction. *Circulation* 1970;41:1025–1030
6. Milne EN, Pistolesi M, Miniati M, Giuntini C: The vascular pedicle of the heart and vena azygos. *Radiology* 1984;152:9–17
7. Bellamy GR, Rasmussen HH, Nasser FN, Wiseman JC, Cooper RA: Value of two-dimensional echocardiography, electrocardiography and clinical signs in detecting right ventricular infarction. *Am Heart J* 1986;112:304–309
8. Berger PB, Ruocco NA, Timm CT, Zaret BL, Wackers FJ, and the TIMI Investigators: The impact of thrombolytic therapy in right ventricular infarction complicating inferior myocardial infarction: Results from TIMI II. *Circulation* 1989;80:313–314
9. Mattioli AV, Bastia E, Mattioli G: Doppler echocardiographic findings in patients with right ventricular infarction. *J Ultrasound Med* 1998;17;297–301
10. Mattioli AV, Mattioli G: Radiographic finding of patients with right ventricular infarction: Prognostic evaluation. *Radiography* 2000; 6:19–26
11. Panidis IP, Ren J, Kotler MN, Mintz G, Iskandrian AM, Ross J, Kane S: Two dimensional echocardiographic estimation of right ventricular ejection fraction in patients with coronary artery disease. *J Am Coll Cardiol* 1983;2:911–918
12. Kircher BJ, Himelman RB, Schiller NB: Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol* 1990;66:493–496
13. Nagueh SF, Kopelen HA, Zoghbi WA: Relation of mean right atrial pressure to echocardiographic and Doppler parameters of right atrial and right ventricular function. *Circulation* 1996;93:1160–1169
14. Sadler DB, Brown J, Mursett H, Roberts J: Impact of hemodialysis on left and right ventricular Doppler diastolic filling indices. *Am J Med Sci* 1992;304:83–90
15. Calvin JE: Optimal right ventricular filling pressures and the role of pericardial constraint in right ventricular infarction in dogs. *Circulation* 1991;84:852–861
16. Kuo LC, Quinones MA, Rokey R, Sartori M, Abinader EG, Zoghbi WA: Quantification of atrial contribution to ventricular filling by pulsed Doppler echocardiography and the effect of age in normal and diseased heart. *Am J Cardiol* 1987;59:1174–1178
17. Goldstein JA, Barzilai B, Rosamond TL, Eisenberg PR, Jaffe AS: Determinants of hemodynamic compromise with severe right ventricular infarction. *Circulation* 1990;82:359–368
18. Kinch JW, Ryan TJ: Right ventricular infarction. *N Engl J Med* 1994;330;1211–1217
19. Oh JK, Hatle LK, Seward JB, Danielson GK, Schaff HV, Reeder GS, Tajik AJ: Diagnostic role of Doppler echocardiography in constrictive pericarditis. *J Am Coll Cardiol* 1994;22:1935–1943
20. Goldstein JA, Tweddell JS, Barzilai B, Yagi Y, Jaffe AS, Cox JL: Importance of left ventricular function and systolic ventricular interaction to right ventricular performance during acute right heart ischemia. *J Am Coll Cardiol* 1992;19:704–711
21. Klein AL, Leung DY, Murray RD, Urban LH, Bailey KR, Tajik AJ: Effects of age and physiologic variables on right ventricular filling dynamics in normal subjects. *Am J Cardiol* 1999;84:440–448