Catheter-Induced Tricuspid Regurgitation*  
Incidence and Clinical Significance  
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The incidence and severity of catheter-induced tricuspid regurgitation has not been studied extensively. Given the frequency with which right heart catheters are employed to measure cardiac output, it is important to know whether the severity of catheter-induced tricuspid regurgitation is sufficient to invalidate the measurement of thermodilution cardiac output. Accordingly, the purpose of the present prospective study was to determine the incidence and severity of catheter-induced tricuspid regurgitation in 25 men (mean age, 58.1 ± 1.4 years) using Doppler ultrasound. The tricuspid valve was interrogated from two orthogonal views using pulsed-wave and color flow Doppler, either in the presence or absence of a 7-French catheter across the tricuspid valve. The severity of catheter-induced tricuspid regurgitation was graded semiquantitatively using a validated scoring system. Pulsed-wave Doppler studies showed that the incidence of catheter-induced tricuspid regurgitation was 48 percent, and that the average tricuspid regurgitation score increased from 0.41 ± 0.16 to 0.61 ± 0.17 (p<0.01). Color flow Doppler studies showed similar findings. Further, the incidence of catheter-induced tricuspid regurgitation was not related to the patient's underlying hemodynamic status or right ventricular geometry. In conclusion, this study shows for the first time that the quantitative extent of catheter-induced tricuspid regurgitation is small, and is therefore unlikely to be important clinically, particularly with regard to the assessment of thermodilution cardiac output.  

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A number of studies have shown that the presence of a catheter across a cardiac valve will lead to functional incompetence of that valve, even in the absence of elevated intracardiac pressures, abnormal ventricular geometry, or underlying anatomic abnormalities of the valve.1-9 Thus far, however, the incidence of catheter-induced tricuspid regurgitation has been studied less extensively.6-9 More surprising, perhaps, is the observation that the severity of catheter-induced tricuspid regurgitation has not yet been quantified in previous studies. Given the frequency with which right heart catheters are employed to measure cardiac output in intensive care units, operating rooms, and cardiac catheterization laboratories, it would appear to be important to not only determine the incidence of catheter-induced regurgitation, but also to quantify the severity of catheter-induced tricuspid regurgitation. That is, if right heart catheterization led to significant tricuspid regurgitation in certain patients, this might in turn have an adverse effect on the calculation of the thermodilution cardiac output. Accordingly, the purpose of the present prospective study was to use Doppler ultrasound to determine (1) the incidence of catheter-induced tricuspid regurgitation and (2) to quantify the severity of any catheter-induced tricuspid regurgitation.

METHODS

Patient Population

This prospective study consisted of 27 male patients undergoing diagnostic right heart catheterization. Two patients were excluded from the final analysis because of technically inadequate Doppler studies; however, no patients were systematically excluded from this study. The final patient population consisted of 25 male patients, aged 58 ± 1.4 years, who were undergoing diagnostic right heart catheterization for the following reasons: assessment of volume status in 12 patients, assessment of left-sided valvular heart disease in five patients, assessment of coronary heart disease in seven patients, and assessment of pulmonary artery pressures in one patient. No patient in this study had a permanent right ventricular endocardial pacemaker at the time of the study.

Noninvasive Studies

Two-dimensional echocardiographic, pulsed-wave, and color flow Doppler studies were performed using a machine (Hewlett-Packard 77020A) equipped with a medium-focus 2.5-MHz transducer. The tricuspid valve was interrogated using both the parasternal long-axis right ventricular inflow view and the apical four-chamber view. All recordings were performed during quiet respiration with the patient supine or in a 20° to 40° left lateral decubitus position. Throughout these studies, care was taken to maintain the same instrument settings for each patient studied. Color flow gain was adjusted from the highest level downward until background noise disappeared. Images were recorded on 1/2-inch VHS videotape for subsequent analysis. Interpretation of the resulting information was performed by two experienced observers; initially discordant readings were resolved by consensus opinion.

Doppler Echocardiography: The severity of tricuspid regurgitation was assessed by pulsed-wave Doppler using a modification of the semiquantitative method of Miyatake et al., wherein the maximal distance of the regurgitant jet from the tricuspid valve annulus is expressed in the following manner: 0 = no detectable regurgitation; +0.5 = trace regurgitation, defined as a flow disturbance confined to the leaflets; +1 = a flow disturbance extending beyond the leaflets but less than 1.5 cm into the right
atrium; + 2 = a flow disturbance extending from 1.5 to 3.0 cm into the right atrium; + 3 = a flow disturbance extending from 3.0 to 4.5 cm into the right atrium; and + 4 = a flow disturbance extending greater than 4.5 cm into the right atrium. To provide a more accurate assessment of the severity of catheter-induced regurgitation, the pulsed-wave Doppler scores obtained from the parasternal and apical windows were first summed and then divided by the number of adequate views obtained. The "average" tricuspid regurgitation score thus obtained has the major advantage of combining Doppler information gathered from two orthogonal views, as opposed to information gathered from a single tomographic plane.

The severity of tricuspid regurgitation was assessed by color flow Doppler using a modification of the semiquantitative method of Miyatake et al,11 wherein the maximal distance of the regurgitant jet from the tricuspid valve annulus is expressed in a manner identical to that described above for the pulsed-wave Doppler examination. The resulting color flow Doppler scores from each acoustic window were then summed, as described for the pulsed-wave Doppler studies, to provide an "average" color flow Doppler score.

2-D Echocardiography: All measurements were performed using the trailing-edge-to-leading-edge convention. Anatomic measurements of the dimension of the right atrial annulus were obtained from the apical four-chamber and parasternal long-axis view of the right ventricular inflow tract. Linear measurements of the major and minor axes of the right ventricle were obtained from the apical four-chamber. The long-axis of the right ventricle was defined as the maximal distance from the tip of the apex to the midpoint of the tricuspid valve annulus. The mid right ventricular minor axis was defined by a line drawn perpendicular to and bisecting the right ventricular long axis.

Hemodynamic Studies

The severity of catheter-induced regurgitation was determined following flotation of a 7-French Swan-Ganz catheter into the main pulmonary artery from the femoral (seven patients), subclavian (one patient), or internal jugular veins (17 patients). The time interval between the echocardiographic/Doppler study with and without an indwelling right heart catheter was 1.5 ± 0.3 days. Following insertion of the catheter, a minimum of at least 15 minutes was allowed before performing echocardiographic measurements, to permit the catheter to become pliable at body temperature. Right heart pressures were obtained using conventional methodology;16 the midchest position was always taken as the zero reference point.

Statistical Analysis

Data are expressed as the mean ± SEM. Specific comparisons of pulsed-wave and color flow Doppler scores were performed using the Wilcoxon rank sum test. Specific comparisons of hemodynamic or morphometric data between groups were performed using a nonpaired t test. In the present study, the incidence of catheter-induced tricuspid regurgitation was defined as the de novo development of tricuspid regurgitation or the worsening of preexisting tricuspid regurgitation, divided by the number of patients studied. χ² was used to test for differences in the frequency of catheter-induced tricuspid regurgitation. Linear regression analysis was used to examine the relationship between peak systolic pulmonary artery pressure and the amount of catheter-induced tricuspid regurgitation. A significant difference was said to exist at the p<0.05 level.

RESULTS

Noninvasive Studies

Doppler Echocardiography: The tricuspid valve could be adequately viewed in at least one view in 25 of the 27 patients enrolled in this study. No patient in this study had anatomic abnormalities of the tricuspid valve. Baseline pulsed-wave Doppler examination showed that 14 patients had no tricuspid regurgitation, seven patients had trace tricuspid regurgitation, two patients had + 1 tricuspid regurgitation, one patient had + 2 tricuspid regurgitation, and one patient had + 3 tricuspid regurgitation. With a catheter across the tricuspid valve, pulsed-wave Doppler examination showed that eight patients did not have tricuspid regurgitation, 12 patients had trace tricuspid regurgitation, four patients had + 1 tricuspid regurgitation, and one patient had + 4 tricuspid regurgitation. The incidence of catheter-induced tricuspid regurgitation determined by pulsed-wave Doppler was 48 percent. χ² analysis indicated that the frequency of catheter-induced tricuspid regurgitation was significant statistically. Further, the incidence of catheter-induced tricuspid regurgitation by pulsed-wave Doppler was similar for patients with and without baseline tricuspid regurgitation. Figure 1A shows the mean pulsed-wave Doppler tricuspid regurgitation scores with and without a catheter across the tricuspid valve. As shown, there was a small, albeit statistically significant (p<0.01) increase in the average severity of tricuspid regurgitation following catheter placement. To exclude the possibility that the time interval between Doppler studies influenced the outcome of the study, the above analysis was repeated after excluding all patients whose pulsed-wave Doppler studies were more than 12 hours apart. This subgroup analysis showed that there was still a significant increase in the amount of catheter-induced tricuspid regurgitation (0.47 ± 0.22 vs 0.73 ± 0.24; p<0.003).

Baseline color flow Doppler examination showed that 21 patients had no tricuspid regurgitation, one patient had trace tricuspid regurgitation, one patient had + 1 tricuspid regurgitation, one patient had + 2 tricuspid regurgitation, and one patient had + 3 tricuspid regurgitation. Following insertion of a catheter across the tricuspid valve, color flow Doppler examination showed that 16 patients had no tricuspid regurgitation, three patients had trace tricuspid regurgitation, five patients had + 1 tricuspid regurgitation, and one patient had + 4 tricuspid regurgitation. The incidence of catheter-induced tricuspid regurgitation determined by color flow Doppler was 28 percent. χ² analysis indicated that the frequency of catheter-induced tricuspid regurgitation was significant statistically. Further, the incidence of catheter-induced tricuspid regurgitation by color flow Doppler was similar for patients with and without baseline tricuspid regurgitation. Figure 1B shows that there was a significant increase in the average tricuspid regurgitation score determined by color flow Doppler following insertion of a catheter across the tricuspid valve (p<0.05). To exclude the possibility that the time
interval between Doppler studies influenced the outcome of the study, the above analysis was repeated after excluding all patients whose color flow wave Doppler studies were more than 12 hours apart. This subgroup analysis showed that there was still a significant increase in the amount of catheter-induced tricuspid regurgitation (0.28 ± 0.22 vs 0.53 ± 0.26; p < 0.02).

2-D Echocardiography: There was no significant difference between patients with and without catheter-induced regurgitation in terms of linear measurements of the tricuspid valve annulus (8.45 ± 5.6 mm vs 10.1 ± 4.6 mm, respectively) or right ventricular major (68.3 ± 4.6 mm vs 76.3 ± 4.9 mm, respectively) or minor axis dimensions (34.6 ± 1.3 mm vs 37.2 ± 3.0 mm, respectively).

Hemodynamic Studies

Table 1 summarizes the hemodynamic data for the patients with and without catheter-induced tricuspid regurgitation during right heart catheterization. As shown, there was no significant difference (p > 0.05) between groups in the heart rate, systolic or diastolic blood pressure, right atrial mean pressure, systolic pulmonary artery pressure, or pulmonary capillary wedge pressure. Furthermore, there was no significant correlation between the peak systolic pulmonary artery pressure and the amount of catheter-induced tricuspid regurgitation, when measured by either pulsed-wave (r = 0.04; p = 0.42) or color flow (r = 0.03; p = 0.44) Doppler.

DISCUSSION

This study, in which pulsed-wave and color flow Doppler ultrasound were used to examine the incidence and severity of catheter-induced tricuspid regurgitation, shows that placing a catheter across the tricuspid valve induces a small, but statistically significant amount of tricuspid regurgitation. This conclusion is supported by two separate lines of evidence. First, pulsed-wave Doppler studies recorded from two orthogonal views showed that there was a significant increase in the amount of catheter-induced tricuspid regurgitation following right heart catheterization (Fig 1A). Moreover, the incidence of catheter-induced tricuspid regurgitation was similar in patients with and without underlying tricuspid regurgitation. Second, when catheter-induced tricuspid regurgitation was examined using color flow Doppler, similar findings were obtained (Fig 1B). The incidence of catheter-induced tricuspid regurgitation did not appear to be related to the patient's underlying hemodynamic status.

Table 1—Hemodynamic Data in Patients with and without Catheter-Induced Tricuspid Regurgitation (TR)*

<table>
<thead>
<tr>
<th></th>
<th>Catheter-Induced TR</th>
<th>No TR</th>
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<tbody>
<tr>
<td>Heart rate, bpm</td>
<td>75.4 ± 5.1</td>
<td>80.2 ± 6.7</td>
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<tr>
<td>Systolic BP, mm Hg</td>
<td>123.2 ± 7.7</td>
<td>135.4 ± 10.2</td>
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<tr>
<td>Diastolic BP, mm Hg</td>
<td>70.3 ± 4.9</td>
<td>72.1 ± 4.9</td>
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<tr>
<td>RA pressure, mm Hg</td>
<td>9.8 ± 1.23</td>
<td>7.8 ± 1.6</td>
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<tr>
<td>PA systolic pressure, mm Hg</td>
<td>41.5 ± 3.9</td>
<td>38.7 ± 4.3</td>
</tr>
<tr>
<td>PCW pressure, mm Hg</td>
<td>19.0 ± 1.3</td>
<td>19.1 ± 2.3</td>
</tr>
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*Data are mean ± SEM. There was no significant difference (p > 0.05) in the heart rate, systolic or diastolic blood pressure, right atrial mean pressure, systolic pulmonary artery pressure, or pulmonary capillary wedge pressure between patients with and without catheter-induced tricuspid regurgitation. bpm = beats per minute; BP = blood pressure; PA = pulmonary artery; PCW = pulmonary capillary wedge pressure; RA = right atrial.
or right ventricular geometry, since there was no significant difference in heart rate, arterial blood pressure, mean right atrial pressure, systolic pulmonary artery pressure, pulmonary capillary wedge pressure, or linear measurements of the major and minor axes of the right ventricle or the tricuspid valve annulus between the patients who did and did not develop catheter-induced tricuspid regurgitation.

**Previous Studies of Catheter-Induced Regurgitation**

Although a number of studies have suggested that catheter catheters may induce regurgitation by interfering with appropriate coaptation of the leaflets of cardiac valves, fewer studies have examined this question for the tricuspid valve. To our knowledge, Sobol et al were the first to report catheter-induced tricuspid regurgitation in a series of 11 patients undergoing right heart catheterization with platinum tip electrode catheters. These investigators reported evidence of tricuspid regurgitation in 60 percent of their patients, none of whom was suspected on the basis of clinical or hemodynamic grounds to have had underlying baseline tricuspid regurgitation. Cairns et al reported catheter-induced tricuspid regurgitation in 30 percent of their series of 141 patients undergoing right heart catheterization with 6- or 7-French catheters. Using a specially shaped 7-French catheter, Lingamneni et al reported a 4.7 percent incidence of catheter-induced tricuspid insufficiency. Thus, the results of the present study would appear to not only confirm the findings of previous invasive studies, but also to expand on these earlier reports by showing that the amount of catheter-induced tricuspid regurgitation is quantitatively small.

In contrast to the above reports, Shandling et al reported a 0 percent incidence of catheter-induced tricuspid regurgitation in a study involving 47 patients undergoing right and left heart catheterization. Using continuous-wave and pulsed-wave Doppler, these investigators concluded that there was no change in the Doppler signal after pullback of a 7-French catheter across the tricuspid valve. Although the reason(s) for the discrepant findings in the present report and the study by Shandling et al is not clear, several explanations would appear to be possible. First, in contrast to the present study in which no patient was systematically excluded, Shandling et al excluded all patients with clinical evidence of underlying tricuspid regurgitation. Thus, it is entirely possible that this selection bias may have influenced the outcome of their study. Second, whereas we used pulsed-wave and color flow Doppler to interrogate the tricuspid valve from two orthogonal views, they recorded continuous-wave Doppler from a single view to identify a change in the Doppler signal during pullback of the catheter. Accordingly, somewhat different methods were used in the two different studies. Finally, about 90 percent of the patients in their report were studied during routine cardiac catheterization. Thus, it is likely that their patients were volume depleted during the Doppler examination, which might have also contributed to their normal findings with respect to catheter-induced tricuspid regurgitation.

**Limitations of the Present Study**

There are two limitations to the present study that bear emphasis. First, the incidence and severity of catheter-induced regurgitation was studied using 7-French catheters. Therefore, the results of the present study may not be directly applicable to smaller- or larger-sized catheters. A second potential limitation of this study pertains to the Doppler echocardiographic assessment of "mapping" the severity of tricuspid regurgitation, which may be subject to a number of interpretative problems as a result of differences in regurgitant jet size, shape, and velocity. For this reason, we examined catheter-induced regurgitant flow using both single-range gate and multigate Doppler methods, thus potentially avoiding some of the limitations inherent in any one method. Given the consistency of the qualitative and quantitative results obtained by two different observers, each of whom used two different Doppler modalities to assess the incidence and severity of tricuspid regurgitation, it is likely that the observed findings represent a true change rather than methodologic variability alone.

**Summary and Clinical Significance**

Given the thin, pliable nature of the tricuspid valve leaflets, it probably comes as no surprise that the presence of a catheter across the valve should interfere with leaflet function and lead to tricuspid valve incompetence. This statement notwithstanding, the importance of the present study is that it shows for the first time that the amount of catheter-induced tricuspid regurgitation is small quantitatively. Therefore, catheter-induced regurgitation, when present, is unlikely to be important clinically, particularly with regard to the thermodilution assessment of cardiac volumes or cardiac output.

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