Clinical Utility of 3-Dimensional Echocardiography in the Evaluation of Tricuspid Regurgitation Caused by Pacemaker Leads

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Background This study evaluated the usefulness of 3-dimensional echocardiography (3-DE) for identifying permanent pacemaker (PPM) or implantable cardioverter defibrillator (ICD) lead-related symptomatic tricuspid regurgitation (TR).

Methods and Results Eighty-seven patients underwent 3-DE examination: 50 patients with PPM, 17 with ICD, and 20 with cardiac resynchronization therapy devices. TR severity was classified as trivial/mild, moderate, or severe according to the ratio of TR area to right atrium area. The 3-DE identified the lead route and position at the tricuspid valve in 82 patients (94.2%). In 5 patients, images without lead-induced artifacts could not be obtained. TR severity was trivial/mild in 50 patients, moderate in 20 patients, and severe in 12 patients. In all patients with trivial/mild TR and all but 1 patient with moderate TR, leads were positioned on the annulus side between leaflets. Lead-induced obstruction to tricuspid valve closing was identified in 1 patient with moderate TR and in 7 of 12 patients with severe TR: 4 patients had septal leaflet obstruction, and 4 had posterior leaflet obstruction.

Conclusions The 3-DE can identify the lead route and position at the tricuspid valve and lead-related severe TR, so may be a useful technique of diagnosing the cause of severe TR in patients with PPM or ICD. (Circ J 2008; 72: 1465–1470)

Key Words: Echocardiography; Pacing; Valvular diseases

Significant tricuspid regurgitation (TR) has been reported in patients with a permanent pacemaker (PPM);1–5 and the leads of such a device or those of an implantable cardioverter defibrillator (ICD) can be the primary cause of symptomatic TR.6 However, in the clinical setting, the diagnosis of lead-induced TR can be challenging because conventional 2-dimensional echocardiography (2-DE) has limitations in identifying the anatomical relationship between the lead and the tricuspid leaflets7 The 3-dimensional echocardiography (3-DE) has been recently developed for assessing tricuspid valve morphology and pathology, including TR8–11 and case reports on its utility in the diagnosis of PPM- and ICD-lead-related TR have been published12–13 However, the ability of 3-DE to identify both the anatomical lead route through the tricuspid valve and lead-induced valve malfunction has not been studied systematically.

Methods

Patient Population
In 87 patients with PPM, ICD or cardiac resynchronization therapy device, 3-DE studies were performed to evaluate the route of the leads and the presence of lead-related TR (Table 1). The underlying cardiac disease for which PPM implantation was required was complete or advanced atrioventricular block in 28 patients and sick sinus syndrome, including slow atrial fibrillation, in 22 patients, and for ICD implantation it was primary or secondary prevention of fatal cardiac arrhythmias in 17 patients. Cardiac resynchronization therapy devices with or without ICD were implanted in 20 patients with advanced heart failure. The study was approved by the local research ethics committee, and all patients gave written informed consent.
Table 2 Comparison of Clinical Characteristics and Echocardiographic Data According to Degree of TR

<table>
<thead>
<tr>
<th>Degree of TR</th>
<th>Trivial or mild (n=50)</th>
<th>Moderate (n=20)</th>
<th>Severe (n=12)</th>
<th>p value across groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>62±14</td>
<td>66±14</td>
<td>71±16</td>
<td>0.18</td>
</tr>
<tr>
<td>Male, %</td>
<td>78</td>
<td>65</td>
<td>50</td>
<td>0.12</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>45±15</td>
<td>44±15</td>
<td>47±19</td>
<td>0.84</td>
</tr>
<tr>
<td>TR/RA area ratio, %</td>
<td>10±4</td>
<td>28±5†</td>
<td>58±10†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>RV dimension, mm</td>
<td>33±6</td>
<td>37±10</td>
<td>42±14*</td>
<td>0.01</td>
</tr>
<tr>
<td>RV pressure, mmHg</td>
<td>27±6</td>
<td>33±16</td>
<td>42±14†</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Time from device implantation, months</td>
<td>26±28</td>
<td>50±63</td>
<td>51±54</td>
<td>0.08</td>
</tr>
<tr>
<td>2 leads passing tricuspid valve, n (%)</td>
<td>1 (2)</td>
<td>1 (5)</td>
<td>2 (17)</td>
<td>0.10</td>
</tr>
<tr>
<td>Lead position identified by 2-DE, n (%)</td>
<td>6 (12)</td>
<td>5 (26)</td>
<td>3 (27)</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Post hoc (Sheffé) test; *p<0.05, †p<0.01 vs trivial or mild, ‡p<0.01 vs other groups.
RA, right atrial; RV, right ventricular; DE, dimensional echocardiography. Other abbreviations as in Table 1.

2-DE

The 2-DE examinations were performed with a Vivid 7 Dimension system (GE Healthcare, Horten, Norway) equipped with a multifrequency M4S transducer. We carefully assessed the lead route in multiple planes. The left ventricular (LV) end-diastolic volume, LV end-systolic volume, and LV ejection fraction were measured using a modified Simpson’s method. Right ventricular (RV) dimensions were assessed by a RV minor-axis diameter method. The degree of TR was assessed as the ratio of the maximal TR jet area to the corresponding right atrial (RA) area: <20% was defined as mild TR, 20–40% as moderate TR, and ≥40% as severe TR. RV systolic pressures were estimated by continuous wave Doppler with the simplified Bernoulli equation (4×[peak TR velocity]²), with 10 mmHg added for the estimated RA pressure.

3-DE

The 3-DE examinations were performed with a Vivid 7 Dimension system (GE Healthcare) equipped with a 3V 3-dimensional (3D) transducer. Pyramidal full-volume real-time 3D datasets were acquired over 4 consecutive cardiac cycles during breathing in the RV inflow, short-axis, and apical 4-chamber views. Gain and brightness of the 3-DE images were adjusted to improve delineation of anatomical structures. All 3D datasets were digitally stored and transferred to a computer for off-line analysis with the EchoPac PC software package (GE Healthcare). We used the EchoPac’s crop function to choose an elevational cutting plane from the RV apex to the RV base or from the RA to the RV base that allowed visualization of all 3 leaflets of the tricuspid valve and that from the RV free wall that allowed visualization of the lead route from the RA to the RV through the tricuspid valve during a cardiac cycle.

To confirm the interobserver reproducibility in identifying lead positions, PPM or ICD lead positions in 20 randomly selected patients were assessed independently on the 2-DE and 3-DE images by 2 observers (Y.S. and H.N.).

Temporal Change in the Degree of TR

We retrospectively evaluated the temporal change in the degree of TR before and after device implantation in patients with significant TR at the time of examination.

Statistical Analysis

Results are expressed as number (%) or mean±SD. Comparisons between groups were performed using Student’s t-test for continuous variables and the χ² test for categorical variables. One-way analysis of variance (ANOVA) was used to compare the variables between 3 or more groups. When significant differences between groups were present, Sheffe’s test was used to compare individual groups. A p value less than 0.05 was considered indicative of statistical significance. The StatView J-5.0 statistical program (Abacus, Berkeley, CA, USA) was used for the analyses.

Results

On the 2-DE examinations, leads passing through the tricuspid valve were identified in 15 of the 87 patients (17.2%). In contrast, on 3-DE examinations lead routes were identified in 82 of the 87 patients (94.2%). In the remaining 5 patients, of whom 4 had trivial or mild (trivial/mild) TR and 1 had moderate TR, appropriate 3-DE images for lead route analysis could not be obtained because of artifacts caused by the lead.

For the interobserver reproducibility in identifying lead positions, the 3 lead positions in the same 3 patients could be identified on the 2-DE by both observers, and the 20 lead positions in 18 patients could be identified on the 3-DE images by each observer, in which only 2 lead positions differed between the observers. Thus, the concordance rate of identification of lead positions was high; however, we determined the final lead positions by consulting several observers.

In the 82 patients with appropriate 3-DE images, the degree of TR was classified as trivial/mild in 50 patients...
Circulation Journal Vol. 72, September 2008

(61%), moderate in 20 patients (24%), and severe in 12 patients (15%). Because both leads could be identified in 1 patient with mild TR, 1 patient with moderate TR, and in 2 patients with severe TR, all of whom had 2 leads passing through the tricuspid valve, a total of 86 leads in 82 patients were analyzed. Clinical characteristics according to degree of TR are summarized in Table 2. Patients with severe TR had a more dilated RV and higher RV pressure than did patients with trivial/mild or moderate TR. Time from device implantation and the proportion of patients with 2 leads passing through the tricuspid valve did not differ between groups.

**TR Severity and Lead Position at the Tricuspid Valve**

In all patients with trivial/mild TR, and all but 1 patient with moderate TR, the lead was positioned on the annulus side between leaflets (Fig 1). Most leads were positioned between the posterior and septal leaflets, followed by leads positioned between the posterior and anterior leaflets (trivial/mild TR group: 63%, 27%; moderate TR group: 52%, 29%, respectively) (Fig 2). Lead-induced obstruction to septal leaflet closing was identified in 1 patient with moderate TR. In contrast, among the 12 patients with severe TR, 7 had lead-induced obstruction to tricuspid valve closing: the posterior leaflet was obstructed in 4 patients and the septal leaflet in 3 patients. The characteristics of these 8 patients with lead-induced obstruction to leaflet closing are summarized in Table 3 (case no. 5 is the patient with moderate TR). Six patients were octogenarians, and more than 6 years had passed since device implantation in 4 of them. All patients with severe TR had clinical features related to right-sided heart failure. In 7 patients, 3-DE revealed that the lead did not move freely and appeared to be adhered to a leaflet (Fig 3). In another patient (case no. 8), the lead changed its position of contact with the posterior leaflet throughout the cardiac cycle, and appeared to impinge only at leaflet closing.

Four of the 7 patients with lead-related severe TR showed improvement of heart failure symptoms by medication alone, but heart failure was refractory to medication in 3 patients (case nos 2, 6 and 8). The lead positions in these 3 patients were then changed transvenously under 3-DE guidance, and none was managed by surgery. In case no. 2, TR decreased dramatically, whereas in case nos 6 and 8, TR decreased only to a moderate level because of failure of leaflet coaptation, combined with a dilated tricuspid valve annulus, but the heart failure symptoms did improve.

In contrast, in 5 patients with severe TR, but without obstruction to tricuspid valve closing, the leads were positioned on the annulus side; 4 of them had had chronic atrial fibrillation for more than 3 years, and 1 had primary pulmonary hypertension. The cause of the severe TR was identified in all as failure of the leaflets to coapt, combined with a dilated tricuspid valve annulus. All patients had been followed by medication only, and remained stable.

**Temporal Change in the Degree of TR**

All patients with severe TR and lead-induced obstruction to tricuspid valve closing had trivial/mild TR before device implantation. Immediately after device implantation, TR in 3 patients worsened to moderate, and more than 1 year later, TR had progressed to severe in all patients.

Table 3  Clinical Characteristics of 8 Patients With Lead-Induced Obstruction to Leaflet Closing

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Age, years</th>
<th>Sex</th>
<th>Cardiac disease</th>
<th>Device (mode)</th>
<th>Months from device implantation</th>
<th>No. of leads crossing tricuspid valve</th>
<th>2-DE identified lead position</th>
<th>Tricuspid valve malfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85 F</td>
<td>DCM, VT</td>
<td>ICD</td>
<td>180</td>
<td>1</td>
<td>No Obstruction to closing of posterior leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>58 M</td>
<td>DCM</td>
<td>CRT (DDD)</td>
<td>26</td>
<td>1</td>
<td>No Obstruction to closing of posterior leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>82 F</td>
<td>SSS, PAF</td>
<td>PPM (DDD)</td>
<td>84</td>
<td>2</td>
<td>No Obstruction to closing of posterior leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>86 M</td>
<td>SSS, Prior MI</td>
<td>PPM (DDD)</td>
<td>11</td>
<td>1</td>
<td>Obstruction to closing of septal leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>80 M</td>
<td>Complete AVB, Prior MI</td>
<td>PPM (DDD)</td>
<td>75</td>
<td>1</td>
<td>No Obstruction to closing of septal leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>32 F</td>
<td>Complete AVB, DCM</td>
<td>CRT (DDD)</td>
<td>12</td>
<td>2</td>
<td>Yes Obstruction to closing of septal leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>82 F</td>
<td>AF</td>
<td>PPM (VVI)</td>
<td>72</td>
<td>1</td>
<td>No Obstruction to closing of septal leaflet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>81 F</td>
<td>VT, Prior MI</td>
<td>ICD</td>
<td>8</td>
<td>1</td>
<td>No Obstruction to closing of posterior leaflet</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DCM, dilated cardiomyopathy; PAF, paroxysmal AF; MI, myocardial infarction. Other abbreviations as in Tables 1, 2.
In the 5 patients with severe TR, but without lead obstruction to tricuspid valve closing, the degree of TR before device implantation was mild in 1 patient, moderate in 2, and severe in 2. Immediately after device implantation, TR severity did not change, but more than 1 year later, TR had worsened to severe in all patients.

**Discussion**

The present study has 2 important findings. First, 3-DE showed a higher potential for identifying lead route and position at the tricuspid valve than did 2-DE. Second, in the patients with a PPM and severe TR, obstruction to the closure of a tricuspid valve leaflet by a PPM lead was the main cause of severe TR.

**3-DE**

To the best of our knowledge, the present study is the first to systematically examine the utility of 3-DE for evaluating PPM-lead-related TR, although several case reports have been published. The 3-DE enables visualization of the entire tricuspid valve, in particular, en face the short axis of the valve, which may contribute to the greater ability of 3-DE to assess the route and position of the lead at the tricuspid valve. Schnabel et al also reported a high ability (96%) of 3-DE to assess the completeness of the tricuspid valve structure. In the present study 2-DE showed poor assessment ability; Lin et al reported that PPM-induced tricuspid malfunction could be diagnosed preoperatively in only 5 of 41 patients (12%) who underwent surgery for PPM-related TR.

The present study confirmed the ability of 3-DE to identify PPM lead positions at the tricuspid valve. In almost all patients with mild to moderate TR, the PPM lead position was between the tricuspid leaflets, particularly the posterior leaflet and septal or anterior leaflet. Anatomical assessment of the posterior leaflet in relation to the main position of the PPM leads has been difficult with 2-DE because only 2 leaflets can be shown simultaneously in the atypical parasternal view, and the posterior leaflet can be seen only on the RV 2-chamber view. This limitation to visualization of the posterior leaflet may contribute to the poor assessment of lead position at the tricuspid valve with 2-DE.

In addition, the present study showed that among patients excluded because of inadequate 3-DE images, all but 1 had trivial/mild TR. Schnabel et al also reported that image quality was less adequate in healthy subjects than in patients with RV dysfunction, which may be related to the fact that the a dilated RV facilitates viewing of the tricuspid valve.

**Relationship Between Severe TR and Device Implantation**

In patients with severe TR and lead obstruction, severe TR occurred after device implantation because none of the patients had moderate or severe TR beforehand. In contrast, TR severity before device implantation in patients with severe TR, but without lead obstruction, varied; that is, 4 of 5 patients had moderate or severe TR before device implantation. The discrepancy in TR severity between patients with and without lead obstruction before device implantation supports the observation that severe TR may be occur in association with device implantation in some patients without significant TR before implantation.

The present study showed that acute aggravation of TR, even at the severe level, after implantation of PPM leads did not usually occur in patients with pre-implantation severe TR and lead obstruction. In previous animal and human studies, acute worsening or new onset of significant TR did not usually occur immediately after PPM or ICD lead implantation. Therefore, aggravation of TR to a severe level may be occurring in the chronic phase and so in the clinical setting it is important to pay attention to the appearance of symptoms of right-sided heart failure in the chronic phase.

In the present study, TR severity worsened from trivial or mild to moderate immediately after device implantation in 3 patients with severe TR and leaflet obstruction. Because we did not perform 3-DE in the acute phase after device implantation, we could not conclude the contribution of leaflet obstruction by PPM or ICD leads in the acute aggravation of TR. In addition to lead obstruction, various factors that worsened TR were assumed: right-sided heart remodeling including tricuspid annular dilatation, and tethering of the tricuspid valve system with a dilated and failed RV. This anatomic remodeling may be caused by various factors, including progression of myocardial disorders, aggravation of heart failure, arrhythmia such as chronic atrial fibrillation, and intra-RV dysynchrony. However, these factors may contribute to TR aggravation in the chronic phase, rather than in the acute phase, after device implantation. Thus, we speculate that lead obstruction to leaflet closing may have been the immediate cause of acute, moderately worsened TR in the 3 patients. In other patients in whom significant TR was found in the chronic phase,
because we had insufficient temporal data, including 3-DE, we could not determine whether the lead had moved during the chronic phase of the aforementioned cardiac disorders or it was a device-induced problem.

**Mechanism of Lead-Related TR**

The present study showed that the most likely mechanism of PPM-lead-related severe TR is obstruction to leaflet closing. Mechanisms that have been reported previously include obstruction to leaflet closing, perforation, and laceration.1-3,12,13 Lin et al found that PPM-related tricuspid malfunctions were caused by various mechanisms; the largest subset of patients (39%) had lead impingement only of the tricuspid valve leaflets at surgery, but other mechanisms included adhesion of the PPM or ICD lead to a tricuspid valve leaflet (34%), leaflet perforation (17%), and entanglement of the tricuspid valve apparatus (10%). On that basis, insufficient valve closure may be the main cause of PPM-lead-related TR, as shown by our data. We did not identify any patients with severe TR caused by perforation or laceration of leaflets, possibly because of the small number of patients in the present study or because we did not perform imaging that would enable diagnosis of perforation or laceration.

In the present study, lead extraction was performed in 3 patients, and no one was managed by surgery. McCarthy et al reported a 30-day operative mortality of 6% for tricuspid valve replacement;19 so surgery for TR caused by a device lead remains controversial and depends on the clinical situation. The present patients who underwent lead extraction were in poor clinical condition with heart failure, so we initially managed them with endovascular leads, and the leads were removed successfully. Recently, Jones et al reported that lead extraction had a high success rate (97.5%) and low complication rate (0.4%) in 975 chronic endovascular leads of 498 patients,20 a large study that may support our strategy.

**Study Limitations**

The first limitation is that our study was retrospective, so we could not assess the lead position and TR before and immediately after device implantation in some patients. Therefore, further prospective studies are needed to confirm the notable issue of whether a temporal change in the position of the leads does occur, with associated changes in clinical symptoms, chest X-ray findings, and TR severity.

TR severity was assessed only by the ratio of maximal TR jet area to the corresponding RA area. Other methods of evaluating TR, including vena contracta and PISA, may affect our results. However, because of the retrospective design we had insufficient data to evaluate TR by those methods.

Transeosophageal echocardiography were not performed in any patients, so we can not compare its ability and utility with those of 2- and 3-DE. Compared with transthoracic echocardiography, transeosophageal echocardiography may be potentially useful in identifying PPM-lead-related TR.21,22 However, Lin et al reported that transesophageal echocardiography was able to visualize the PPM or ICD leads as a cause of TR in only 45% of patients, and on that basis they recommended the use of 3-DE to identify intracardiac lead routes.

In the present study, the pathological causes of TR were not identified because neither surgery for repair of TR nor autopsy had been performed. As mentioned earlier, insufficient valve closure may be the main cause of PPM-lead-related TR, but we could not definitely identify the mechanism of severe TR, which may include adhesion, perforation, or leaflet laceration, because of the inability of 3-DE imaging to identify the latter causes. Therefore, further studies are needed to assess the accuracy of 3-DE in the clinical diagnosis of lead-related TR and its pathological causes.

**Conclusion**

In patients with severe TR, 3-DE can identify the intra-cardiac route of PPM or ICD leads, the position of the lead at the tricuspid valve, and obstruction to leaflet closure caused by the lead. Therefore, 3-DE may be useful in the evaluation of the cause of severe TR in patients who have received a PPM or ICD.

**References**


