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ORIGINAL RESEARCH

Proposal for a Standard Echocardiographic Tricuspid Valve Nomenclature

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ABSTRACT

OBJECTIVES The purpose of this study was to introduce a novel clinically relevant nomenclature system for the TV and determine the relative incidence of each morphological type.

BACKGROUND With the rapid development of transcatheter tricuspid valve (TV) repair techniques, there is a growing recognition of the variability in leaflet morphology and a need for a unified nomenclature, which could aid in procedural planning and execution.

METHODS Patients from 4 medical centers (2 in Europe, 2 in the United States) referred for transesophageal echocardiography (TEE) to assess native TV function, were retrospectively analyzed for leaflet morphology with the use of a novel classification scheme. Four morphological types were identified: type I, 3 leaflets; type II, 2 leaflets; type IIIA, 4 leaflets with 2 anterior; type IIIB, 4 leaflets with 2 posterior; type IIIC, 4 leaflets with 2 septal; and type IV, >4 leaflets.

RESULTS A total of 579 patients were analyzed: mean age 78.1 ± 8.0 years, 50.4% female, 70.9% in atrial fibrillation, and 32.2% with previous left heart surgery or transcatheter intervention. Tricuspid regurgitation was moderate or less in 9.4%, severe in 40.5%, massive in 32.3%, and torrential in 17.7%. The etiology of tricuspid regurgitation was primary in 9.4%, mixed in 10.8%, and secondary in all of the other patients (18.6% atriogenic/isolated). The incidence of type I morphology was 312 of 579 (53.9%), type II was 26 of 579 (4.5%), type IIIA was 15 of 579 (2.6%), type IIIB was 186 of 579 (32.1%), type IIIC was 22 of 579 (3.8%), and type IV was 14 of 579 (2.4%).

CONCLUSIONS A novel TV leaflet nomenclature classification scheme can be used to identify 4 types of TV morphologies with the use of TEE imaging. From this multinational retrospective study, the TV has 3 well defined leaflets in only ~54% of patients and 4 functional leaflets in ~39% of patients, with type IIIB (2 posterior leaflets) being the most common of the latter. The utility of this classification scheme deserves further study. (J Am Coll Cardiol Img 2021;14:1299–305) © 2021 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

With the recognition of a strong association between tricuspid regurgitation (TR) and long-term outcomes (1–5) as well as the high mortality associated with surgical intervention for isolated disease (6–12), transcatheter tricuspid valve (TV) repair or replacement device procedures have been increasingly used to treat this morbid disease. The leaflet coaptation devices are

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ABBREVIATIONS AND ACRONYMS

2D = 2-dimensional

3D = 3-dimensional

A = anterior

P = posterior

S = septal

TEE = transesophageal echocardiography

TR = tricuspid regurgitation

TV = tricuspid valve

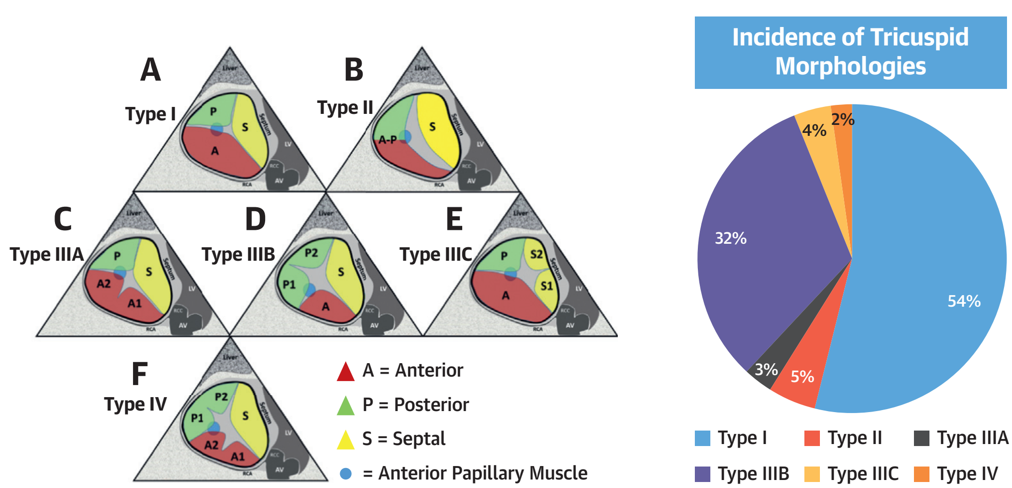
currently the most frequently implanted transcatheter TV repair devices (13); however, challenges for device efficacy remain (14,15). One of these challenges is the variability of number and location of supernumery leaflets or scallops that, if unrecognized, may contribute to procedural failure. Pathologic studies vary in the terminology used to describe these additional leaflets (16,17), and a simplified nomenclature is needed to aid in procedural planning, intraprocedural guidance, and prediction of procedural success. Herein we propose a simple echocardiographic TV nomenclature classification scheme based upon the echocardiographic analysis of this multi-center, multi-national consortium.

METHODS

IMAGING PROTOCOL. The comprehensive transesophageal echocardiographic (TEE) imaging protocol for the TV was determined by the sites. In general, 3 levels of imaging were obtained: midesophageal; distal esophageal; and transgastric. In addition, 2-dimensional (2D) single-plane imaging, as well as 3-dimensional (3D) modalities of multiplane imaging and 3D-rendered images, was performed from multiple levels. Views that allowed the simultaneous imaging of all leaflets were used to determine valve morphology and included the 2D transgastric short-axis view and 3D rendered en face view. Color Doppler from these views was also performed to help determine the presence of commissures or deep folds.

DETERMINATION OF LEAFLET MORPHOLOGY. The tricuspid valve nomenclature classification scheme is shown in the **Central Illustration** in the orientation of a transgastric TEE short-axis view. When described relative to the anatomic position in the body (attitudinally appropriate nomenclature), the 3 leaflets would be the septal, anterior-superior, and inferior leaflets. However, the authors felt that the leaflet designations of septal, anterior, and posterior are generally accepted and therefore were used in this scheme. To determine the position of these 3 basic leaflet locations, there are 3 anatomic structures that are identified in every patient: 1) anteroseptal commissure (identified by the location of the adjacent aortic valve); 2) interventricular septum; and 3) anterior papillary muscle (identified as the most anterior prominent papillary muscle, typically fused with the moderator band). The leaflets can then be defined as: 1) septal leaflet: leaflet attached to the interventricular septum; 2) anterior leaflet: leaflet

CENTRAL ILLUSTRATION Tricuspid Valve Nomenclature Classification Scheme



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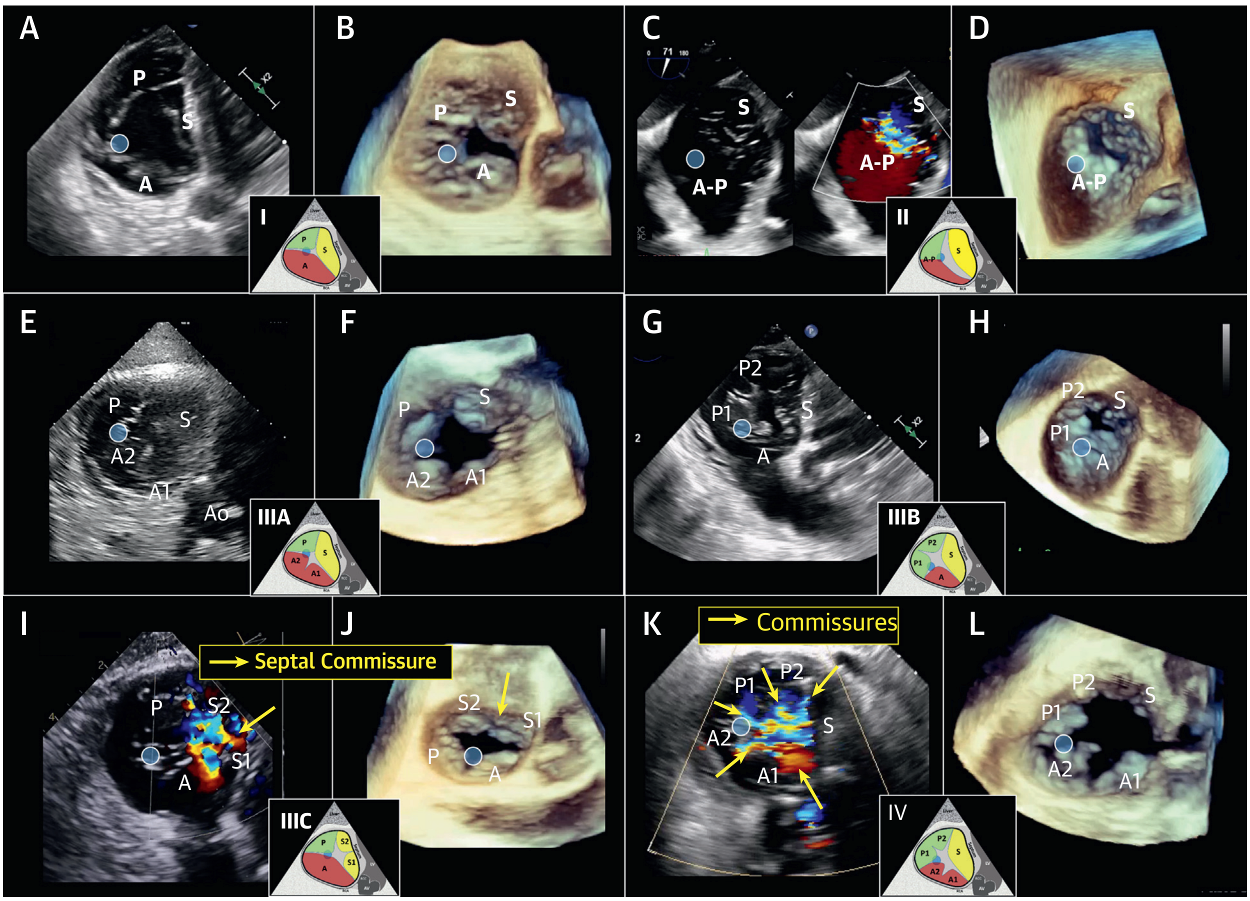
(Left) A proposed tricuspid valve nomenclature classification scheme is shown. The anterior papillary muscle is indicated as a **blue circle** and defines the separation of the anterior from the posterior leaflets. **(A)** Type I: 3-leaflet configuration. **(B)** Type II: 2-leaflet configuration. **(C to E)** Type III: 4-leaflet configurations. **(F)** Type IV: 5-leaflet configuration. **(Right)** Incidence of each morphology in the present study of 579 patients. A = anterior leaflet; AV = aortic valve; LV = left ventricle; NCC = noncoronary cusp; P = posterior leaflet; RCC = right coronary cusp; S = septal leaflet.

FIGURE 1 **Transesophageal Imaging Examples of Tricuspid Valve Nomenclature Classification Scheme**



In the examples shown in this Figure, locating the anterior papillary muscle **(blue circle)** defines the commissure between the anterior and posterior leaflets. **(A, C, E, G, I, K)** Transgastric 2-dimensional imaging plane; **(B, D, F, H, J, L)** 3-dimensional en face midesophageal view. **(A, B)** Type I, 3-leaflet configuration; **(C, D)** type II, 2-leaflet configurations; **(E, F)** type IIIA, quadricuspid valve with 2 anterior leaflet; **(G, H)** type IIIB, quadricuspid valve with 2 posterior leaflets; **(I, J)** IIIC, quadricuspid valve with 2 septal leaflets; **(K, L)** type IV, 5-leaflet configuration. A = anterior leaflet; P = posterior leaflet, S = septal leaflet.

extending from the anteroseptal commissure to the anterior papillary muscle; and (3) posterior leaflet: leaflet extending from the anterior papillary muscle along the inferior wall of the right ventricle (RV) to the posteroseptal commissure.

Separating leaflet from scallops (and thus true commissures from indentations or clefts) is difficult by means of echocardiography; however, it is the consensus of the authors that this anatomic distinction may not be necessary for the purposes of procedural planning, execution, and outcomes. Both commissures and indentations or clefts within a leaflet may have more numerous chordae or arcades of complex chordal attachments that may make device positioning more difficult. Thus, the term leaflet is used throughout the manuscript, understanding that it may not be possible to distinguish a leaflet from a scallop. More difficult is determining if a leaflet is simply redundant but continuous versus multileaflet. A separate leaflet was defined by: 1) motion independent from the adjacent leaflet; and 2) color Doppler systolic flow extending into the region around the leaflet (Figure 1). For multiple anterior leaflets, the numbering of the leaflets begins at the anteroseptal commissure with A1, and the next more inferior/lateral leaflet would be A2. For multiple posterior leaflets, the numbering of the leaflets begins at the anterior papillary muscle with P1, and the next more posterior leaflet would be P2. For multiple septal leaflets, the numbering of the leaflets begins at the anteroseptal commissure with S1, and the next more posterior leaflet would be S2. For a bileaflet

TABLE 1 Baseline Clinical Characteristics, Etiology of Tricuspid Regurgitation, and Tricuspid Valve Morphology

Age (n = 579)	78.1 ± 7.98
Female (n = 579)	292 (50.4)
Rhythm (n = 573)	
NSR	83 (14.5)
Atrial fibrillation/flutter	406 (70.9)
Paced	84 (14.7)
Previous cardiac interventions (n = 575)	
None	390 (67.8)
SAVR	40 (7.0)
TAVR	27 (4.7)
Surgical MV intervention (±SAVR)	55 (9.6)
Transcatheter MV repair (±TAVR)	49 (8.5)
CABG only	14 (2.4)
CIED (n = 575)	
Ventricular pacing wire	128 (22.2)
Leadless pacemaker	4 (0.7)
Etiology of tricuspid regurgitation (n = 575)	
Primary/degenerative	66 (11.5)
Secondary/functional	
Atriogenic	107 (18.6)
Left heart disease	166 (28.9)
Pulmonary hypertension	75 (13.0)
Other	99 (17.2)
Mixed	62 (10.8)
Severity of tricuspid regurgitation (n = 575)	
≤Moderate	54 (9.4)
Severe	233 (40.5)
Massive	186 (32.3)
Torrential	102 (17.7)
Morphology of tricuspid valve (n = 579)	
Type I	312 (53.9)
Type II	26 (4.5)
Type IIIA	15 (2.6)
Type IIIB	186 (32.1)
Type IIIC	22 (3.8)
Type IV	14 (2.4)
Indeterminate	4 (0.7)

Values are mean ± SD or n (%).

CABG = coronary artery bypass graft; CIED = cardiac implantable electrode device; MV = mitral valve; NSR = normal sinus rhythm; SAVR = surgical aortic valve replacement, TAVR = transcatheter aortic valve replacement; TV = tricuspid valve.

valve, there is usually fusion of the anterior and posterior leaflets. Finally, small (<10% of the circumference of the annulus) commissural leaflets are frequently seen at the anteroseptal and posteroseptal commissures and should be separately identified but not numbered, because given their position in the commissure, identifying the primary cusp (and thus naming the leaflet) is not possible.

DEFINITION OF REGURGITANT ETIOLOGY. The morphological abnormalities which defined primary TR included prolapse, flail or any other primary leaflet abnormality. The morphological abnormalities which defined secondary TR included: 1) tethering or tenting of the TV leaflets; 2) displacement of the papillary muscles (either anterior papillary muscle with RV dilation or septal papillary muscles with septal displacement); and 3) dilation of the annulus or RA. When using the term "mixed disease," there were components of both degenerative disease (i.e., prolapse or flail) in addition to functional disease (i.e., tethering of the leaflets or marked annular dilation).

The inclusion of patients in this study was approved in each center by a local ethical committee or per local practice for the collection of retrospective data.

RESULTS

The transesophageal echocardiograms (TEEs) of 579 patients from 4 medical centers with expertise in imaging the TV (2 in Europe and 2 in the United States) were retrospectively analyzed by each site for TV leaflet morphology with the use of a standard naming algorithm. Consecutive studies were performed specifically to evaluate the TV and included comprehensive imaging from transgastric views.

BASELINE CHARACTERISTICS. A total 579 patients (253 from Munich, 140 from New York, 133 from Leipzig, and 53 from Minneapolis) were included in the analysis. Baseline and TV characteristics are presented in Table 1. The mean age was 78.1 ± 8.0 years; 50.4% were female. There were 22.9% with a ventricular cardiac implantable electronic device; however, only 14.7% of the patients were in a paced rhythm at the time of evaluation. The majority of patients were otherwise in atrial fibrillation (70.9%), with only 14.5% in normal sinus rhythm. The majority of patients (67.8%) had no previous left heart surgery performed. Of the remaining 185 patients, the majority had undergone a mitral procedure (104 of 185; 56%) either in isolation or in combination with an aortic procedure, and 67 of 185 patients (36%) had a previous isolated surgical aortic valve procedure.

TRICUSPID VALVE FUNCTION. Only 11.5% of patients had primary TR (either degenerative or pacemaker related). Left heart valve disease was thought to be the etiology of secondary TR in 28.9%, with atriogenic secondary TR the next most common etiology (18.6%). A precise etiology of secondary TR could not be identified in 17.2% of patients, and a mix of primary and secondary disease was seen in 10.8%. The severity of TR was assessed with the use of a 5-grade scale as previously described (18). Of the patients presenting for evaluation of the TV, only 9.4% had moderate or less TR, 40.5% had severe TR, 32.3% had massive TR, and 17.7% had torrential TR.

TABLE 2 Prevalence of Tricuspid Valve Types in Patients With Severe, Symptomatic Tricuspid Regurgitation in Patients Who Could Be Assessed by Transesophageal Echocardiography

Site	Type I	Type II	Type IIIA	Type IIIB	Type IIIC	Type IV
Universität München (n = 249)	48.2 (120)	4.0 (11)	1.2 (3)	41.1 (102)	1.6 (4)	3.6 (9)
Columbia University (n = 140)	57.1 (80)	4.2 (6)	2.9 (4)	25.0 (35)	7.1 (10)	3.5 (5)
University of Leipzig (n = 133)	61.7 (82)	2.3 (3)	1.5 (2)	33.8 (45)	0.8 (1)	0.0 (0)
Abbott Northwestern (n = 53)	56.6 (30)	11.3 (6)	11.3 (6)	7.5 (4)	13.2 (7)	0.0 (0)
Total = 575	54.3 (312)	4.5 (26)	2.6 (15)	32.3 (186)	3.8 (22)	2.4 (14)

Values are % (n).

TRICUSPID VALVE MORPHOLOGY. Of the 575 patients in whom valve morphology could be determined (Table 2), 54% had type I, 4.5% had type II, 2.6% had type IIIA, 32.1% had type IIIB, 3.8% had type IIIC, and 2.4% had type IV. The 4 patients whose morphology could not be assessed did not have transgastric views, which is the primary 2D imaging level for assessment of the short-axis TV annular plane.

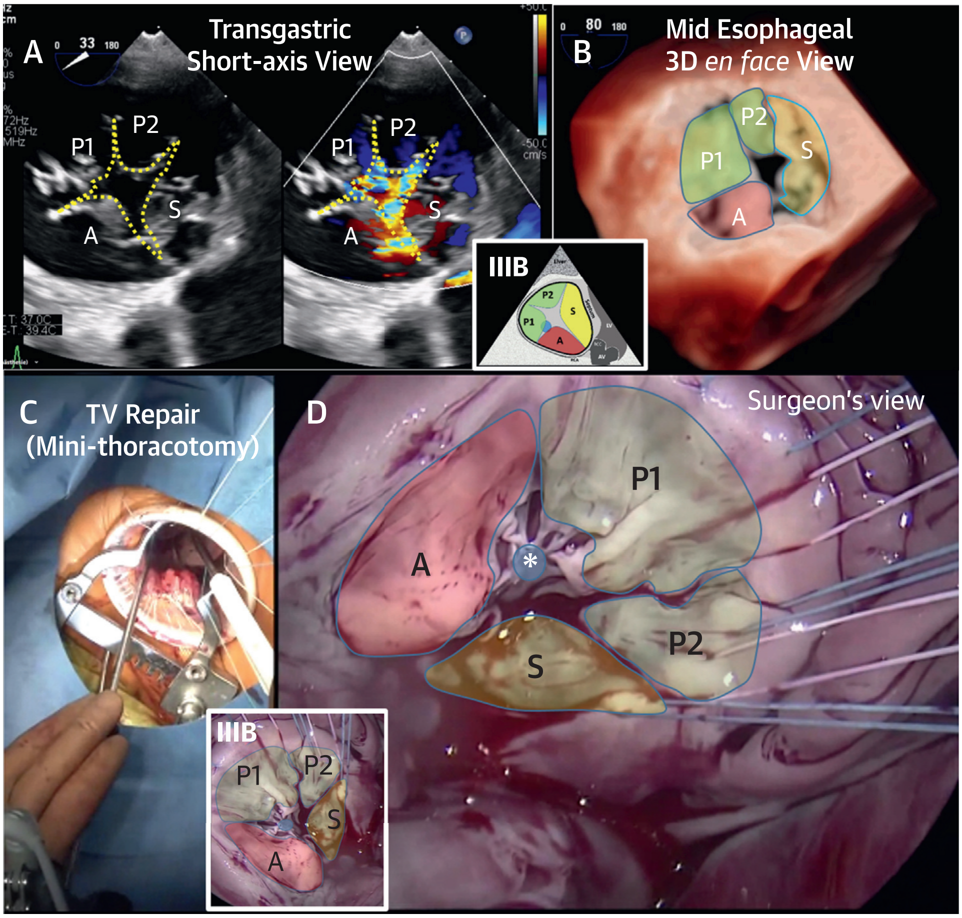
DISCUSSION

This study demonstrates the feasibility of identifying complex TV leaflet anatomy in vivo with the use of TEE imaging and a defined algorithm for determining leaflet location and number. The proposed methods were easily instituted by multiple institutions but do require adequate transgastric short-axis views of the TV (both without and with color Doppler), as well as 3-dimensional en face views. Additional leaflets not only may have more complex chordal structures or limited leaflet grasping area, but also may add significant complexity to the shape of the regurgitant orifice. Because leaflet anatomy may influence transcatheter TV device success, knowing the precise anatomy of the valve may improve preprocedural planning and intraprocedural technical success. Use of this nomenclature may allow physicians to use a morphology-specific approach to device choice.

The current proposed classification scheme is based on multiple pathological studies that have confirmed the existence of these TV variants (16,17,19) as well as direct surgical visualization (Figure 2). Type I is the classic 3-leaflet morphology with anterior, septal, and posterior leaflets. This configuration occurs in 28% to 58% of cases. (16,17). In the typical 3-leaflet configuration, the anterior and septal leaflets are usually the largest circumferentially, and thus the anteroseptal commissure is typically the longest. Type II is the 2-leaflet configuration which from pathological studies, occurs in ~2% to 10% of cases. The anterior and posterior leaflets are not clearly separated and form a single large leaflet. Type III tricuspid valves have 4 leaflets. In pathological studies, this configuration may be seen in 42% to 52% of cases. The fourth leaflet can be in the typical location of the anterior leaflet (IIIA), posterior leaflet (IIIB), or septal leaflet (IIIC). Distinguishing between types IIIA and IIIB is determined by the location of the large anterior papillary muscle: IIIA has 2 leaflets anterior to the anterior papillary muscle, and IIIB has 2 leaflets posterior to the anterior papillary muscle. Some studies suggest that type IIIB may be the most common of the 4-leaflet morphologies. When more than 3 leaflets are present, numbering the leaflets starting from the anterior-septal commissure is preferred, because the location of this commissure is the most consistent and associated with the anatomic landmark of the aortic valve. Using the numbering system that uses the anterior-septal commissure as the starting point makes identification of additional leaflets simple and logical. Whether the supernumerary leaflets are actual leaflets (with commissures extending to the annulus) or deep folds may not be relevant to the discussion for leaflet coaptation devices, because either are an impediment to grasping leaflet tissue.

The use of the anterior papillary muscle to distinguish anterior from posterior leaflets is based on pathological studies showing that the anterior papillary muscle is the largest and most consistent in location and structure (20). It arises from the anterior/lateral wall of the RV near the trabeculations that incorporate the moderator band near the RV apex (21). This papillary muscle has chordal attachments to the anterior and posterior leaflets. Posteriorly, there may be multiple smaller papillary muscles, which have chordal attachments to the posterior and septal leaflets. The variable septal papillary muscle is the smallest one and may be a complex of small muscles in close proximity that have chordal attachments to the anterior and septal leaflets. Chordae frequently arise directly from the septum to the anterior and septal leaflets (21).

FIGURE 2 **Surgical Confirmation of Type IIIb Morphology**



(A, B) Intraoperative transesophageal imaging from the 2-dimensional transgastric view **(A)** and the 3D-rendered en face midesophageal view **(B)** showed a type IIIB (insert), quadricuspid tricuspid valve with 2 posterior leaflets. **(C, D)** During the minimally invasive surgical repair **(C)**, the surgeon's direct visualization **(D)** showed a large anterior papillary muscle **(blue circle/asterisk)** separating the anterior leaflet (A, **red-shaded region**) from the first large posterior leaflet (P1, **green-shaded region**). A completely separate leaflet (P2) was also identified, between the P1 and septal leaflet (S, **yellow-shaded region**). The **inset** shows a rotation of the surgeon's view to an orientation similar to the transgastric transesophageal imaging view (Imaging by the Heart Center Leipzig, University of Leipzig).

STUDY LIMITATIONS. The 4 institutions that participated in this study have significant experience in both imaging the TV and performing transcatheter TV device procedures and as such, have TEE imaging expertise. How feasible the identification of leaflet morphology is in less experienced sites or with limited imaging is not known. Even with this cumulative experience, the relative incidence of each type of leaflet morphology differs between the sites and may be related to the difficulty in differentiating leaflet redundancy from true commissures or deep indentations. As we continue to refine imaging protocols to differentiate the complex leaflet anatomy, the interobserver variability that may contribute to differences in the relative incidences of subgroup types should improve. Population-based differences, however, could also exist. In addition, the majority of the patients had TEEs performed to assess for suitability of transcatheter TV device therapy in patients with symptoms of right heart failure, so selection bias may influence the incidence of leaflet anatomy. Nonetheless, the overall incidence of each type of TV morphology seems to correlate well with autopsy studies, giving credibility to the nomenclature and the method of identification. In the future, the use of multimodality imaging could be used for leaflet identification. Finally, the purpose of this study was to introduce this nomenclature and describe how best to define each morphological class; although it is the general impression of the authors that certain morphologies may be more difficult to address with leaflet coaptation devices, this deserves further study.

CONCLUSIONS

A simple TV nomenclature classification can be used to identify complex leaflet anatomy with the use of TEE. From this multinational retrospective study, the TV has 3 well defined leaflets in only 54% of patients and 4 functional leaflets in 39% of patients, with type IIIB (2 posterior leaflets) being the most common among the latter. The utility of this scheme and relation to transcatheter TV device technical success deserve further study.

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Dr. Hahn received speaker fees from Edwards Lifesciences; consulting for Abbott Vascular, Boston Scientific, and Medtronic; equity with Navigate; and is the Chief Scientific Officer for the Echocardiography Core Laboratory at the Cardiovascular Research Foundation for multiple industry-sponsored trials, for which she receives no direct industry compensation. Dr. Bae is a consultant for Abbott Vascular. Dr. Hausleiter has received research support and speaker honoraria from and serves as a consultant for Abbott Vascular and Edwards Lifesciences. Dr. Nabauer has received speaker fees from Abbott Vascular and Edwards Lifesciences. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: The tricuspid valve leaflet anatomy is highly variable, with fewer than 55% of patients exhibiting the classic 3-leaflet conformation. The next most common morphological subtype is a quadricuspid valve with 2 posterior leaflets.

TRANSLATIONAL OUTLOOK: Identification of leaflet morphology may be an important determinant of transcatheter tricuspid valve repair device success, allowing for informed pre-procedural planning and device choice. Further studies clarifying the role of valve morphology for technical success of leaflet coaptation devices are warranted.

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