



ORIGINAL RESEARCH

# 3D Echocardiographic Location of Implantable Device Leads and Mechanism of Associated Tricuspid Regurgitation

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**OBJECTIVES** This study sought to: 1) determine the feasibility of using 3-dimensional transthoracic echocardiography (3D TTE) in patients with implantable cardiac resynchronization devices, pacemakers, and defibrillators to visualize the device leads in the right heart and their position relative to the tricuspid valve leaflets; 2) determine the prevalence of different lead positions; and 3) study the relationship between lead location and tricuspid regurgitation (TR) severity.

**BACKGROUND** Pacemaker, defibrillator, and cardiac resynchronization device implantation is currently guided by fluoroscopy, not allowing targeted lead positioning relative to the tricuspid valve leaflets. These leads have been reported to cause TR of variable degrees, but echocardiography is not routinely used to elucidate the mechanisms of lead interference with tricuspid valve leaflets in individual patients.

**METHODS** 3D TTE full-volume images of the right ventricle and/or zoomed images of the tricuspid valve were obtained in 121 patients with implanted devices. Images were viewed offline to determine the position of the device-lead relative to the tricuspid valve leaflets. Severity of TR was estimated on the basis of vena contracta measurements.

**RESULTS** 3D TTE clearly depicted lead position in 90% of patients. The right ventricular lead was impinging on either the posterior (20%) or septal (23%) leaflet or was not interfering with leaflet motion (53%) when positioned near the posteroseptal commissure or in the central portion of the tricuspid valve orifice. In the remaining patients, leads were impinging on the anterior leaflet (4%) or positioned in either the anteroposterior or anteroseptal commissure (3%). Leads interfering with normal leaflet mobility were associated with more TR than nonimpinging leads (vena contracta: median 0.62 cm [1st and 3rd quartiles: 0.51, 0.84 cm] vs. 0.27 cm [1st and 3rd quartiles: 0.00, 0.48 cm];  $p < 0.001$ ).

**CONCLUSIONS** 3D TTE showed a clear association between device lead position and TR. To minimize TR induced by device-leads, 3D TTE guidance should be considered for placement in a commissural position. (J Am Coll Cardiol Img 2014;7:337–47) © 2014 by the American College of Cardiology Foundation

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Permanent pacemaker, implantable cardioverter-defibrillator (ICD), and cardiac resynchronization device implantations are growing steadily as life expectancy of the population increases and indications for these devices expand. The association between permanent pacemaker, ICD, or cardiac resynchronization device leads and tricuspid regurgitation (TR) has not been well-described. Published data on the frequency of device-related TR are conflicting, with reported incidence ranging anywhere between 7% and 39%

and right ventricular device-lead as it traverses the valve; 2) the prevalence of different lead positions with respect to tricuspid valve leaflets and commissures; and 3) the mechanism and relationship between lead position and TR severity.

## METHODS

**Patient population.** We identified 135 consecutive patients from our echocardiography database with permanent pacemaker, ICD, or cardiac resynchronization device therapy who had undergone complete 2D and 3D TTE imaging of the tricuspid valve with the device lead in situ between January 2010 and April 2013. All patients had 3D TTE studies including a full volume and/or zoomed acquisition of the tricuspid valve. Care was taken during offline analysis to optimally depict the course of the device lead at the level of the tricuspid valve leaflets, resulting in exclusion of 14 of 135 patients due to inadequate image quality (10%). Therefore, 121 patients were included in the study (64 male and 57 female; mean age  $65 \pm 15$  years, range 28 to 104 years). Of the 121 patients, 62 also had pre-implantation 2D echocardiograms. Of these, 9 did not have adequate imaging of the tricuspid valve; thus 53 of the study patients (24 male and 29 female; mean age  $65 \pm 15$  years, range 31 to 93 years) who had pre-implantation echocardiograms were included.

Demographic information, site of device generator implantation (left vs. right chest pocket), and type of device placed (permanent pacemaker, ICD, or cardiac resynchronization device) were obtained from a chart review. This study was approved by the institutional review board.

**2D TTE.** Comprehensive 2D and color Doppler evaluation was performed by an experienced sonographer with the iE33 imaging system equipped with an S5 transducer (Philips Healthcare, Andover, Massachusetts). Digital loops were stored and analyzed offline (Xcelera Workstation, Philips Healthcare). Quantification of TR was achieved by measuring the largest vena contracta in centimeters from either the right ventricular inflow view or the apical 4-chamber view, following published guidelines (10) (Fig. 1). Vena contracta measurements were similarly performed on the 53 available pre-implantation echocardiograms. Pre- and post-implantation vena contracta were compared between the group classified as impinging and the group designated nonimpinging (see the following device-lead position assessment section for details). Peak TR gradient was measured with the modified

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(1). Much of the available data originates from autopsy reports and surgical case series, where the mechanism of device-related TR was determined in a “non-beating” heart (1–4). To date, there is no reliable imaging technique to assess device-lead-related interference with the tricuspid valve.

Tricuspid regurgitation is not a benign condition. Although generally well-tolerated in its early stages, with time, TR might lead to pulmonary hypertension, right sided heart failure, and increased morbidity. A recent study indicates that more than moderate TR is associated with reduced 1-year survival (65% to 80%) (5). Therefore, it would be beneficial to be able to identify device-lead interference with normal tricuspid valve leaflet mobility leading to TR.

Two-dimensional (2D) transthoracic echocardiography (TTE) can only visualize device leads crossing the tricuspid valve in 12% to 17% (4,6) of patients, making it an unreliable technique to assess device-lead related TR. Prior 2D TTE studies focused on demonstrating worsening TR severity after device-lead implantation (7–9). None of these studies, however, were able to clearly describe the mechanism by which the device-lead resulted in TR worsening.

Three-dimensional (3D) TEE allows detailed en-face visualization of the tricuspid valve anatomy from both the atrial and ventricular perspectives, including simultaneous visualization of all 3 tricuspid valve leaflets. Accordingly, we hypothesized that 3D TTE datasets would be able to depict the course and position of the device-lead as it traverses the tricuspid valve and determine the mechanism of device-lead induced TR, when present.

The aims of this study were to determine: 1) the feasibility of 3D TTE imaging of the tricuspid valve

### ABBREVIATIONS AND ACRONYMS

<b>A</b>	= anterior
<b>AP</b>	= anteroposterior
<b>AS</b>	= anteroseptal
<b>ICD</b>	= implantable cardioverter-defibrillator
<b>M</b>	= middle or central location of implantable device lead
<b>P</b>	= posterior
<b>PS</b>	= posteroseptal
<b>S</b>	= septal
<b>3D TTE</b>	= 3-dimensional transthoracic echocardiography
<b>TR</b>	= tricuspid regurgitation
<b>2D TTE</b>	= 2-dimensional transthoracic echocardiography

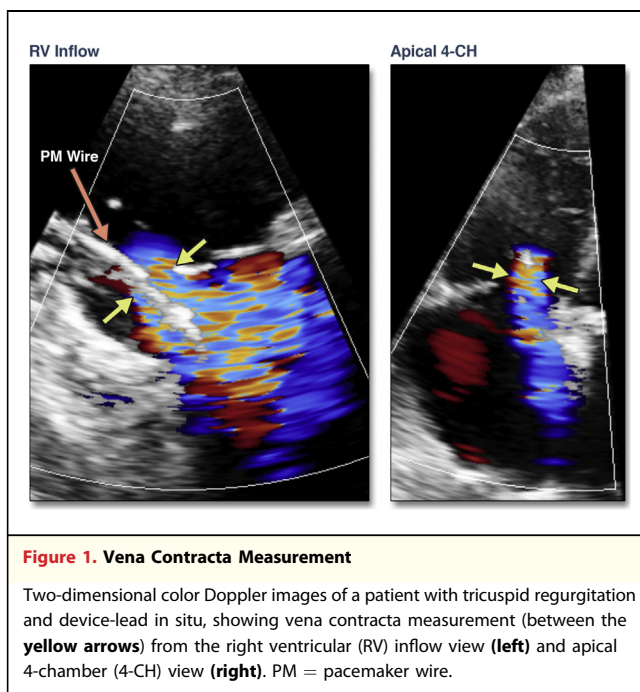
Bernoulli equation, incorporating the maximum TR jet velocity.

**3D TEE.** The 3D TTE studies were performed with a Phillips iE33 ultrasound system (Philips Healthcare) with a fully sampled matrix-array transducer (model X7-2t). The tricuspid valve was imaged from the apical 4-chamber view with full volume and/or 3D zoom modes. The full volume imaging was performed in the right ventricle-focused view, wherein the central axis of the pyramidal scan volume was aligned with the right ventricle long axis. Image acquisition was performed with electrocardiographic gating over 4 consecutive cardiac cycles during a single breath-hold (11). For the zoom mode acquisitions, biplane imaging was initially performed to ensure that the entire tricuspid valve was captured. In the zoom mode, the box height and width were optimized to enclose a section of the right ventricle and right atrium together with the full width of the valve within the scan volume. After the gain was optimized, the image was cropped and oriented to visualize the tricuspid valve in the en face view (right ventricular or right atrial perspective), depending on which orientation best depicted the device-lead. The tricuspid valve was oriented with the septum in the 6-o'clock position in accordance with American Society of Echocardiography guidelines (Fig. 2) (11).

**Device lead position assessment.** The 3D images were cropped (QLAB 9.0, Phillips Healthcare) and displayed to enable identification of the device-lead position at the level of the tricuspid annulus. The device lead was described as impinging on either the anterior (A), posterior (P), or septal (S) leaflets if it was seen interfering with leaflet motion (Fig. 2, left panel). If the device-lead was in the commissure, the lead position was named according to the commissural location between the respective 2 tricuspid leaflets (i.e., antero-septal [AS], antero-posterior [AP], and postero-septal [PS]). Finally, the position was noted as mobile (M) when the lead was seen traversing the tricuspid valve in the middle without interfering with valvular function. The 3D images alone were used to make the assessment, and corroboration was not sought from 2D imaging.

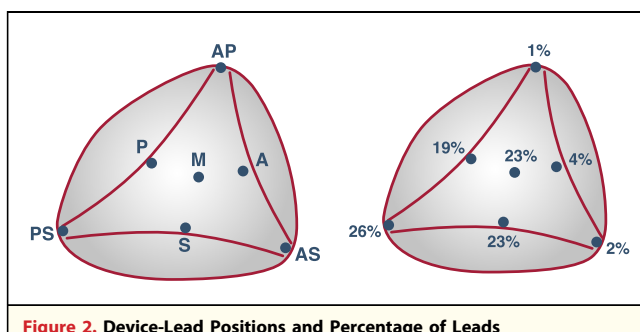
Device pulse generator position was recorded as “left chest” or “right chest” or “both” if 2 pockets had been constructed and leads from the first pulse generator were left in the heart. Device pulse generator position was assessed on the chest x-ray taken closest to the time of 3D TTE.

**Inter-reader agreement analysis.** A randomly selected group of 32 patients was used to assess



the inter-reader agreement in the evaluation of lead position. Determinations of 2 experienced independent observers were compared with each other by calculating the rate of agreement.

A randomly selected group of 50 patients was used to assess the inter-reader agreement in the evaluation of TR. Two experienced independent observers performed vena contracta measurements, while being blinded to the results of each other. Measured vena contracta values were used to classify TR severity as “mild,” “moderate,” or “severe,”



according to the scale published for mitral regurgitation (10). Inter-reader agreement in this classification was assessed with kappa statistics. The calculated kappa coefficients were judged as follows: 0.0 to 0.2 low, 0.21 to 0.4 moderate, 0.41 to 0.6 substantial, 0.61 to 0.8 good, and  $>0.8$  excellent.

**Statistical analysis.** Continuous variables were expressed with mean  $\pm$  SD or medians (with 1st and 3rd quartiles) for variables that did not follow a normal distribution, according to the Kolmogorov-Smirnov test. Mann-Whitney *U* test was used to make comparisons between independent groups, and Wilcoxon rank paired test was used to compare related samples (namely between pre- and post-device-lead insertion vena contracta values). Independent samples Kruskal-Wallis test was used to determine whether differences existed between data in more than 2 groups. Categorical variables such as prevalence of different lead positions were expressed in percentage, and differences were tested with chi-square statistics. A *p* value  $<0.05$  was considered statistically significant.

## RESULTS

3D TTE was feasible in 121 of 135 patients (90%). Of the 121 patients studied, 63 (52%) had ICDs, 30 (25%) had cardiac resynchronization devices, and 27 (22%) had permanent pacemaker leads. Most patients had device implantation from a left-sided chest pocket ( $n = 97$ , 80%), whereas only 13 patients (11%) had implantation from a right-sided pocket. Seven patients had 2 leads in the right ventricle. See Table 1 for a summary of baseline characteristics.

Pacemaker leads were best evaluated from the right ventricle perspective in both the zoomed and full volume acquisitions. Fifty-six patients (46%) showed device-lead impingement against 1 of the leaflets; S leaflet motion was restricted in 28 patients (23%) (Online Videos 4 and 6), the P leaflet in 24 patients (20%) (Online Video 3), and the A leaflet in 5 patients (4%) (Online Videos 5 and 7) (Fig. 2, right panel). In the remaining 65 patients (54%) the device lead was located either in a commissure ( $n = 35$ , 29%) (Online Videos 1 and 2) or in the middle of the tricuspid orifice M ( $n = 28$ , 23%). When the lead was either in a commissure or in the middle of the tricuspid valve orifice, the device-lead did not seem to restrict leaflet mobility, because the leaflets were noted to move freely around the lead. In the commissural position, most

of the leads were seen in the PS commissure ( $n = 32$ , 26%). Only 3 leads were found in the AS commissure (2%), and only 1 was found in the AP commissure (1%) (Fig. 3, Table 2). Two independent observers agreed on device-lead location in 27 of 32 cases (84%). Disagreements were between S versus PS position (4 cases) and PS versus P position (1 case).

The TR associated with device-lead impingement (A, S, or P) was significantly more severe compared with that associated with a lead located in the center of the orifice (M) or in a commissural position (AP, AS, PS) (vena contracta 0.62 cm [1st and 3rd quartiles: 0.51, 0.84 cm] vs. 0.27 cm [1st and 3rd quartiles: 0.00, 0.48 cm];  $p < 0.001$ ) (Figs. 3 to 5). In patients with severe TR (vena contracta  $\geq 0.7$  cm,  $n = 26$ ), most (22 of 26, 85%) had device leads impinging on a leaflet (A, S, or P). The calculated kappa coefficient for vena contracta measurement was 0.70, signifying good agreement between the 2 independent observers. The peak TR gradient associated with an impinging device-lead (A, S, or P) was higher than the peak TR gradient associated with a non-impinging device-lead (located in the M, AP, AS, or PS position) (peak TR gradient 35 mm Hg [1st and 3rd quartiles: 26, 41 mm Hg] vs. 29 mm Hg [1st and 3rd quartiles: 23, 37 mm Hg];  $p = 0.04$ ).

In the subset of patients with pre- and post-lead implantation 3D echocardiograms ( $n = 53$ , 44%), a significant increase in TR severity was noted after device-lead implantation in those with leads noted to be impinging on the A, S, or P tricuspid leaflets (vena contracta: 0.00 cm [1st and 3rd quartiles: 0.00, 0.59 cm] pre-implantation vs. 0.62 cm [1st and 3rd quartiles: 0.47, 0.74 cm] post-implantation;  $p < 0.01$ ). In contrast, in patients with nonimpinging device-leads, no significant worsening in TR was noted (vena contracta: 0.00 cm [1st and 3rd quartiles: 0.00, 0.43 cm] pre-implantation vs. 0.30 cm [1st and 3rd quartiles: 0.00, 0.51 cm] post-implantation;  $p = 0.52$ ) (Fig. 6). In all cases with 2 device-leads ( $n = 7$ ), 1 lead was noted to be impinging. Therefore, these cases were included in the group with the impinged leaflet.

Device pulse generator position (left or right chest) was not associated with a difference in TR (vena contracta left-sided implantation [ $n = 97$ ] 0.48 cm [1st and 3rd quartiles: 0.00, 0.68 cm] vs. right-sided implantation [ $n = 13$ ] 0.56 cm [1st and 3rd quartiles: 0.00, 0.49 cm],  $p = 0.21$ ).

Device type (i.e., pacemaker, ICD, or biven-tricular ICD) did not have any impact on the



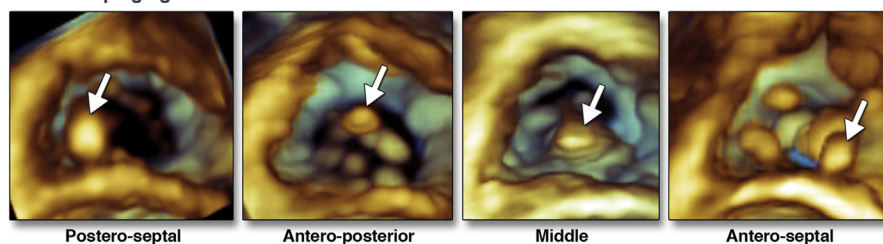
**Table 1. Baseline Characteristics of Study Subjects and Subgroup With Pre- and Post-Device-Lead Implantation 3D Echocardiography**

	Total Population (n = 121)	Pre-/Post-Implantation Echo (n = 53)
Age, yrs	65 ± 15 (28–104)	65 ± 15 (31–93)
Male	64 (53)	24 (45)
Peak TR gradient, mm Hg	33 ± 12 (103)	34 ± 11 (45)
Interval between device implantation and 3D echo, yrs	3.9 ± 3.9 (80)	3.9 ± 4.3 (50)
Interval between pre- and post-implantation 3D echo, yrs	—	3.8 ± 3 (53)
Device data		
With ICD	63 (52)	26 (49)
With PPM	27 (22)	9 (17)
With BIV ICD	30 (25)	18 (34)
Unknown device type	1 (1)	0 (0)
Left-sided implantation	97 (80)	45 (85)
Right-sided implantation	13 (11)	8 (15)
Unknown implantation site	10 (8)	0 (0)
Leads from both right and left	1 (1)	0 (0)
Patients with 2 wires in situ	7 (6)	0 (0)

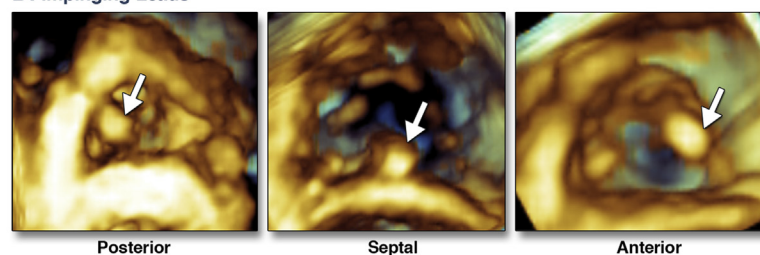
Values are mean ± SD (range), n (%), or mean ± SD (n).

BIV = biventricular; echo = echocardiogram; ICD = implantable cardioverter-defibrillator; PPM = permanent pacemaker; 3D = 3-dimensional; TR = tricuspid regurgitation.

**A: Non-impinging Leads**



**B: Impinging Leads**



**Figure 3. Device Lead Locations on 3D Transthoracic Echocardiography**

(A) Three-dimensional (3D) zoom examples of nonimpinging leads. From **left-to-right**: device-leads are found in the PS commissure ([Online Video 1](#)), AP commissure ([Online Video 2](#)), M, and AS. (B) 3D zoom examples of impinging leads. From **left-to-right**: device-leads are found against the P ([Online Video 3](#)), S ([Online Video 4](#)), and A ([Online Video 5](#)). All these positions were associated with interference of leaflet motion ([Online Videos 1, 2, 3, 4, and 5](#)). **Arrows** point to the device-lead. Abbreviations as in [Figure 2](#).

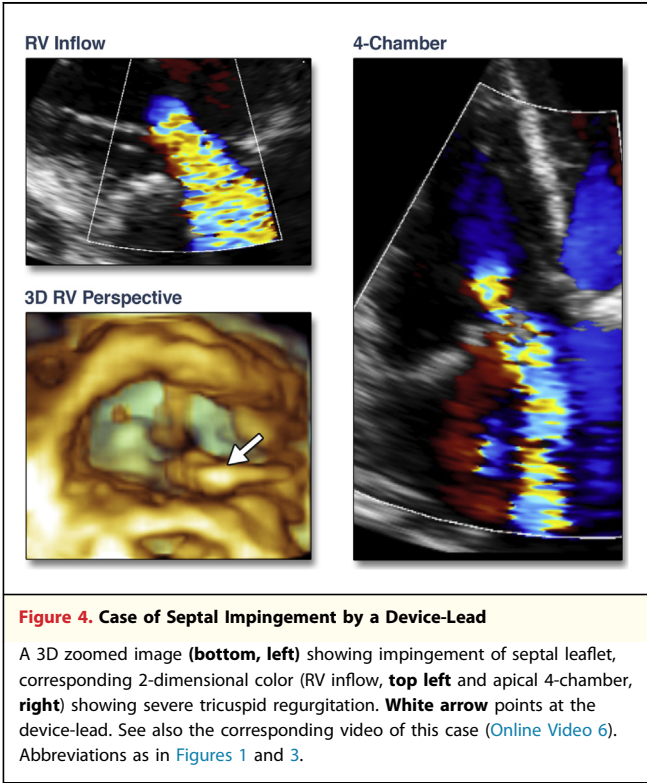
	Device Lead Positions							VC (cm)
	A (n = 5)	P (n = 24)	S (n = 28)	PS (n = 32)	AP (n = 1)	AS (n = 3)	M (n = 28)	
Device type*								
ICD (n = 63)	3	10	13	27	0	2	15	0.46 [0.00, 0.63]
PPM (n = 27)	2	5	7	5	1	1	6	0.51 [0.00, 0.70]
BIV ICD (n = 30)	2	9	8	5	0	0	6	0.53 [0.07, 0.64]
Post-implantation site†								
Left (n = 97)	3	19	26	27	1	3	18	0.50 [0.00, 0.58]
Right (n = 13)	1	3	1	3	0	0	5	0.56 [0.49, 0.72]
No data (n = 10)	1	2	1	2	0	0	4	0.15 [0.00, 0.49]
Pre-implantation tricuspid regurgitation VC, cm								
VC (n = 53)	0.62 —	0.59 [0.47, 0.64]	0.72 [0.48, 0.77]	0.24 [0.00, 0.45]	—	0.00	0.39 [0.00, 0.63]	0.46 [0.00, 0.63]
	1	9	11	17	—	2	13	53
Post-implantation tricuspid regurgitation VC, cm								
VC (n = 121)	0.62 [0.57, 0.72]	0.61 [0.53, 0.78]	0.65 [0.48, 0.85]	0.12 [0.00, 0.44]	0.41 —	0.00 [0.00, 0.25]	0.33 [0.00, 0.51]	0.49 [0.00, 0.66]
Values are n or median [1st and 3rd quartiles]. *One patient did not have any records of device type. †One patient had device-leads coming from both left and right chest pockets; this patient was not included in the table. A = anterior impingement; AP = anteroposterior commissure; AS anteroseptal commissure; M = center of the valve; P = posterior impingement; S = septal impingement; PPM permanent pacemaker; PS = posteroseptal commissure; VC = vena contracta; other abbreviations as in Table 1.								

severity of TR. Median vena contracta for the group that received ICD versus pacemaker versus the cardiac resynchronization device therapy was 0.46 [1st and 3rd quartiles: 0.00, 0.63], 0.51 [1st and 3rd

quartiles: 0.00, 0.70], and 0.55 [1st and 3rd quartiles: 0.07, 0.64], respectively. Even with non-impinging leads excluded (i.e., leads in the AS, AP, PS, or M position), the group that received ICDs (biventricular ICD or ICD only, n = 43, vena contracta 0.61 cm [1st and 3rd quartiles: 0.51, 0.81 cm]) did not show significantly different TR severity than those who received pacemakers (n = 14, vena contracta 0.68 cm [1st and 3rd quartiles: 0.58, 0.82 cm]).

The date of device-lead implantation was available in 80 of 121 (66%) patients. Interval between device-lead implantation and the 3D TTE was not longer in patients with impinging leads (A, S, or P) when compared with patients with nonimpinging leads (M, AP, AS, or PS positions; 3.4 years [1st and 3rd quartiles: 1.5, 5.9 years] vs. 2.6 years [1st and 3rd quartiles: 1.0, 5.1 years]; p = 0.33). Furthermore, the correlation between the age of the device-lead (number of years between lead placement and 3D TTE) was poor (r = 0.06, p < 0.00001), suggesting that TR severity was not associated with older device-leads.

In most cases, device-related TR was secondary to lead adherence to or impingement on a leaflet, resulting in impaired leaflet mobility. Perforation was identified in 2 cases; malcoaptation was identified in 3 cases (Online Video 8). In 7 patients with 2 leads present, 1 of 2 leads was felt to be impinging upon a leaflet, interfering with leaflet



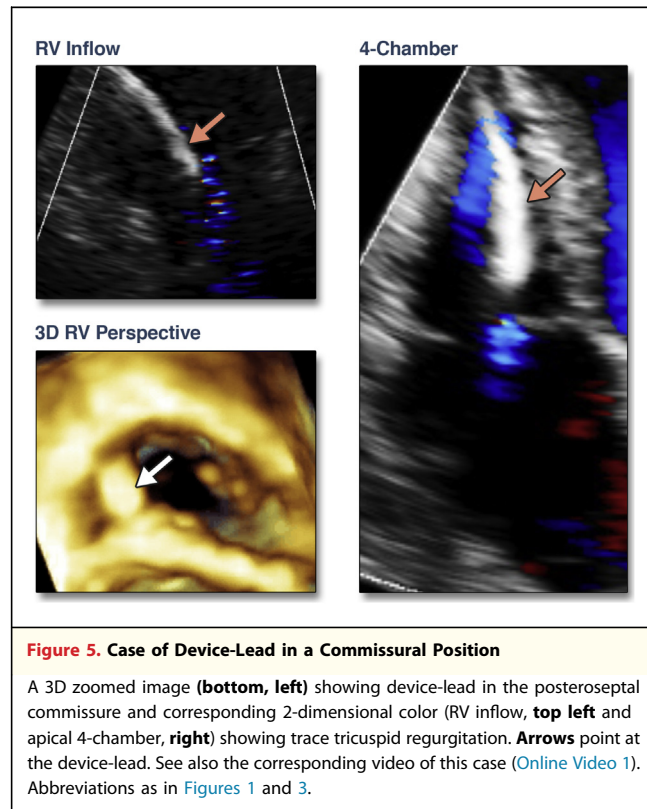
mobility. Average vena contracta in tricuspid valves with 2 leads was  $0.56 \pm 0.26$  cm (range 0.20 to 0.95 cm). Examples of mechanisms of TR as seen on 3D echocardiographic images are depicted in Figures 7 and 8.

## DISCUSSION

This study confirmed that 3D TTE is feasible for the visualization of device-lead position in the tricuspid valve in most patients. Leads positioned against tricuspid leaflets impinge upon or restrict leaflet motion, resulting in a greater severity of TR, compared with leads positioned within 1 of the commissures or leads that remain mobile as they cross the tricuspid valve through its center. In the subset of patients who had pre- and post-device implantation images, an increase in TR severity was noted selectively in patients with leads impinging on the leaflets.

**Device-lead placement techniques and the tricuspid valve.** Placement of ICDs, permanent pacemaker, and biventricular devices is performed under fluoroscopic guidance with the aim of directing the tip of the lead most commonly to the right ventricle apex, the interventricular septum, or the right ventricle outflow tract. Determining the lead position at the level of the tricuspid valve annulus with respect to the leaflets is difficult, because tricuspid valve leaflets are not seen on fluoroscopy. Right ventricle lead placement techniques vary, depending on the operator and the center where the procedure is performed. In general, 1 of 3 different techniques is used: 1) prolapsing the lead across the tricuspid valve by first looping it in the right atrium, then pushing the loop forward with the inner stylet until it falls through the valve; 2) crossing the valve directly, aimed toward the target location with a shaped stylet in place; or 3) crossing the valve directly toward the right ventricle outflow tract with a curved stylet in place, then retracting the lead until it is aimed at the target location (12). As shown in our study, device-lead placement results in a variety of lead locations at the level of the tricuspid valve annulus. Although in this study it was not possible to determine whether individual procedural technique resulted in preferential lead positions that are associated with less severe TR, this remains to be determined in future studies.

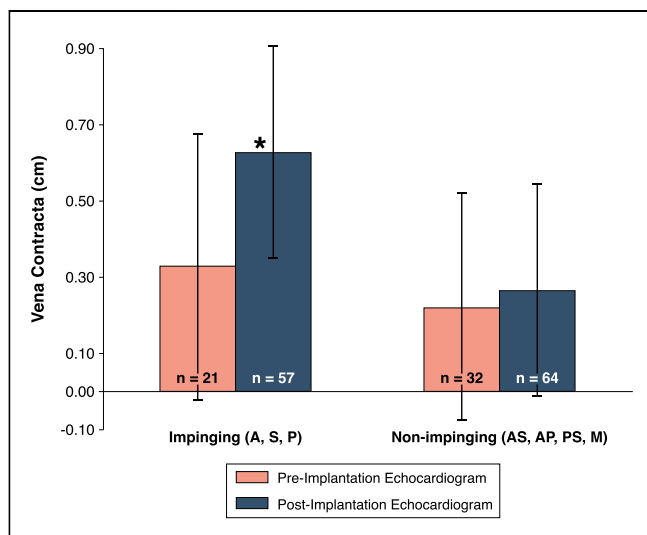
**TR in the presence of device-leads.** Previous studies have reported a prevalence of device-lead related TR ranging from 7% to 39% (1). This wide range is likely attributable to multiple factors. First, device-lead associated TR is difficult to evaluate in a



**Figure 5. Case of Device-Lead in a Commissural Position**

A 3D zoomed image (**bottom, left**) showing device-lead in the posteroseptal commissure and corresponding 2-dimensional color (RV inflow, **top left** and apical 4-chamber, **right**) showing trace tricuspid regurgitation. **Arrows** point at the device-lead. See also the corresponding video of this case ([Online Video 1](#)). Abbreviations as in [Figures 1 and 3](#).

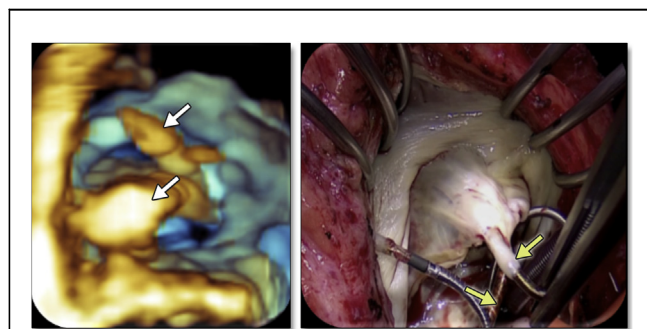
beating heart. So far, there has been no reliable method to assess the position of a device-lead as it crosses the tricuspid valve. Most of the current information was obtained from autopsy reports and surgical case series (2–4,13–15). Moreover, initial studies using 2D echocardiography described conflicting findings with regard to the association between severity of TR and the presence of a device-lead (1). Whereas early animal studies and prospective human studies showed no significant difference in TR severity pre- and post-endocardial lead implantation (16–18), later studies suggested an increase in TR severity after device implantation (8,19,20). These conflicting observations probably originate from the fact that, with 2D TTE, device-leads are fully visualized as they traverse the tricuspid valve annulus in only 15% of cases (1,6). Indeed, the tricuspid valve is difficult to assess with 2D TTE, because of the anterior position of this valve, its non-planar shape (21), and the complex geometry of the right ventricle. Accordingly, 2D echocardiography does not seem to provide sufficient information to assess the mechanism of TR in patients with device-leads. In contrast, 3D TTE takes advantage of the anterior position of the tricuspid valve, allowing en face visualization of the



**Figure 6. Patients With Pre- and Post-Device-Lead Implantation Echocardiograms**

Pre- and post-implantation tricuspid regurgitation severity (as measured by vena contracta) for patients with impinging device-leads (A, S, P) and patients with nonimpinging device-leads (AS, AP, PS, M). Pre-implantation data (n = 53) correspond with **pink bars**, whereas post-implantation data (n = 121) correspond with **blue bars**. Post-implantation tricuspid regurgitation was significantly more severe in patients with impinging leads (\*p < 0.05) than in patients with nonimpinging leads. The n values on the **bar graphs** represent the number of patients in the corresponding groups. Abbreviations as in [Figure 2](#).

tricuspid valve from both the atrial or ventricular perspective and easy, simultaneous identification of all leaflets and commissures. In addition, the course of the device-lead as it traverses the tricuspid annulus is easily appreciated ([11,22–24](#)). It has been previously reported that 3D TTE images of the



**Figure 7. Case of Lead Adherence**

A 3-dimensional zoomed image of tricuspid valve demonstrating 2 leads (**arrows**), with the top lead adherent to the anterior leaflet. This patient had severe symptomatic tricuspid regurgitation and was taken to the operating room for lead removal. Note that the lead is adhering to the anterior leaflet of the tricuspid valve (see surgical photo on the **right**—**arrows** point at the 2 leads, top lead is adherent). See accompanying [Online Video 7](#).

tricuspid valve can be acquired in 90% of patients who have adequate 2D images ([25](#)). We demonstrated that with 3D TTE it was feasible to consistently and simultaneously image the 3 tricuspid valve leaflets. Furthermore, the 3D datasets were of sufficient quality to allow multiplanar reconstruction and offline cropping to facilitate visualization of the device-lead at the level of the tricuspid annulus and its anatomic relationship with the leaflets.

To our knowledge, only 1 other study has used 3D TTE to evaluate device-lead location and its association with TR ([6](#)). Similar to our study, Seo et al. ([6](#)) found that 3D TTE was useful to follow the course and position of the lead as it traverses the tricuspid annulus and that device-lead location in a commissural position was associated with less severe TR. However, in their study, the number of patients with significant TR was much lower. Accordingly, we were able to draw stronger conclusions with regard to the association between device-lead position and significant TR. In addition, the method used to quantify TR severity in their study was the ratio of TR area to right atrial area, which has several limitations. In contrast, we used the vena contracta of the TR jet, because it is simple, reproducible, has been previously validated, and seems to be equally useful with both central and eccentric jets with a sensitivity and specificity of 89% and 93%, respectively, in identifying severe TR ([26](#)). In addition, the vena contracta has been shown to be superior to jet area and the ratio of jet area to right atrial area, correlating more closely with the effective regurgitant orifice ([27](#)). We were also able to show that impinging device-leads were associated with a higher peak TR gradient (used in this study as a surrogate marker for pulmonary arterial hypertension) than nonimpinging device-leads. This association might simply reflect that impinging device-leads are associated with more TR or that worsening pulmonary hypertension (if not related to the presence of TR) might have a tendency to guide the lead into a noncommissural position. This association requires further study.

**Mechanism of device-lead induced TR.** A number of mechanisms have been proposed to explain device-lead associated TR, including leaflet perforation ([4](#)), mechanical interference of the lead with the leaflets, leading to incomplete closure or malcoaptation ([4,8](#)), entanglement of the lead within the tricuspid valve chordal apparatus ([4,28](#)), adherence of the lead to a leaflet ([4](#)), and delayed right ventricle activation or alteration in right ventricle geometry

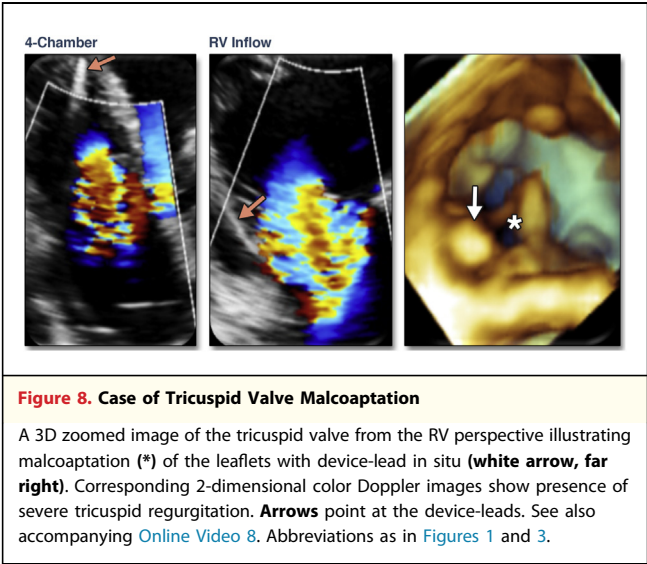


during pacing (29). Most of these observations have originated from autopsy or operative reports.

The usefulness of 3D TTE to elucidate the mechanism of device-lead associated tricuspid valve interference was first described in 2007 (30) when findings on 3D TTE suggestive of leaflet impingement were confirmed by surgical findings. With 3D TTE, we were able to observe both normal leaflet mobility and restricted leaflet motion due to a device-lead impingement, with the septal leaflet being the most commonly affected. In the subset of patients who had pre-implantation echocardiograms of satisfactory quality to allow vena contracta measurements, we were able to confirm that device-leads impinging on a leaflet worsened TR severity post-implantation.

In our study group, we were also able to clearly identify the following mechanisms: leaflet perforation, leaflet malcoaptation, and presence of multiple device leads. Most of the interfering leads were noted to be adhering to or impinging upon a leaflet and impairing leaflet coaptation (Figs. 3, 7, and 8). Therefore, 3D TTE studies should focus on determining whether a device-lead is freely mobile, located in a commissural position, or restricting leaflet motion. If the device-lead is felt to be restricting leaflet motion, further imaging or offline cropping of the 3D dataset should be performed to determine the mechanism causing TR, if possible (Table 3).

One would expect that the older the device-lead the greater the likelihood of impingement, adherence, and therefore worsening TR; however, in our population, the age of the device-lead did not seem to have an obvious impact on TR severity or likelihood of leaflet impingement. We were able to accumulate information on implantation dates in only 66% of our patients, so it is possible that this



information is limited; however, these results might suggest that correction of the device-lead associated TR might lie in the method of lead placement or final anchoring, the material from which the pacemaker is made or the reaction induced in the endocardium after a lead wire is introduced, which might be different between patients.

**Study limitations.** The main limitation of this study is its retrospective nature. However, this might also be its strength, because it shows that the acquisition of the 3D datasets necessary to analyze device-lead position and relationship with surrounding tricuspid valve leaflets does not entail any additional complexity. Also it is possible that vena contracta alone might not be sufficient in estimating TR severity in some patients with devices, because the device lead itself might either interfere with the visualization of the TR jet or, alternatively, result in

Table 3. 3D Transthoracic Imaging in Patients With a Pacemaker, ICD, or CRT/Biventricular Device		
Transducer Position	Structures	Acquisition
Apical 4-chamber	Tricuspid valve and pacemaker lead	Biplane imaging to confirm acquisition of the entire valve in orthogonal views. 3D zoom acquisition with 4-beat breath-hold to maximize frame rate. Crop and position from right ventricular and right atrial perspectives to follow the device-lead at the level of the annulus and leaflets.
	Right ventricle and pacemaker lead	Full-volume acquisition with 4-beat breath-hold. Maximize frame rate by decreasing sector width to include only the right ventricle and atrium, view the acquisition in 3 to 4 image planes to confirm acquisition of all walls of the right ventricle, especially the lateral wall. Tilt pyramidal volume toward you and crop in a plane parallel to the valve plane to the level of the valve leaflets to visualize the device-lead in reference to the leaflets; the volume can also be cropped perpendicular to the valve plane to follow the course of the device-lead or, alternatively device-lead course can also be followed in the multiplanar mode to assess position of the device tip.
CRT = cardiac resynchronization therapy; 3D = 3-dimensional; other abbreviation as in Table 1.		

overestimated vena contracta measurement. Perhaps 3D color full-volume imaging might overcome this obstacle (31), but it was not available in this retrospective study. Another potential limitation is the lack of any gold standard with which to compare the severity of TR. However, such a gold standard does not exist, and the comparison between pre- and post-implantation studies has clearly demonstrated a relationship between right ventricle lead position and TR severity. Furthermore, the clinical impact, if any, of the TR seen in this study is not yet known.

**Future directions.** Awareness of an association between device-lead location and TR severity is important, because re-positioning of the device-lead at the time of implantation is typically the simplest and safest opportunity to correct the problem. Inflammatory changes are known to occur at the site of device-lead placement as early as a few days after lead implantation, with fibrous tissue formation weeks to months later. These changes could potentially preclude repositioning of the device-lead later (32). Although the morbidity and mortality associated with device implantation is reportedly low (0.6% to 1.1%) (33,34), the mortality associated with tricuspid valve surgery is considerably higher (6% to 10%) (35–37). Another important consideration is that, in the presence of significant TR, the tricuspid valve annulus often progressively dilates so that later lead repositioning might be less beneficial, because TR will likely persist and worsen despite correction of lead placement (38). Accordingly, a study that compares 3D TTE targeted guidance of device-lead placement with non-guided lead placement (current

practice) could be very informative. It is not known whether targeted placement of the device-lead in a commissure or in the middle of the valve means that the lead will remain in that position. It has been shown previously that, immediately after device-lead implantation, TR is usually mild and not clinically important (16), so that guiding placement of device-leads on the basis of presence or absence of TR on echocardiography or auscultation is not likely to be useful. Accordingly, evaluation of TR severity and lead position before, immediately after, and several months after device-lead placement needs to be assessed in future studies. It is possible that, if the device-lead was placed in the intercommissural position, device-related TR could be avoided altogether.

## CONCLUSIONS

In this study, we found that device-lead position can be assessed on 3D TTE in most patients. An intercommissural or middle-of-the-annulus position is desired to minimize device-related TR post-implantation. Accordingly, this imaging modality should be routinely used in this context. The results of this study indirectly suggest that 3D TTE-assisted device placement might lead to a reduction in lead-associated TR.

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**Key Words:** intracardiac defibrillator ■ pacemaker ■ 3-dimensional echocardiography ■ tricuspid regurgitation ■ tricuspid valve.

#### APPENDIX

For supplemental videos and their legends, please see the online version of this article.