Pulsed Doppler tissue imaging of the velocity of tricuspid annular systolic motion

A new, rapid, and non-invasive method of evaluating right ventricular systolic function

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Aims Rapid, accurate, and widely available non-invasive evaluation of right ventricular function still presents a problem. The purpose of the study was to determine whether the parameters derived from Doppler tissue imaging of tricuspid annular motion could be used as indexes of right ventricular function in patients with heart failure.

Methods Standard and pulsed Doppler tissue echocardiography were obtained in 44 patients with heart failure (mean left ventricular ejection fraction 24±7%) and in 30 age- and sex-matched healthy volunteers. The tricuspid annular systolic and diastolic velocities were acquired in apical four-chamber views at the junction of the right ventricular free wall and the anterior leaflet of the tricuspid valve using Doppler tissue imaging. Within 2 h of Doppler tissue imaging, the first-pass radionuclide ventriculogram, determining right ventricular ejection fraction and equilibrium gated radionuclide ventriculography single photon emission computed tomography, were performed in all patients.

Results In patients with heart failure, the peak systolic annular velocity was significantly lower and the time from the onset of the electrocardiographic QRS complex to the peak of systolic annular velocity was significantly greater than the corresponding values in healthy subjects (10·3±2·6 cm · s⁻¹ vs 15·5±2·6 cm · s⁻¹, P<0·001, and 198±34 ms vs 171±29 ms, P<0·01, respectively). There was a good correlation between systolic annular velocity and right ventricular ejection fraction (r=0·648, P<0·001). A systolic annular velocity <11·5 cm · s⁻¹ predicted right ventricular dysfunction (ejection fraction <45%) with a sensitivity of 90% and a specificity of 85%.

Conclusion We conclude that the evaluation of peak systolic tricuspid annular velocity using Doppler tissue imaging provides a simple, rapid, and non-invasive tool for assessing right ventricular systolic function in patients with heart failure.

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Key Words: Doppler tissue imaging, right ventricle, myocardial function, tricuspid annulus.

See page 280 for the Editorial comment on this article

Introduction

The evaluation of right ventricular systolic function is useful in a variety of clinical situations³¹–³³. However, the choice of a non-invasive, widely available, inexpensive, and accurate method still represents a problem. The accurate and most often applied methods, radionuclide ventriculography³³ and magnetic resonance imaging³⁵, are time-consuming and relatively expensive methods, which cannot be used at the bedside. Standard two-dimensional echocardiographic evaluation of right ventricular volumes and ejection fraction is inaccurate because it is difficult to define endocardial surfaces (right ventricular trabeculation and often suboptimal quality of right ventricular imaging) and calculating volumes is also a problem because of the complexity of the shape of the right ventricle³⁵. The accuracy of echocardiographic evaluation of right ventricular function can be improved by the application of a contrast agent³⁶, but it increases...
the cost of the investigation and may not be comfortable for all patients. In addition to volume calculations and assessing wall motion abnormalities, another way to evaluate myocardial function is by determining velocities of mitral or tricuspid annular motion. This motion reflects the contraction and relaxation of longitudinal myocardial fibres in both ventricles.

Pulsed Doppler tissue imaging is a unique method of measuring systolic and diastolic velocities of motion of both annulæ. While the velocity of motion of the mitral annulus has been repeatedly shown to accurately and reproducibly represent global left ventricular systolic or diastolic function[7-9], no report has been published on the impact of impaired right ventricular function on tricuspid annular velocities in systole and diastole. Thus the aim of our study was to determine whether tricuspid annular velocities, as assessed by pulsed Doppler tissue imaging, could be used as indexes of right ventricular function in patients with heart failure.

**Methods**

**Study population**

The study included 44 consecutive patients with symptoms of heart failure (class II–III according to the New York Heart Association), who were referred to our department as potential candidates for orthotopic heart transplantation for pre-transplant investigation. The inclusion criteria were: (a) good quality echocardiographic imaging of the tricuspid annular motion, (b) sinus rhythm on electrocardiography, and (c) the patients had to be clinically stable. Only one patient was excluded because of poor quality Doppler tissue recording of tricuspid annular velocities. The aetiology for heart failure was ischaemic cardiomyopathy (>70% angiographically verified luminal diameter narrowing in at least one major coronary artery or documented myocardial infarction — 18 patients), dilated cardiomyopathy (25 patients), and primary pulmonary hypertension (one patient, candidate for both heart and lung transplantation). The diagnosis of dilated cardiomyopathy was made on the basis of echocardiography and clinical criteria. In 11 patients with dilated cardiomyopathy, coronary artery disease was excluded by coronary angiography. There were 36 men and eight women, aged 49 ± 11 years (range, 17–63). Thirty age- and sex-matched healthy subjects (age range 20–74 years, mean age 50 ± 16 years) were selected as a control group. The study protocol was approved by the ethics committee of our institution and informed consent of all subjects was obtained. The study complies with the Declaration of Helsinki.

**Echocardiography**

Standard and pulsed Doppler tissue echocardiograms were obtained in all the patients and healthy volunteers, with SONOS 5500 (Hewlett Packard, Andover, Mass, U.S.A.) equipment with a phased array transducer of 2.5 MHz, and with a system equipped with Doppler tissue imaging technology. Pulsed Doppler tissue imaging is a relatively new echocardiographic method based on the display of low frequency, high amplitude Doppler signals originated in the myocardium. A detailed concept and technical aspects of this approach have been published previously[10,11]. In our study, the spectral pulsed Doppler was adjusted to obtain a Nyquist limit of 20–30 cm . s⁻¹. We used the minimal gain to assure clear and well-defined pulsed Doppler tissue imaging wave borders. Doppler tissue measurements were acquired with subjects in the left lateral decubitus position during shallow respiration or end-expiratory apnoea.

Guided by the 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 videotape at a speed of 50 and 100 mm . s⁻¹ for subsequent analysis. The recording at a speed of 100 mm . s⁻¹ was used for determining the time interval between the onset of the electrocardiographic QRS complex and the peak of the systolic Doppler tissue imaging wave (Q-Sa). For assessing peak pulsed Doppler tissue imaging velocities, the calculation software package present in the echo machine was used. Evaluating peak systolic velocity, the initial peak that occurs during isometric contraction was ignored. All pulsed Doppler tissue imaging parameters were measured on 5–8 consecutive heart cycles by readers who were blinded to radionuclide ventriculography data, and the mean values were calculated. In addition to pulsed Doppler tissue imaging, conventional echocardiography was performed, including M-mode, two-dimensional, pulsed and colour Doppler echocardiography. Right ventricular and left ventricular diameters, and septal and posterior wall thickness values were measured according to the recommendations of the American Society of Echocardiography, and left ventricular ejection fractions were calculated using the biplane method according to the modified Simpson’s rule[12]. In healthy volunteers with no left ventricular wall motion abnormalities, the Teichholz formula for calculation of left ventricular ejection fractions was used[13].

To assess the day-to-day variability of tricuspid annular motion indexes, pulsed Doppler tissue imaging was repeated 24 h later in the same conditions in the first 10 subjects.

**First-pass radionuclide ventriculography**

First-pass radionuclide ventriculography was started within 2 h of standard and Doppler tissue echocardiog-
raphy in all patients. The investigation was performed after a rapid bolus injection of 740 MBq of 99m technetium (Tc) pertechnetate in a right antecubital vein with a polyethylene catheter, followed by 20 ml saline solution. First-pass radionuclide ventriculography was acquired in the 30 degree right anterior oblique projection, in the supine position, using a single photon emission computed tomography (SPECT) gamma camera (Prism 1000, Picker). The camera was equipped with a low-energy high resolution collimator, and a 15% window was centred at the 140-keV photopeak of 99m Tc. The bolus quality was tested using a time activity curve in the region of interest drawn on the superior caval vein. The study was acquired in the frame mode of 0.200 s per frame using a matrix size of 64 × 64 pixels and using a zoom factor of 1.48. Two hundred and fifty frames were collected. The first pass data were processed by a special curve analysis programme on an Odyssey computer. Right ventricular ejection fraction was calculated from end-diastolic and end-systolic counts using background corrected radionuclide time activity curves emanating from the right ventricular chamber.

Equilibrium gated radionuclide ventriculography SPECT

Immediately after the first pass radionuclide ventriculogram, equilibrium gated radionuclide ventriculography SPECT was performed in all patients. In vivo red blood cells were labelled with stannous pyrophosphate, followed by 740 MBq 99mTc pertechnetate within 30 min. Studies were acquired on a one detector SPECT camera (Prism 1000, Picker) connected to an Odyssey computer. The camera used a low-energy high resolution collimator, a step and shoot detector rotation with 32 projections, and 50 s of data collection per projection. We used a matrix size of 64 × 64 pixels and a zoom factor of 1.48, distributed over 12 cardiac frames. The projection data were pre-filtered with a standard two-dimensional Wiener filter. The projection was then reconstructed over 180 degrees (45 degree right anterior oblique projection to a left posterior oblique projection) with a filtered back-projection-ramp filter without attenuation corrections. Reconstructing each interval of the gated pool ventriculography SPECT study into a tomographic image allowed visual or quantitative estimation of a functional parameter such as myocardial wall motion. The image with the best separation of the left and right ventricle was edited and converted from a three-dimensional to a planar miltigate image. A time activity curve from right ventricular counts corrected for background activity was generated to calculate peak filling rate. The time to peak filling rate was measured from end-systole to the time of peak filling rate.

Right heart catheterization

Of 44 patients with heart failure, 32 underwent right heart catheterization within 24 h of echocardiography. Right heart catheterization was performed via the right subclavian vein. A 7F thermodilution catheter (model 131HF7, Baxter Healthcare Corporation, Irvine, CA, U.S.A.) was inserted through the right heart cavities and the pulmonary artery into the pulmonary capillary wedge position. Measurements of mean right atrial pressure, mean pulmonary artery pressure, and mean pulmonary capillary wedge pressure were obtained with patients in a supine position using a mechano-electrical transducer (model P23XL, Ohmeda Medical Devices Division, Oxnard, CA, U.S.A.) connected to a bedside monitor (model 90308, SpaceLabs, Inc., Redmond, WA, U.S.A.). 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 (l . min⁻¹ . m⁻² = cardiac output (l . min⁻¹)/body surface area (m²).

Statistical analysis

Clinical, echocardiographic, and right heart catheterization data are expressed as mean ± standard deviation for continuous variables or as a number (percent) for categoric variables. The patient and control group differences in continuous variables were tested using the Kruskal–Wallis test; the differences in categoric variables were evaluated using the Fisher exact test. To determine the relationship between Doppler tissue imaging, radionuclide ventriculography, and right heart catheterization variables, correlation coefficients and regression functions were used[14]. A P<0.05 was regarded as statistically significant. The cut-off values of Sa and Q-Sa, enabling the prediction of right ventricular systolic dysfunction (ejection fraction <45%) with the highest sensitivity and specificity, were identified by means of linear discriminant analysis[15]. The statistical package S-PLUS 4 (Math Soft, Inc., 1997) was used. Sensitivity and specificity were calculated as follows: sensitivity (%)=(true positive results/true positive+false negative results) × 100; specificity (%)=(true negative results/true negative+false positive results) × 100.

In the first 15 subjects, the Doppler tissue imaging parameters were evaluated from video recordings by two independent observers (J.M. and L.S.) to test inter-observer variability, and reassessed 30 days after the first measurement by one observer (J.M.) to test intra-observer variability. The differences in two evaluations of the same subjects are expressed as a mean ± standard deviation. Similarly, the day-to-day variability was determined as the mean difference ± standard deviation between two sets of measurements of the same patients in the interim of 24 h. For the assessment of variabilities, standard deviations are also expressed as the percent of the mean values of the first measurements.
Table 1  Clinical and standard echocardiographic data in patients with heart failure and in healthy control subjects

<table>
<thead>
<tr>
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<th>Patient group (n=44)</th>
<th>Control group (n=30)</th>
<th>P</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>49 ± 11</td>
<td>50 ± 16</td>
<td>ns</td>
</tr>
<tr>
<td>Men</td>
<td>36 (82%)</td>
<td>21 (70%)</td>
<td>ns</td>
</tr>
<tr>
<td>Heart rate (beats. min⁻¹)</td>
<td>76 ± 16</td>
<td>66 ± 12</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Systolic BP (mmHg)</td>
<td>118 ± 13</td>
<td>126 ± 14</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>LVDD (mm)</td>
<td>69 ± 10</td>
<td>46 ± 5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVDD (mm)</td>
<td>59 ± 10</td>
<td>29 ± 4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RVDD (mm)</td>
<td>35 ± 8</td>
<td>28 ± 4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Septum (mm)</td>
<td>10 ± 2</td>
<td>10 ± 1</td>
<td>ns</td>
</tr>
<tr>
<td>Posterior wall (mm)</td>
<td>10 ± 2</td>
<td>10 ± 1</td>
<td>ns</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>24 ± 7</td>
<td>66 ± 6</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data are expressed as a mean ± standard deviation or a number (percent); BP= blood pressure; LVDD= left ventricular end-diastolic diameter; LVSD= left ventricular end-systolic diameter; RVDD= right ventricular end-diastolic diameter; LVEF= left ventricular ejection fraction.

Table 2  Pulsed Doppler tissue imaging variables in patients with heart failure and in healthy control subjects

<table>
<thead>
<tr>
<th></th>
<th>Patient group (n=44)</th>
<th>Control group (n=30)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sa (cm. s⁻¹)</td>
<td>10.3 ± 2.6</td>
<td>15.5 ± 2.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Q-Sa (ms)</td>
<td>198 ± 34</td>
<td>171 ± 29</td>
<td>&lt;0.01</td>
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<tr>
<td>Ea (cm. s⁻¹)</td>
<td>10.8 ± 2.5</td>
<td>15.6 ± 3.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Aa (cm. s⁻¹)</td>
<td>15.0 ± 4.9</td>
<td>15.4 ± 4.5</td>
<td>ns</td>
</tr>
<tr>
<td>Ea/Aa</td>
<td>0.79 ± 0.27</td>
<td>1.15 ± 0.69</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Data are expressed as a mean ± standard deviation; Sa= peak systolic tricuspid annular velocity; Ea= peak early diastolic tricuspid annular velocity; Aa= peak late diastolic tricuspid annular velocity; Q-Sa= time from the onset of electrocardiographic QRS complex to the peak of systolic tricuspid annular velocity.

Results

Characteristics of the study groups

The baseline clinical and standard echocardiographic data of the patients and healthy volunteers are presented in Table 1. The groups were comparable in age, gender, and thickness values of the septum and posterior wall. Patients with congestive heart failure had an increase in heart rate, lower blood pressure, larger ventricular dimensions and markedly lower left ventricular ejection fraction.

Pulsed Doppler tissue imaging

Table 2 represents pulsed Doppler tissue imaging characteristics in patients with heart failure and in healthy control subjects. Both groups differed significantly in all variables compared, except for late diastolic velocity (Aa). Systolic (Sa) and early diastolic (Ea) velocities and Ea/Aa ratio were decreased in patients with heart failure, while the Q-Sa interval was prolonged. The Q-Sa cut-off value was Sa <11.5 cm. s⁻¹, as calculated by linear discriminant analysis, predicted right ventricular dysfunction (ejection fraction <45%) with a sensitivity of 90% and a specificity of 85%. All healthy volunteers exhibited Sa values exceeding this cut-off point (mean 15.5 ± 2.6 cm. s⁻¹, range 11.6 cm. s⁻¹ to 21.1 cm. s⁻¹). The Q-Sa >201 ms reached a sensitivity of only 47% and a specificity of 54% in predicting right ventricular dysfunction. There was a large overlap in Q-Sa values between patients with right ventricular dysfunction and healthy subjects.

First-pass radionuclide ventriculography and equilibrium gated radionuclide ventriculography SPECT results and their correlation with Doppler tissue imaging variables

Of 44 patients with heart failure, 31 (70%) exhibited right ventricular systolic dysfunction (ejection fraction <45%). The mean right ventricular ejection fraction was 36 ± 12% (range, 17% to 61%). Of right ventricular diastolic variables, the mean peak filling rate was 1.72 ± 0.73 EDV . s⁻¹ (range, 0.33 EDV . s⁻¹ to 3.4 EDV . s⁻¹), and the time to peak filling rate reached 134 ± 70 ms (range, 61 ms to 381 ms). In five patients, gated radionuclide ventriculography SPECT revealed regional right ventricular wall motion abnormalities. Figure 1 represents a significant correlation of Sa with right ventricular ejection fraction (r=0.648, P<0.001). Figure 2 demonstrates no significant correlation between Q-Sa and right ventricular ejection fraction (r=−0.204, P=ns). Similarly, there was no correlation between Ea and the peak filling rate (r=0.171) or the time to peak filling rate (r=0.008), and between Ea/Aa and the peak filling rate (r=−0.233) or the time to peak filling rate (r=0.283), respectively. The correlations did not significantly change after exclusion of five patients with regional right ventricular wall motion abnormality.

Right heart catheterization

Right heart catheterization variables reached the following values: mean right atrial pressure, 7 ± 5 mmHg; mean pulmonary artery pressure, 29 ± 10 mmHg; mean pulmonary capillary wedge pressure, 21 ± 10 mmHg; and cardiac index 2.2 ± 0.61 min⁻¹ m⁻². Because of a possible loading dependence of right ventricular function, the parameters derived from the tricuspid annular...
motion were correlated with the mean pulmonary artery pressure and the mean right atrial pressure. There was a significant negative correlation between Sa and mean pulmonary artery pressure \( (r = -0.354, P < 0.05) \). Sa did not correlate with mean right atrial pressure \( (r = 0.325) \). Q-Sa exhibited no relationship to mean pulmonary artery pressure \( (r = 0.119) \) or to the mean right atrial pressure \( (r = -0.312) \). Of the right ventricular diastolic function variables, only Aa correlated with the mean right atrial pressure \( (r = 0.486, P < 0.01) \), but not with the mean pulmonary artery pressure \( (r = -0.283) \). There were no correlations of Ea with the mean pulmonary artery pressure \( (r = 0.197) \) or with the mean right atrial pressure \( (r = -0.233) \). Similarly, Ea/Aa correlated neither with the mean pulmonary artery pressure \( (r = -0.095) \) nor with the mean right atrial pressure \( (r = 0.068) \).

Reproducibility
The intra-observer variability was \(-0.11 \pm 0.41 \text{ cm} \cdot \text{s}^{-1} \) (3.3%) for Sa, \(-0.25 \pm 0.52 \text{ cm} \cdot \text{s}^{-1} \) (4.1%) for Ea, \(-0.17 \pm 0.50 \text{ cm} \cdot \text{s}^{-1} \) (3.4%) for Aa, and \(-0.67 \pm 6.92 \text{ ms} \) (3.6%) for Q-Sa, respectively. The inter-observer variability was \(0.14 \pm 0.58 \text{ cm} \cdot \text{s}^{-1} \) (4.7%) for Sa, \(-0.13 \pm 0.89 \text{ cm} \cdot \text{s}^{-1} \) (7.1%) for Ea, \(-0.03 \pm 0.79 \text{ cm} \cdot \text{s}^{-1} \) (5.3%) for Aa, and \(2.01 \pm 15.93 \text{ ms} \) (8.2%) for Q-Sa, respectively. The day-to-day variability was \(-0.61 \pm 0.84 \text{ cm} \cdot \text{s}^{-1} \) (6.8%) for Sa, \(-0.51 \pm 1.33 \text{ cm} \cdot \text{s}^{-1} \) (10.5%) for Ea, \(-0.91 \pm 2.27 \text{ cm} \cdot \text{s}^{-1} \) (15.4%) for Aa, and \(2.4 \pm 25.43 \text{ ms} \) (13.1%) for Q-Sa, respectively.

Discussion
Doppler tissue imaging, as a method of evaluating systolic and diastolic myocardial function, has been validated in numerous studies\(^{16-25}\). Most of them measured systolic and diastolic myocardial velocities to assess regional systolic and diastolic myocardial function. In addition to evaluating myocardial velocities, this method also enables mitral and tricuspid annular velocities to be recorded. For the right ventricle, the determination of velocities of tricuspid annular motion may provide a new tool for assessing systolic and diastolic function in patients with heart failure.

Mitral and tricuspid annular motion as an index of myocardial function
The idea to use mitral or tricuspid annular motion to evaluate myocardial function is not new. Animal experiments have demonstrated that the position of the apex during the cardiac cycle is relatively stable\(^{26}\) and both mitral and tricuspid annular planes move toward the apex in systole and away from the apex in diastole, as a consequence of contraction and relaxation of longitudinal myocardial fibres. While the left ventricle...
jects blood primarily by diminishing the diameter of the chamber with some shortening of its long axis, the primary function of the right ventricular free wall is to move the atrioventricular valve ring towards the apex[26]. The range of excursions of the mitral[27–29] or tricuspid[4,30] annulus measured in mm by two-dimensional or M-mode echocardiography has been shown to reflect the systolic function of both ventricles. Kaul et al[4] demonstrated a close correlation between the tricuspid annular plane systolic excursion, measured by means of 2-D echocardiography, and right ventricular ejection fraction, obtained by radionuclide angiography. The clinical importance of assessing annular excursions is documented by reports by Willenheimer et al[31] and Karatasakis et al[32], who confirmed the relationship of both mitral and tricuspid annular excursion to mortality in patients with heart failure. Thus assessment of tricuspid annular motion may clearly be used in the clinical setting. Recently, pulsed Doppler tissue imaging enabled the direct measurement of annular velocities[7–9,21,33,34]. As compared with the evaluation of annular excursions, the Doppler tissue imaging approach is quicker, simpler, and measurements can be made on-line within a very short time interval, of approximately 10–15 s. In addition, this method enables both systolic and diastolic functional parameters to be measured simultaneously. Vinereanu et al[33] have demonstrated good reproducibility on acquiring and measuring tricuspid annular velocities recorded by Doppler tissue echocardiography, which corresponds to our results, especially for the peak systolic velocity, which appeared to be the most clinically useful parameter. Tricuspid annular velocities may be widely used clinically because they can be obtained in nearly all patients[34], and systolic velocities are independent of age[34]. In our study, Doppler tissue image recording of tricuspid annular velocities was of good quality in 43 of 45 consecutive patients (96%). While mitral annular velocities have been used to assess left ventricular systolic[33,36] and diastolic[9] function, reports on the effect of right ventricular contraction and relaxation on tricuspid annular velocities are lacking. In our study, there were significant differences in systolic and diastolic Doppler tissue imaging parameters between patients with heart failure and healthy subjects. Of systolic Doppler tissue imaging indexes, Sa offered obvious clinical benefit enabling the prediction of right ventricular dysfunction with a good sensitivity of 90% and a specificity of 85%. The Q-Sa interval, although significantly prolonged in patients with heart failure, did not offer prediction of right ventricular dysfunction with an acceptable sensitivity and specificity. The clinical importance of indexes of right ventricular diastolic function has to be validated in future studies.

Correlation of tricuspid annular velocities with first-pass radionuclide ventriculography and equilibrium gated radionuclide ventriculography SPECT results

Of right ventricular systolic function variables, a significant correlation was found between Sa and right
ventricular ejection fraction. The reason for a weak and insignificant correlation between Q-Sa and right ventricular ejection fraction may have been caused by conduction abnormalities (left or right bundle branch block on electrocardiography) which were very common and occurred in 21 (48%) patients with heart failure. Exclusion of such patients could improve this correlation, however, at the cost of marked patient selection. Right ventricular diastolic function variables identified by Doppler tissue imaging (Ea and Ea/Aa ratio) correlated neither with the peak filling rate nor with the time to peak filling rate. Similar weak or no correlations were described between the peak early diastolic velocities of the mitral annulus and the parameters of left ventricular transmural filling (peak early diastolic transmitral velocity and the ratio of early to late diastolic transmitral velocities), especially in patients with elevated pulmonary capillary wedge pressure[37,38]. Several reports studying peak early diastolic velocities of basal myocardial segments or of the mitral annulus have demonstrated a significant and steady decrease with progressive diastolic dysfunction[37,39] without the reversing effect caused by pre-load compensation with an increase in left ventricular filling pressure. In contrast, the left ventricular filling indexes change in a parabolic or U-shaped pattern during the progression from normal to severe diastolic dysfunction[40-43]. Even if these reports studied the left ventricle, there is a strong supposition that the analogical principles of ventricular filling and of annular movement are also valid for the right ventricle. Thus the difference in preload-dependence of correlated variables most likely accounts for the lack of correlation of diastolic indexes derived from Doppler tissue imaging and equilibrium gated radionuclide ventriculography SPECT.

With respect to the relationship of systolic tricuspid annular motion variables to the right atrial and pulmonary artery pressures, a significant inverse correlation was demonstrated between Sa and the pulmonary artery pressure. This is in accordance with previous reports describing afterload dependence of the right ventricular systolic function, mostly represented by ejection fraction[44,45].

**Clinical implications**

This study demonstrates the utility of Doppler tissue imaging of tricuspid annular motion for the non-invasive evaluation of right ventricular function. The peak systolic tricuspid annular velocity significantly correlates with the right ventricular ejection fraction assessed by first-pass radionuclide ventriculography, and its value <11.5 cm·s⁻¹ enables right ventricular dysfunction to be predicted (ejection fraction <45%) with a good sensitivity of 90% and a specificity of 85%. The method has many advantages. It is very quick, non-invasive, inexpensive, and widely available. Good quality recordings of tricuspid annular velocities can be obtained in more than 95% of patients. However, like other parameters of right ventricular function, the peak systolic tricuspid annular velocity is load-dependent.

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**References**

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