Comparison of the proximal flow convergence method and the jet area method for the assessment of the severity of tricuspid regurgitation

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Aims To compare the value of the proximal flow convergence method and the jet area method for the determination of the severity of tricuspid regurgitation.

Methods and Results The proximal isovelocity surface area radius and the jet area/length were measured in 71 consecutive patients with angiographically graded (grade 0/I–III) tricuspid regurgitation. Rank correlation coefficients with the angiographic grade were 0.71 (P < 0.001) for the proximal isovelocity surface area radius (aliasing border of 28 cm s⁻¹), 0.66 (P < 0.001) for the jet area, and 0.63 (P < 0.001) for the jet length. The proximal isovelocity surface area radius was significantly correlated with the jet area/length (correlation coefficients 0.82/0.77, P < 0.001). Correct differentiation between mild to moderate (grade I–II) and severe (grade III) tricuspid regurgitation was achieved in 62 of 71 patients (87%) by means of the proximal isovelocity surface area radius, in 61 of 71 (86%) by the jet area, and in 62 of 71 (87%) by the jet length. Grade III tricuspid regurgitation was not identified in five of 21 patients (24%) by means of the proximal isovelocity surface area radius, in six of 21 (29%) by the jet area, and in seven of 21 (33%) by the jet length.

Conclusion The flow convergence method and the jet area method are of similar value for the determination of the severity of tricuspid regurgitation. Both methods differentiated mild to moderate from severe tricuspid regurgitation in most patients. However, underestimation of severe tricuspid regurgitation in 20–30% of the cases represents a serious limitation of both methods.

Key Words: Tricuspid regurgitation, colour flow Doppler imaging, proximal flow convergence region, regurgitant jet area.

Introduction

Determination of the severity of tricuspid regurgitation is important since it influences the outcome of patients after mitral valvuloplasty or mitral valve surgery and determines in whom tricuspid surgery is considered necessary in the latter group.

Promising results were reported for the quantification of tricuspid regurgitation from studies using colour Doppler imaging of the regurgitant jet area. However, the quantification of valvular regurgitation by means of the jet area method has several methodological problems.

The existence of a flow convergence region proximal to a restrictive orifice has been demonstrated by colour flow Doppler imaging in experimental and clinical studies. Colour flow Doppler imaging of the proximal flow convergence region has proven to be reliable in the quantification of mitral as well as tricuspid regurgitation.

One study compared the value of parameters of the proximal flow convergence region and of the regurgitant jet in order to quantify tricuspid regurgitation. However, this study did not investigate the widely used jet parameters, jet area and jet length. It is clinically significant to determine which of the (Doppler) echocardiographic methods are most suitable to measure severity of tricuspid regurgitation. Therefore, our study compared the value of the radius of the proximal flow convergence region (proximal isovelocity surface area radius) with that of the jet area and jet length for the determination of the severity of tricuspid regurgitation.
Methods

Patients

Seventy-one patients (29 men, 42 women; age 60 ± 13 years, range 23–76 years) with tricuspid regurgitation (verified by a typical continuous-wave Doppler signal) were consecutively included in the study. One patient had tricuspid regurgitation due to a prolapse of the septal tricuspid leaflet without any abnormality of the left heart. The remaining 70 patients suffered from: mitral valve failure (39), mitral valve prosthesis (4), aortic valve failure (12), coronary heart disease (11), atrial septal defect (3), primary pulmonary hypertension (2), dilatative cardiomyopathy, constrictive pericarditis and pulmonary valve stenosis (one patient each). Six of the 70 patients had thickened leaflets of the tricuspid valve. None patient had a tricuspid stenosis. Twenty-five patients were in sinus rhythm, 46 patients had atrial fibrillation. All patients gave informed written consent.

Cardiac catheterization

The severity of tricuspid regurgitation was determined by right ventricular angiography that was routinely performed during cardiac catheterization. Grading was according to the criteria of Suzuki et al., after injection of 35 ml Solvatrel® at 18 ml . s⁻¹ into the right ventricle using a 6F pigtail catheter: grade I (mild), grade II (moderate); grade III (severe) tricuspid regurgitation. The angiograms were interpreted by two independent observers. In 10 patients in whom the grading of the two observers differed by one grade, grading was determined by a third independent observer. A distinct right atrial V wave was defined as prominent if it exceeded 10 mmHg.

Echocardiographic examination

All patients were examined by the same experienced investigator using a 2.5 MHz transducer of a phased array sector scanner (Toshiba SSH 160A, Toshiba Corp., Tokyo, Japan) from the apical four-chamber view and the parasternal view (short-axis view, right ventricular inflow view). The view with the maximal colour Doppler measurements was selected. Colour flow Doppler imaging was performed at a pulse repetition frequency of 3 kHz and a scanning rate of 13 frames . s⁻¹. The wall filter was 600 Hz. The optimal gain setting was defined as the maximal gain level possible without the introduction of signals outside the flow areas. Continuous-wave Doppler spectra of the tricuspid regurgitant jet were obtained. The intensity of the Doppler signal was graded against the tricuspid forward flow signal using a three-grade scale: signal of low intensity; signal of moderate intensity clearly distinguishable from background noise; signal of strong intensity that was (nearly) equal to that of the forward flow signal. A rapid fall of the velocity of the continuous-wave Doppler signal through the latter half of systole due to a rapid decrease in the pressure gradient between the right ventricle and right atrium was used to indicate severe tricuspid regurgitation. The difference in the systolic pressure between the right ventricle and right atrium was calculated using the maximum velocities of the Doppler spectra. The diameter of the tricuspid valve annulus (mm) was measured from an apical four-chamber view as the maximal late systolic diameter between the insertion points of the septal and anterior tricuspid leaflets. The dimension of the right ventricle (mm) was obtained from VHS videotapes. An electrocardiogram was registered simultaneously. The echocardiographic examination was performed before cardiac catheterization within a time interval of 24 h in 55 patients and 48 h in 16 patients. Medication remained unchanged between both diagnostic procedures.

Colour Doppler measurements

A frame-by-frame analysis was performed to obtain the maximum extension of the proximal isovelocity surface areas (PISAs) in the flow convergence region on the right ventricular side of the tricuspid valve for blood velocities of 28 and 41 cm . s⁻¹ (indicated by the corresponding first aliasing borders) (Fig. 1). This was obtained by zero-shifting, which alters the colour reversal from blue to yellow for flow away from the transducer. The proximal isovelocity surface area radius (PISA radius) was defined as the largest distance (mm) between the aliasing border and the regurgitant orifice measured parallel to the direction of the Doppler beam. If the exact location of the regurgitant orifice was not possible, the level of the tricuspid valve leaflets during systole was used as a reference. Flattening of the proximal isovelocity surface areas close to the regurgitant orifice leads to an underestimation of the PISA radius, particularly in tricuspid regurgitation, where the alias velocities of 28 and 41 cm . s⁻¹ are a significant proportion of the flow velocity at the regurgitant orifice. A correction was applied according to Rivera et al.,. The PISA radii were multiplied by (vₒ/(vₒ–vₐ))¹/². vₒ was derived from continuous-wave Doppler. The regurgitant jet area within the right atrium was measured by planimetry from the frame with the maximal jet area during systole (Fig. 1). The jet area included the aliased signals, surrounded by contiguous non-disturbed velocities coded in blue. The area of the right atrium was determined in a representative frame from the same view during the same portion of systole. The jet area was expressed as an absolute value (cm²) and as a percentage of the right atrial area. The jet length was defined as the maximum distance (cm) of the regurgitant signals from the tricuspid orifice. Jets were regarded as eccentric if they were in close contact with one of the tricuspid valve leaflets.
behind the regurgitant orifice and remained in close contact with one of the right atrial walls. Jets which were initially directed into the right atrial cavity were defined as central. This differentiation of jet morphology was according to that proposed by Enriquez-Sarano et al. in mitral regurgitation.[25].

Variability of colour Doppler measurements
Thirty-two patients were randomly selected; their videotapes were analysed again by the primary investigator >6 months after the first examination and by a second investigator.

Statistical analysis
Values are given as mean (SD). For comparison of paired data the Wilcoxon signed rank test was used. Unpaired data were analysed by the K ruskal-Wallis test followed by the Mann-Whitney test. Correction for multiple testing was done according to Bonferroni. The correlation between angiographic grading and the colour Doppler measurements was assessed according to the Spearman’s rank correlation method. The PISA radii and the parameters derived from the regurgitant jet were correlated by using linear regression analysis. Coefficients of variation were calculated to determine intra-observer and inter-observer variability. A P-value of <0.05 was considered significant.

Results

Haemodynamic data
The heart rate was 80 (16) min⁻¹ during echocardiography and during cardiac catheterization (ns). Systolic blood pressure was 130 (29) mmHg during echocardiography and 132 (23) mmHg during cardiac catheterization (ns). Diastolic blood pressure was higher during echocardiography (76 (13) vs 71 (13) mmHg, P <0.01). The systolic pressure difference between the right ventricle and the right atrium derived from continuous-wave Doppler was 35 (10) mmHg and derived from cardiac catheterization 33 (13) mmHg (ns). The right ventricular end-diastolic pressure was 9 (3) mmHg in grade 0/I, 10 (5) mmHg in grade II, and 13 (6) mmHg in grade III tricuspid regurgitation (ns). A prominent right atrial V wave could be detected in six of 26 patients with grade 0/I, in 11 of 24 patients with grade II, and in 15 of 21 patients with grade III tricuspid regurgitation. The V wave was 14 (2) mmHg in grade 0/I, 16 (4) mmHg in grade II, and 20 (9) mmHg in grade III tricuspid regurgitation (ns).

Angiographic grading
The severity of tricuspid regurgitation was assessed by cardiac catheterization as grade I in 22, grade II in 24,
and grade III in 21 patients. In four patients there were no angiographic signs of tricuspid regurgitation (grade 0).

Echocardiographic measurements

The intensity of the regurgitant signal derived from continuous-wave Doppler was low or moderate in all patients with grade 0/I–grade II tricuspid regurgitation. A signal of strong intensity was present in seven of the 21 patients with grade III tricuspid regurgitation. A rapid fall of the velocity of the continuous-wave Doppler signal through the latter half of systole was observed only in two of our patients. Both had grade III tricuspid regurgitation.

The systolic diameter of the tricuspid valve annulus was 28 (5) mm in grade 0/I, 31 (5) mm in grade II, and 35 (4) mm in grade III tricuspid regurgitation (P < 0.01). A tricuspid valve annulus ≥ 34 mm was present in five of the 50 patients with grade 0/I–grade II tricuspid regurgitation, and in 15 of the 21 patients with grade III tricuspid regurgitation. The right ventricular dimension derived from M-mode was 29 (5) mm in grade III tricuspid regurgitation. The right ventricular tricuspid regurgitation, and in 15 of the 21 patients with grade III tricuspid regurgitation. The right ventricular dimension derived from M-mode was 29 (5) mm in grade III tricuspid regurgitation. The right ventricular dimension derived from M-mode was 29 (5) mm in grade 0/I, 31 (5) mm in grade II, and 35 (4) mm in grade III tricuspid regurgitation.

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The corrected PISA radius (see Methods) for 28 cm s⁻¹ flow velocity (alias velocity) was 3·8 (2·6) mm (grade 0/I), 7·0 (2·4) mm (grade II), and 11·1 (5·0) mm (grade III) (P < 0·001). The corresponding values for the corrected PISA radius for 41 cm s⁻¹ flow velocity were 2·7 (1·9) mm, 4·8 (2·0) mm, and 7·3 (3·0) mm (P < 0·001). The rank correlation coefficient between the angiographic grade and the corrected PISA radius for 28/41 cm s⁻¹ flow velocity was 0·72/0·63 (P < 0·001). The accuracy of the differentiation of grade 0/I–grade II from grade III tricuspid regurgitation was 87% for the corrected PISA radius for 28 cm s⁻¹ flow velocity (cut-off value 9·0 mm) and 86% for the corrected PISA radius for 41 cm s⁻¹ flow velocity (cut-off value 7·0 mm).

Ventricular dimensions and angiographic grading

Intra-observer variability: coefficients of variation were 10·9% for the PISA radius for a flow velocity of 28 cm s⁻¹, 15% for the PISA radius for a flow velocity of 41 cm s⁻¹, 7·2% for the jet area, and 6·9% for the jet length. Inter-observer variability: coefficients of variation were 10·8% for the PISA radius for a flow velocity of 28 cm s⁻¹, 14·2% for the PISA radius for a flow velocity of 41 cm s⁻¹, 7·6% for the jet area, and 7·0% for the jet length.

Table 1 Values of the colour Doppler measurements for the different angiographic grades of tricuspid regurgitation

<table>
<thead>
<tr>
<th>Angiographic grade</th>
<th>0/I</th>
<th>II</th>
<th>III</th>
</tr>
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<tbody>
<tr>
<td>r₁₂₈</td>
<td>3·6</td>
<td>6·6</td>
<td>10·6</td>
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<tr>
<td>r₄₁₈</td>
<td>2·5</td>
<td>4·3</td>
<td>6·8</td>
</tr>
<tr>
<td>J</td>
<td>2·8</td>
<td>5·5</td>
<td>10·6</td>
</tr>
<tr>
<td>JL</td>
<td>2·5</td>
<td>3·7</td>
<td>5·3</td>
</tr>
<tr>
<td>JA %</td>
<td>14</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

| Pₖₛₜ | 1.000 | 0.001 |

JA = jet area (cm²); JA% = relation of jet area to left atrial area (%); JL = jet length (cm); r₁₂₈ = PISA radius for the flow velocity of 28 cm s⁻¹ (mm); r₄₁₈ = PISA radius for the flow velocity of 41 cm s⁻¹ (mm); 0/I vs II, 0/I vs III, and II vs III differed significantly for all colour Doppler measurements except II vs III for JA %. A P-value of < 0·0125 was considered significant. Pₖₛₜ = P value derived from the Kruskal–Wallis test.
Discussion

The results of this study indicate that the visualization of a flow convergence region and of a regurgitant jet in the right atrium by colour flow Doppler imaging is a sensitive method for the diagnosis of tricuspid regurgitation. These data agree with previously published data\[6,7,18\]. In four of our patients, a flow convergence region and/or a regurgitant jet could be visualized without angiographic evidence of tricuspid regurgitation. This was probably due to the limited sensitivity of angiography\[6,7\].

A quantitative assessment of tricuspid regurgitation may be possible by means of the flow convergence method\[18\], which cannot be obtained by the jet parameters used in this study. However, if one accepts semiquantification of tricuspid regurgitation adequate in the clinical setting\[2,3\], there is no crucial advantage of one of the methods over the others investigated in our study. The rank correlation coefficients between the PISA radii and the angiographic grade were similar to those between the jet parameters and the angiographic grade. PISA radii and jet parameters were significantly correlated. Both methods differentiated mild to moderate from severe regurgitation in a comparable portion of the patients. This is in contrast to data derived from patients with mitral regurgitation, in whom the flow convergence method was clearly superior for semiquantification\[17,26\]. This study was not designed to compare data between patients with tricuspid regurgitation and those with mitral regurgitation. Nevertheless, some reasons have to be discussed that may contribute to these different results in tricuspid and mitral regurgitation. The correlation between the PISA radius and the angiographic grade appeared weaker in tricuspid than in mitral regurgitation\[13,26\]. The flow convergence method provided a less accurate differentiation of mild to moderate from severe tricuspid regurgitation than that obtained in mitral regurgitation\[17,26\]. Severe tricuspid regurgitation was underestimated in a considerable number (5/7 of 21) of our patients. This represents a serious limitation of the flow convergence method. The quality of echocardiographic imaging was limited in two of these patients and moderate in one. Poor imaging quality obviously hampered the flow convergence method. The localization of the regurgitant orifice, for which a displacement beyond the level of the annulus towards the apex has been demonstrated in tricuspid regurgitation\[27\], may have been less accurate for the tricuspid valve than for the mitral valve. This agrees with a higher intra- and inter-observer variability of the PISA radii in tricuspid regurgitation than previously reported in mitral regurgitation\[13,26\]. The localization of the regurgitant orifice remains a crucial problem of the flow convergence method\[28,29\]. Obviously, the flattening of the proximal isovelocity surface areas close to the

![Figure 2](image-url)
Regurgitant orifice did not significantly contribute to our results. Correction of the PISA radii according to Rivera et al.\[^{18}\] did not improve either the rank correlation between the PISA radii and the angiographic grade or the accuracy of the flow convergence method concerning the correct differentiation between grade 0/I–II and grade III tricuspid regurgitation. The number of patients in whom severe tricuspid regurgitation was underestimated remained unchanged.

The correlation between the jet parameters and the angiographic grade was closer in tricuspid regurgitation than in mitral regurgitation.\[^{26}\] Rivera et al. found a good correlation between the proximal size of the regurgitant jet and other measures of the severity of tricuspid regurgitation.\[^{19}\] The differentiation between mild to moderate and severe valvular failure was more accurate by means of the jet area method than traditionally observed in mitral regurgitation.\[^{17,26}\] Due to the high incidence of functional tricuspid regurgitation without an intrinsic valve disease (e.g., a valve prolapse) most of our patients had a centrally directed regurgitant jet irrespective of the severity of tricuspid regurgitation. This has probably made the jet area method more suitable for semiquantification of tricuspid regurgitation than of mitral regurgitation. However, the jet area method failed to identify severe tricuspid regurgitation in about 30% of patients.

**Figure 3** Comparison of the jet area in the right atrium with the angiographic grade of tricuspid regurgitation. Open symbols = eccentric jets; solid symbols = centrally directed jets; solid line = cut-off value at 8 cm\(^2\) for the differentiation of grades 0/I–II from grade III tricuspid regurgitation.

**Table 2** Rank correlation coefficients between angiographic grade and the different parameters derived from the proximal flow convergence region and the regurgitant jet.

<table>
<thead>
<tr>
<th></th>
<th>(r_{v28})</th>
<th>(r_{v41})</th>
<th>JA</th>
<th>JL</th>
<th>JA%</th>
</tr>
</thead>
<tbody>
<tr>
<td>all</td>
<td>0.71*</td>
<td>0.64*</td>
<td>0.66*</td>
<td>0.63*</td>
<td>0.55*</td>
</tr>
<tr>
<td>cen</td>
<td>0.73*</td>
<td>0.66*</td>
<td>0.70*</td>
<td>0.68*</td>
<td>0.61*</td>
</tr>
<tr>
<td>ecc</td>
<td>0.45**</td>
<td>0.38</td>
<td>0.41**</td>
<td>0.55**</td>
<td>0.23</td>
</tr>
</tbody>
</table>

**Table 3** Correlation coefficients between measurements of the proximal flow convergence zone and the regurgitant jet.

<table>
<thead>
<tr>
<th></th>
<th>JA</th>
<th>JL</th>
<th>JA%</th>
</tr>
</thead>
<tbody>
<tr>
<td>(r_{v28})</td>
<td>0.82*</td>
<td>0.77*</td>
<td>0.63*</td>
</tr>
<tr>
<td>(r_{v41})</td>
<td>0.77*</td>
<td>0.74*</td>
<td>0.61*</td>
</tr>
</tbody>
</table>

all = whole study group; cen = patients with centrally directed jets; ecc = patients with eccentric jets; JA = jet area; JA% = relation of jet area to left atrial area; JL = jet length; \(r_{v28}\) = PISA radius for the flow velocity of 28 cm s\(^{-1}\); \(r_{v41}\) = PISA radius for the flow velocity of 41 cm s\(^{-1}\). *\(p<0.001\). **\(p<0.05\).
the patients. This means a limitation of the jet area method which is important under clinical conditions. The eccentricity of the regurgitant jet remains one fundamental problem of the jet area method\textsuperscript{10,25}. Three of the six patients, in whom grade III tricuspid regurgitation was underestimated by the jet area, had an eccentric jet. Weak correlations with the angiographic grade were obtained for all Doppler parameters in the patients with an eccentric jet. The small number of these patients (n = 17) may have favoured an accidental broad overlap even for the PISA radii between the different angiographic grades.

It has to be emphasized that angiographic grading was a qualitative (at most semi-quantitative) reference method, whereas the proximal flow convergence method as well as the jet area method provided a quantitative parameter of the severity of tricuspid regurgitation (such as the PISA radius or the jet area). Angiography might, therefore, have failed to detect an advantage of one colour Doppler method over another, even if present.

The evaluation of further echocardiographic parameters of the severity of tricuspid regurgitation may, in part, overcome the problem of underestimation of severe tricuspid regurgitation by the colour Doppler methods investigated. In two of the five/six patients, in whom the proximal flow convergence method/jet area method failed to identify severe tricuspid regurgitation, the systolic tricuspid valve annulus exceeded 34 mm. A diameter of the systolic tricuspid valve annulus $\geq$ 34 mm may indicate severe tricuspid regurgitation, even in the presence of a small PISA radius or jet area. The dimension of the right ventricle was not of any value for the differentiation between grade 0/I–II and grade III tricuspid regurgitation in our patients. Strong intensity of the regurgitant signal or a rapid decrease in the velocity of the continuous-wave Doppler signal through the latter half of systole were highly specific, but hardly sensitive for the diagnosis of severe tricuspid regurgitation. None of our patients, in whom severe tricuspid regurgitation was underestimated by the colour Doppler methods, had a strong regurgitant signal or a rapid decrease of the velocity of the Doppler signal during late systole. Hepatic vein flow and tricuspid valve forward flow may also be used in addition to colour Doppler measurements in order to improve the echocardiographic assessment of the severity of tricuspid regurgitation. However, only of these parameters was evaluated in this study.

**Limitations**

A serious problem of this study evaluating the value of different colour Doppler methods for the determination of the severity of tricuspid regurgitation is the lack of a criterion standard for quantification. As discussed above, angiography is a qualitative (semi-quantitative) reference method. Furthermore, angiographic grading is influenced by several factors including arrhythmias, volume and rate of injection of the contrast agent, size of the right atrium, and subjective interpretation of the angiograms\textsuperscript{30}. The induction or aggravation of tricuspid regurgitation by the cardiac catheter interfering with valve closure is considered the main limitation of angiography\textsuperscript{31,32}. There was no prominent right atrial V wave in two of the patients with angiographic grade III tricuspid regurgitation, in whom the proximal flow convergence method as well as the jet area method failed to identify severe regurgitation. It is possible that the limited accuracy of the angiographic grading of tricuspid regurgitation influenced our results. However, more recent studies demonstrated neither an induction nor a significant aggravation of regurgitation by a catheter across the tricuspid valve\textsuperscript{28,33}. We have chosen angiography as the reference method since it is still widely accepted for the grading of tricuspid regurgitation and can be regarded as helpful for deciding whether tricuspid surgery is necessary in an individual patient or not\textsuperscript{31}.

Additionally, even though angiographic grading is an imperfect reference method for the determination of the severity of tricuspid regurgitation it does not necessarily falsify the comparison of the two colour Doppler methods, since the results of both were affected in the same way.

A further drawback of our study is that echocardiography and cardiac catheterization were not performed simultaneously. Altered haemodynamic conditions may have changed the severity of tricuspid regurgitation between both diagnostic procedures. Furthermore, changes in right ventricular pressure may have altered the jet dimensions. However, only the diastolic blood pressure differed slightly between echocardiography and cardiac catheterization. The remaining haemodynamic parameters including the systolic pressure difference between right ventricle and right atrium remained constant.

**Conclusions**

In contrast to data obtained in mitral regurgitation, the flow convergence method and the jet area method were of similar value for the determination of the severity of tricuspid regurgitation. Both methods provided a correct differentiation between grade 0/I–II from grade III tricuspid regurgitation in >80% of the patients. However, underestimation of severe tricuspid regurgitation in a considerable number of our patients seriously limited the clinical value of both methods. The use of further echocardiographic parameters in addition to the colour Doppler parameters may improve the assessment of the severity of tricuspid regurgitation.

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The proximal flow convergence method and the jet area method in severe tricuspid regurgitation


[27] N e g o d e M, S h a m h e n t a l E, P a d i a l L R, V a z q u e z d e P r a d a J, W ey m a n A E, L e v i n A R A. Determinants of functional tricuspid regurgitation in incomplete tricuspid valve closure: Doppler color flow study of 109 patients. J Am Coll Cardiol 1994; 24: 446–53.


