Tricuspid annular dynamics, not diameter, predicts tricuspid regurgitation after mitral valve surgery: Results from a prospective randomized trial

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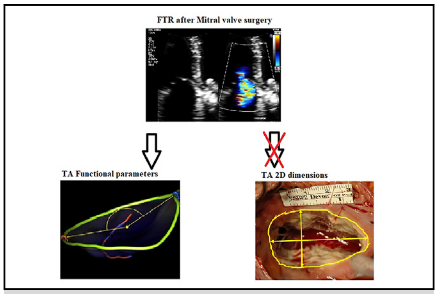
ABSTRACT

Objective: Current guidelines advise using prophylactic tricuspid valve annuloplasty during mitral valve surgery, especially in the presence of annular diameter enlargement. However, several retrospective studies and a prospective randomized study from our department could not confirm that diameter enlargement is predictive of late regurgitation. We examined whether 2- and 3-dimensional echocardiographic and clinical characteristics could identify patients who will develop moderate or severe recurrent tricuspid regurgitation.

Methods: Patients with less than severe functional tricuspid regurgitation (FTR) were randomized not to receive tricuspid annuloplasty, and 11 of 53 of them were excluded from the study because 3-dimensional echocardiographic analysis was not possible. Cox regression was used to estimate the model-based probability of moderate or severe FTR (vena contracta $\geq$3 mm) or progression of TR and FTR regression using valve dimensions (annulus area, diameter perimeter, nonplanar angle, and sphericity index), dynamics (annulus contraction, annulus displacement, and displacement velocity), and clinical parameters as possible predictors.

Results: At a median follow-up of 3.8 years (range, 3-5.6 years), 17 patients had moderate or severe FTR or progression, and 13 had FTR regression. Our models identified annular displacement velocity as a significant predictor for FTR recurrence and nonplanar angle as a significant predictor for FTR regression.

Conclusions: Annular dynamics, not the dimension, predict recurrence and regression of FTR. Annular contraction should be systematically investigated as a possible surrogate of right ventricle function to prophylactically treat the tricuspid valve. (JTCVS Open 2023;14:92-101)



Not diameter but annular dynamics predict functional tricuspid regurgitation.

CENTRAL MESSAGE

The tricuspid annulus's saddle shape and annular displacement predict postoperative functional tricuspid regurgitation, not the simple diameter or area.

PERSPECTIVE

In patients treated with mitral valve surgery, 3D echo-derived annular parameters predict postoperative functional tricuspid regurgitation as a surrogate of right ventricle function and thus tricuspid regurgitation derived from subclinical dysfunction of the right ventricle.

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Severe functional tricuspid regurgitation (FTR) is associated with reduced exercise capacity and decreased long-term survival.[1,2] Severe FTR seldom decreases spontaneously after left-sided valve surgery,[3] and both the American College Cardiology/American Heart Association (ACC/AHA) and European Society of Cardiology guidelines[4] recommend performing tricuspid annuloplasty on patients with severe FTR undergoing left-sided valve surgery as a Class I indication. However, it remains uncertain whether patients with milder degrees of FTR should also undergo prophylactic tricuspid surgery.

The results of recent nonrandomized[5] and randomized[6] studies suggest that such patients do benefit from the addition of tricuspid annuloplasty to left-sided valve surgery, as

Abbreviations and Acronyms

2D	= 2-dimensional
3D	= 3-dimensional
ACC	= American College Cardiology
AHA	= American Heart Association
FTR	= functional tricuspid regurgitation
LS	= late systole
RV	= right ventricle/ventricular
SA	= septum to the anterior leaflet
TA	= tricuspid annulus
TEE	= Transesophageal echocardiography
TR	= tricuspid regurgitation

they display less postoperative tricuspid regurgitation (TR),[5] improved functional capacity,[7] and better right ventricular (RV) function.[8] Accordingly, recent ACC/AHA and European Society of Cardiology guidelines now recommend, as a Class IIa indication, to perform tricuspid valve (TV) annuloplasty on patients undergoing left-sided valve surgery, provided that they exhibit both mild-to-moderate TR and a dilated tricuspid annulus (TA; 21 mm/m^2 or 40 mm). These cutoff values were previously found to best discriminate between patients with and without severe TR after left-sided valve surgery.[9] However, recent studies have questioned the validity of these anatomical criteria, as they have failed to demonstrate any meaningful association between preoperative 2-dimensional (2D) echo tricuspid annular dimensions and either the presence or severity of postoperative TR.[10,11]

Because the TV has a complex 3-dimensional (3D) and noncircular geometry, 2D echocardiography may not be the most accurate method for TA quantification.[12] In this regard, we have recently demonstrated that 3D echo measurements of the TA correlate better with surgery than 2D echo measurements (Figure E1).[13] Based on these observations, the aim of the present study was to assess the ability of 3D echocardiography to identify patients who will develop or exhibit persistent moderate or severe FTR after mitral valve surgery.

METHODS

Study Population

Between May 2009 and December 2010, 106 patients with less-than-severe FTR (<7-mm vena contracta) were enrolled in a randomized trial to evaluate the effects of TV annuloplasty on the persistence or recurrence of moderate-to-severe postoperative FTR. Patients with primary disease of the TV were excluded. The surgical protocol and techniques have been described previously, and the clinical and echocardiographic results have been reported.[6] The study protocol was approved by the institutional review board (Ethical committee, Cliniques Universitaires Saint-Luc, approval number: 03604484, date of approval January 2, 2009), and each patient gave written informed consent before inclusion. This study is a subanalysis of the randomized trial. From the original population, among patients who were not treated by TV annuloplasty (53 patients), 42 had 3D echocardiographic images available and were included in the study population.

Pre- and Postoperative 2D Transthoracic Echocardiography

Standardized pre- and postoperative transthoracic echocardiography examinations were performed according to established guidelines using iE33 Ultrasound Systems (Philips Medical Systems), which were equipped with a 3.5/1.75-MHz phased-array transducer. For offline analysis, images were stored on an XCELERA 2.1 PACS server (Philips Medical Systems). Four-chamber views centered on the RV were used to evaluate RV dimensions and function and to measure the TA dimensions. Magnified 2D color Doppler images centered on the TV were used to measure the vena contracta of the tricuspid regurgitant jet.

Intraoperative 2D and 3D Transesophageal Echocardiography (TEE)

Experienced cardiologists or anesthesiologists performed all TEE examinations after induction of general anesthesia and before cardiopulmonary bypass using an iE-33 ultrasound system equipped with an X7-2t TEE probe (Philips Medical Systems). First, 2D standard and magnified color Doppler images of the TV were acquired at an average frame rate of 55 to 60 Hz. The TA diameter was measured at end-systole and end-diastole from 3 different views: a 4-chamber view, RV inflow–outflow view, and transgastric right ventricle inflow view. 3D echo images of the TA were then acquired during brief periods of breath holding without electrical interference or patient movement over 4 to 8 cardiac cycles. Great care was taken to include the entire TA within the 3D volume.

3D Echo Data Analysis

3D echo datasets were analyzed offline using Image Arena software (Tom-Tec Corporation GmBH) and the 4D mitral valve analysis package. This package was initially designed for the semiautomatic identification and measurements of the mitral annulus and leaflets throughout the entire cardiac cycle. However, we recently demonstrated that it can also be used to assess the dimension and shape of the TA.[13]

For annular measurements, only 6 specific time points were analyzed: early systole: the first frame after closure of the TV; late systole (LS): the last frame before TV opening; midsystole: the midpoint between early systole and late systole; early diastole: the first frame after valve opening; late diastole: the last frame before completing TV closure; and mid-diastole: the midpoint between early diastole and late diastole. For each of the prespecified time points, the software automatically generates the following measurements: (1) the maximal diameter from the septum to the anterior leaflet (SA diameter); (2) the lateral–lateral diameter (the largest diameter perpendicular to the previous); (3) the annulus area (2D and 3D); (4) the annulus perimeter (2D and 3D); (5) the annulus height; (6) the sphericity index of the annulus; (7) the annular displacement and displacement velocity (defined as the longitudinal movement of the annulus centroid and its first derivative); (8) the annular area fraction, defined as the follows: (max annulus area–min annulus area)/(max annulus area); and (9) the nonplanar angle, defined as the angle between the 2 vectors from the 2 hinge points of the annulus in the SA plane to the center of the laterolateral axis (Figure 1).

End Points of the Study

The primary end point was the presence of more than mild FTR (defined as vena contracta $\geq$3 mm) in the latest postoperative transthoracic echo available or an increase in FTR severity (increase in vena contracta width of $\geq$2 mm) from the preoperative transthoracic echo to the last postoperative transthoracic echo available. The secondary end point was the regression of FTR, which was defined as a reduction in the vena contracta width of $\geq$2 mm between pre- and postoperative echoes. The definition of the

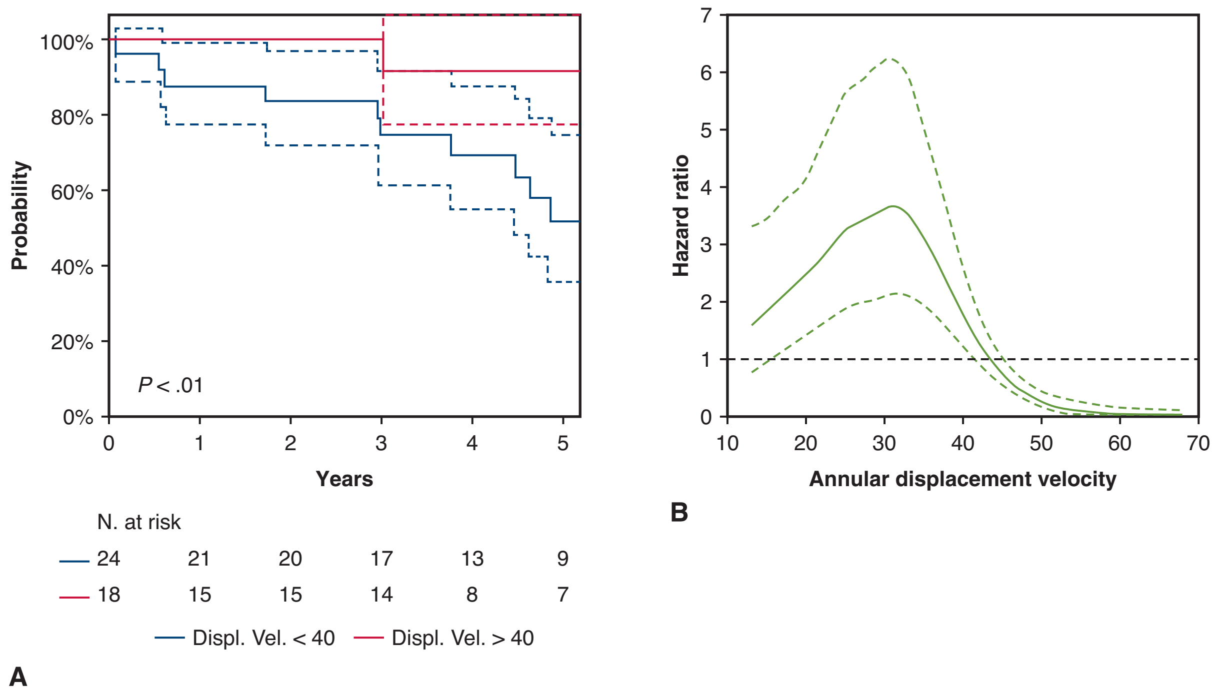

FIGURE 1. A, Kaplan–Meier curve of moderate-to-severe FTR in function of annular displacement velocity (Displ. Vel.) with 95% confidence intervals. B, Spline function of hazard risk of FTR and its progression in function of annular displacement velocity with 95% confidence intervals. *FTR*, Functional tricuspid regurgitation.

vena contacta threshold was derived from the intra-rater and inter-rater reliability analysis of the FTR. Those measurements were are 0.09 ± 0.3 and 0.15 ± 0.4 mm and therefore we chose the 2-mm threshold, taking in consideration the variability of the FTR measurements.

Statistical Analysis

All analyses were conducted with RStudio software (Version 1.0.153; RStudio, Inc). Continuous variables were expressed as the mean ± standard deviation, categorical variables were expressed as counts and percentages,

TABLE 1. Clinical, hemodynamic, and echocardiographic characteristics

Parameters	All N = 42	TR progression N = 17	TR regression N = 13	Stable TR N = 12
Demographic data				
Age, y	62 ± 14	60 ± 14	60 ± 13	68 ± 15
Male, n (%)	27 (64)	10 (66)	10 (66)	7 (58)
BSA, m^2	1.8 ± 0.2	1.8 ± 0.2	1.9 ± 0.2	1.7 ± 0.3
Risk factor				
Arterial hypertension, n	20 (47)	8 (53)	6 (40)	6 (50)
Smoking, n (%)	7 (16)	3 (20)	3 (20)	1 (8)
Diabetes, n (%)	2 (5)	1 (7)	1 (7)	0 (0)
Comorbidities				
Stroke, n (%)	2 (5)	0 (0)	1 (7)	1 (8)
COPD, n (%)	3 (7)	0 (0)	1 (7)	2 (17)
PVD, n (%)	1 (2)	1 (7)	0 (0)	0 (0)
Kidney failure, n (%)	1 (3)	0 (0)	0 (0)	1 (8)
Sinus rhythm, n (%)	36 (85)	14 (93)	13 (87)	9 (75)
Symptoms and etiology				
NYHA III-IV, n (%)	11 (26)	4 (26)	2 (13)	5 (41)
Degenerative, n (%)	27 (64)	11 (73)	8 (53)	8 (66)
Barlow, n (%)	8 (19)	2 (13)	4 (27)	2 (17)
Rheumatic, n (%)	7 (16)	2 (13)	3 (20)	2 (16)

TR, Tricuspid regurgitation; *BSA*, body surface area; *COPD*, chronic obstructive pulmonary disease; *PVD*, peripheral vascular disease; *NYHA*, New York Heart Association.

TABLE 2. Preoperative 2D echocardiographic data

Parameters	All N = 42	TR and progression TR N = 17	Regression TR N = 13	Stable N = 12
LV dimension and function				
LVEDD, mm	52 ± 10	52 ± 9	52 ± 7	53 ± 15
LVESD, mm	34 ± 8	35 ± 9	33 ± 7	32 ± 9
LVEDV, mL	228 ± 67	228 ± 59	227 ± 79	231 ± 63
LVESV, mL	91 ± 43	91 ± 43	90 ± 48	91 ± 38
EF, %	60 ± 10	61 ± 12	61 ± 9	57 ± 7
LV stroke volume, mL	40 ± 29	48 ± 26	24 ± 33	43 ± 31
Atrial dimension				
LA vol, mL	113 ± 53	126 ± 72	107 ± 45	105 ± 29
RA vol, mL	67 ± 40	66 ± 32	54 ± 27	85.3 ± 62
Mitral valve				
Pre-VC MR, cm	0.7 ± 0.3	0.8 ± 0.3	0.7 ± 0.3	0.7 ± 0.3
Pre-ERO PISA MR, cm^2	0.6 ± 0.3	0.6 ± 0.3	0.6 ± 0.3	0.6 ± 0.2
RV dimension and function				
TAPSE RV, mm	2 ± 0.6	2.1 ± 0.5	2 ± 0.4	2.2 ± 0.9
RVED area, cm^2	23 ± 5	24 ± 5	23 ± 5	24 ± 4
RVES area, cm^2	15 ± 3	15 ± 4	14 ± 3	14 ± 2
RV FAC, %	36 ± 9	35 ± 10	36 ± 9	37 ± 7
RV basal diameter, mm	42 ± 7	42 ± 7	42 ± 7	41 ± 9
RV mid-diameter, mm	36 ± 9	36 ± 6	33 ± 6	41 ± 16
PAP systolic, mm Hg	39 ± 18	39 ± 15	44 ± 16	31 ± 23
Tricuspid valve				
TR mild	20 (47%)	8 (53%)*	10 (66%)†	2 (16%)
TR moderate	7 (16%)	2 (13%)†	5 (33%)†	0 (0%)
TR vena contracta, mm	2.0 ± 2.1	1.4 ± 2.1	3.7 ± 1.4*,†	0.4 ± 1.0

2D, 2-Dimensional; *TR*, tricuspid regurgitation; *LV*, left ventricular; *LVEDD*, left ventricle end-diastolic diameter; *LVESD*, left ventricle end-systolic diameter; *LVEDV*, left ventricle end-diastolic volume; *LVESV*, left ventricle end-systolic volume; *EF*, ejection fraction; *LA*, left atrium; *RA*, right atrium; *VC*, vena contracta; *MR*, mitral regurgitation; *ERO*, effective regurgitant orifice; *TAPSE*, tricuspid annular phase systolic excursion; *RV*, right ventricle; *RVED*, right ventricle end diastolic; *RVES*, right ventricle end systolic; *FAC*, fractional area change; *PAP*, pulmonary artery pressure. *$P < .01$ versus TR and regression group. †$P < .01$ versus stable group.

and follow-up times were expressed as the median and range. Continuous variables were compared using a Student *t*-test or the Mann–Whitney *U* test. Categorical variables were compared using the χ^2 test or Fisher exact test as appropriate. All tests were 2-sided. Kaplan–Meier curves and Cox proportional hazard regression analyses were used to identify the factors independently associated with the primary and secondary end points. Penalized smoothing splines were used to show the association between independent predictors as a continuous variable and the risk of primary and secondary end points and to identify adequate cutoff values. A sensitivity analysis was performed for the primary and secondary outcome after exclusion of the patients who underwent reoperation or died during the follow-up.

RESULTS

Clinical, Hemodynamic, and Echocardiographic Characteristics

The study population was divided into 3 groups. Group 1 consisted of patients exhibiting at least moderate postoperative FTR or presenting with worsening FTR, Group 2 consisted of patients showing TR regression, and Group 3 included patients with stable FTR between pre- and postoperative echoes. Table 1 shows their clinical characteristics. No significant differences were found between groups.

The hemodynamic and echocardiographic characteristics of the 3 groups are shown in Tables 2 and 3. As shown, the 3 groups differed in the severity of preoperative FTR, which was significantly lower in group 3 than the 2 other groups. Group 2 had smaller nonplanar angles, and group 1 displayed lower annular displacement velocity and lower absolute annular displacement. Interestingly, no significance differences in annular dimensions were found between the 3 groups.

Outcome

The median follow-up was 3.1 years. During follow-up, 3 patients died: one patient from acute pulmonary bleeding, one from progressive pulmonary insufficiency (severe chronic obstructive pulmonary disease), and one from progressive heart failure. The overall 5-year survival rate was 92 ± 4%. During the same period, 3 patients needed mitral reoperation because of recurrent severe mitral regurgitation. The overall 5-year rate of freedom from reoperation was of 89 ± 6%. At the end of follow-up, 94% of the patients were in New York Heart Association class I to II.

TABLE 3. Preoperative 3D echocardiographic data

Parameters	All N = 42	TR and progression N = 17	Regression TR N = 13	Stable N = 12
Annulus dimension				
SA diameter, mm	33 ± 7	33 ± 7	32 ± 6	34 ± 7
LL diameter, mm	35 ± 7	34 ± 5	36 ± 7	36 ± 8
Sphericity index	0.9 ± 0.1	1.0 ± 0.2	0.9 ± 0.1	1.0 ± 0.1
Nonplanar angle, °	162 ± 13	165 ± 11*	153 ± 14†	169 ± 7
Circumference (3D), cm	11 ± 2	11 ± 2	11 ± 2	12 ± 2
Area (2D), cm^2	9 ± 3	9 ± 2	9 ± 3	10 ± 4
Area (3D), cm^2	10 ± 3	9 ± 3	10 ± 3	10 ± 4
Height, cm	0.7 ± 0.2	0.7 ± 0.3	0.6 ± 0.2	0.6 ± 0.2
Tenting values				
Tenting volume, mL	0.7 ± 0.8	1.2 ± 1.1	0.5 ± 0.5	0.3 ± 0.1
Tenting area, cm^2	0.6 ± 0.5	0.7 ± 0.4	0.6 ± 0.6	0.5 ± 0.4
Tenting height, mm	19 ± 16	26 ± 21	14 ± 10	18 ± 12
Leaflet dimension				
SL area, cm^2	4.1 ± 1.8	4.1 ± 1.6	4.0 ± 1.7	4.3 ± 2.3
AL + PL area, cm^2	7.7 ± 2.9	7.5 ± 2.7	7.8 ± 3.0	8.0 ± 3.1
SL length, cm	1.4 ± 0.5	1.4 ± 0.3	1.3 ± 0.4	1.5 ± 0.7
AL + PL length, cm	2.3 ± 0.9	2.2 ± 0.6	2.7 ± 1.4	2.2 ± 0.5
Annular dynamics				
Displacement, mm	9.9 ± 5.5	7.9 ± 2.7	11.3 ± 8.4	11.0 ± 3.2
Displacement velocity, mm/s	38 ± 13	31 ± 8†	38 ± 15	46 ± 11
Annulus area fraction, %	14 ± 8	12 ± 4	12 ± 5	18 ± 11

3D, 3-dimensional; *TR*, tricuspid regurgitation; *SA*, septal anterior; *LL*, laterolateral; *2D*, 2-dimensional; *SL*, septal leaflet; *AL*, anterior leaflet; *PL*, posterior leaflet. **P* < .01 compared with regression of TR. †*P* < .01 compared with the stable group.

Primary End Point

At the end of follow-up, 17 patients displayed more than mild FTR or had experienced progression of FTR. The Cox regression analysis identified LS annular displacement velocity as the sole independent predictor of persistent or progressing FTR (hazard ratio, 0.93; confidence interval, 0.87-0.99, *P* = .02; Table 4). Using penalized spline function analysis (Figure 2), a cutoff value of 45 mm/s for the annular displacement velocity was found to best predict the primary end point, with sensitivity of 94%, specificity of 50%, overall accuracy of 78%, and area under the receiver operating characteristic curve of 75%. As shown in Figure 3, the 5-year rate of freedom from the primary end point was significantly better in patients with LS annular displacement velocity of more than 45 mm/s.

TABLE 4. Cox analysis for TR or its progression

Parameters	Univariate HR	Univariate *P* value	Multivariate HR	Multivariate *P* value
LS displacement velocity, mm/s	0.93	.02	0.93	.02
MS displacement, mm	0.75	.04		
LS tenting height, cm	1.5	.08		
Annulus area fraction, %	0.92	.13		
PAP systolic, mm Hg	1.06	.16		

TR, Tricuspid regurgitation; *HR*, hazard ratio; *LS*, late systole; *MS*, midsystole; *PAP*, pulmonary artery pressure.

Secondary End Point

At the end of follow-up, 13 patients experienced FTR regression. The Cox regression analysis identified the mid-diastole nonplanar angle as the sole independent predictor of FTR regression (hazard ratio, 0.92; confidence interval, 0.86-0.98, *P* = .01; Table 5). Using penalized spline function analysis, we found a cutoff value of 165° for the nonplanar angle to best predict FTR regression with sensitivity of 92%, specificity of 68%, overall accuracy of 77%, and area under the receiver operating characteristic curve of 75%. As shown in Figure 4, the 5-year rate of freedom from the secondary end point was significantly better in patients with a nonplanar angle less than 150°.

DISCUSSION

The aim of the present study was to assess the ability of 3D echocardiography to identify patients who will develop or exhibit persistent moderate or severe FTR after mitral valve surgery. Our findings can be summarized as follows:

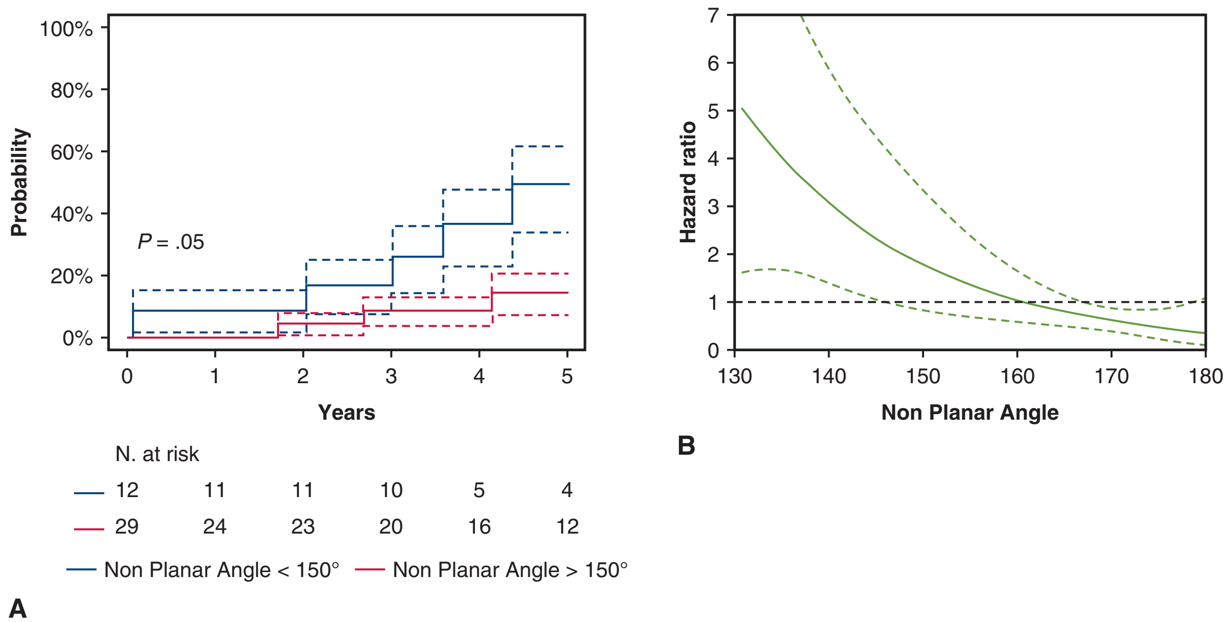

FIGURE 2. A, Kaplan–Meier curve of FTR regression in function of annulus nonplanar angle with 95% confidence intervals. B, Spline function of hazard risk of FTR regression in function of annulus nonplanar angle with 95% confidence intervals. *FTR*, Functional tricuspid regurgitation.

- Preoperative annular dimensions, including diameter, area, and perimeter, did not differ among patients with stable, progressing, or regressing FTR after mitral valve surgery.
- Preoperative annular displacement velocity was lower in patients with progressing FTR than in those with stable FTR, and annular displacement velocity was the

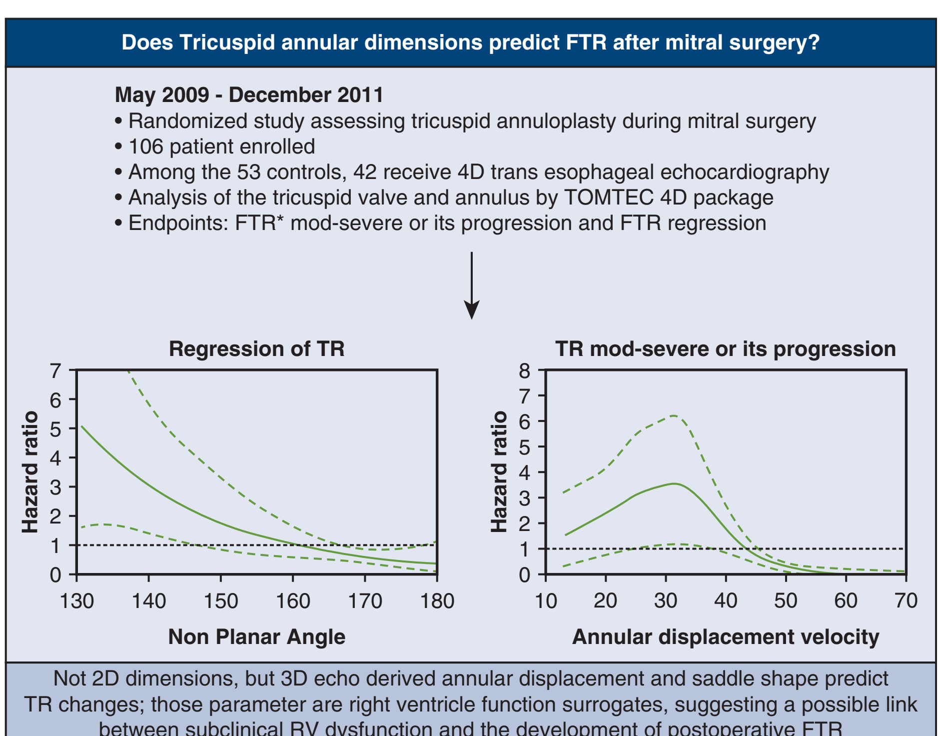

FIGURE 3. 3D echo-derived annular displacement and saddle shape predict TR changes suggesting a possible link between subclinical RV dysfunction and the development of postoperative FTR. *3D*, 3-Dimensional; *TR*, tricuspid regurgitation; *RV*, right ventricular; *FTR*, functional tricuspid regurgitation; *4D*, 4-dimensional; *2D*, 2-dimensional.

TABLE 5. Cox analysis for regression of TR

Parameters	Univariate		Multivariate	
	HR	*P* value	HR	*P* value
MD nonplanar angle	0.91	.006	0.91	.006
LS sphericity index	0.03	.05		
LS tenting height	0.65	.11		
ES annular displacement	0.77	.21		

TR, Tricuspid regurgitation; *HR*, hazard ratio; *MD*, mid-diastole; *LS*, late systole; *ES*, early systole.

only parameter able to predict FTR progression over time.

- The nonplanar angle was smaller in patients with regressing FTR than in those with either stable of progressing FTR and was also the only parameter able to predict FTR regression over time.

The usefulness of TV annuloplasty for patients undergoing mitral surgery remains a matter of debate. Based on the observations made by Dreyfus and colleagues,[14] the most recent ACC/AHA guidelines[15] advocate performing tricuspid ring annuloplasty in the presence of mild or moderate TR and concomitant annular dilatation. Chopra and colleagues[9] proposed first proposed the threshold recommended by the guidelines to indicate tricuspid surgery in 1989 (ie, SA diameter ≥40 mm). They studied 90 patients undergoing left heart valve surgery and observed that 88% of patients with severe TR exhibited a maximum diastolic SA diameter ≥38 mm or 21 mm/m^2. We recently demonstrated[13] that an SA diameter ≥42 mm predicts severe FTR with a sensitivity of 50% and a specificity of 81%, thus corroborating the cutoff value proposed by the guidelines. In the same study, we also showed that preoperative 3D-echo measurements of annular area/perimeter and tenting height provided a much better prediction of preoperative FTR severity and could thus be the preferred method for assessing annular dilatation.

In the present study, we investigated whether the preoperative 3D echocardiography-derived annular area/perimeter could also predict spontaneous postoperative changes in TR severity. Surprisingly, none of the 3D annular dimensional parameters correlated with changes in postoperative TR. This is in line with the findings of Sordelli and colleagues,[16] who were also unable to demonstrate any significant correlation between 3D annular dimensions and postoperative TR severity. Nonetheless, our study identified 2 independent parameters associated with postoperative TR dynamics: the tricuspid annular displacement velocity and the annular nonplanar angle.

Annular Displacement

The annular displacement parameter that we measured is analogous to tricuspid annular phase systolic excursion, a well-known index of RV function. The relationship between the RV diameter or function and FTR after TV surgery has

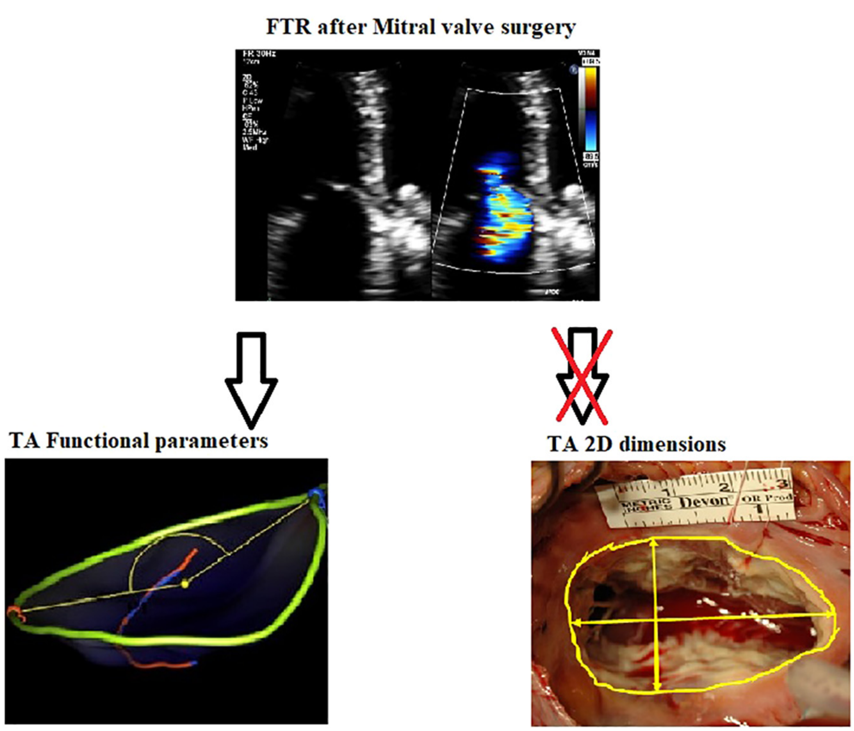

FIGURE 4. Postoperative FTR is best predicted by functional parameter of the tricuspid annulus. *FTR*, Functional tricuspid regurgitation; *TA*, tricuspid annulus; *2D*, 2-dimensional.

been demonstrated before.[17,18] In a recent series of 688 patients undergoing mitral valve surgery and treated for FTR, Calafiore and colleagues[17] reported that the major predictors of recurrent severe TR were TV apparatus remodeling and RV dilatation. Florescu and colleagues[19] reported similar results in patients with pulmonary hypertension. In the present study, we did not observe any significant relationship between FTR and RV dimensions or volumes, which was probably attributable to our exclusion of patients with severe FTR. However, we did observe a significant relationship between the velocity of annular displacement and FTR progression, suggesting a possible link between subclinical RV dysfunction and the development of postoperative FTR. Further studies are needed to confirm this hypothesis.

Nonplanar Angle

The nonplanar angle is an index of the saddle shape of the TA. Our study demonstrates that the maintenance of a saddle-shaped TA is needed for FTR to regress after mitral surgery. Previous investigators also reported similar results.[20,21] Nonetheless, in each of these studies, development of FTR was also linked to annular dilatation. This was not necessarily the case in our study, because only 8 patients (only in the regression group) exhibited annular dilatation. This could indicate that the flattening of TA precedes the development of TA dilatation and subsequent FTR.

Taken together, these data suggest that the development of FTR after mitral procedure is the result of the complex interplay between the shape, dimension, and function of both the TA and the RV. Our data suggest that subclinical RV dysfunction and reduced saddle shape of the TA are the initial triggers and precede annular dilation and RV remodeling. Accordingly, tricuspid annuloplasty should probably be performed before the onset of annular or RV dilatation in the presence of these triggers. Nonetheless, larger studies are needed to support this approach.

Limitations

Our study has limitations that should be acknowledged. Despite the prospective design, the analysis was retrospective and limited to patients with available 3D images. Therefore, the results need to be confirmed in larger prospective cohorts. Furthermore, we did not have specific analysis software dedicated to the TV, so we used a vendor-independent software that was primarily designed for the mitral valve. This forced us to consider the TV as a 2-commissure structure rather than a 3-commissure structure. This probably affected most of the leaflet measurements and likely explains why none of these came out from the analysis. However, we do not believe that it affected the assessment of the TA dynamics as, visually, TA was always well tracked by the software throughout the cardiac cycle.

CONCLUSIONS

Our study identified 3D echo-derived annular displacement and saddle shape as possible early predictors of TR changes after mitral valve surgery. Nevertheless, our findings should be considered more as hypothesis-generating, and further studies are needed to clarify their role in indicating concomitant TA surgery in patients undergoing left heart-valve interventions.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: tricuspid valve, annuloplasty, tricuspid regurgitation

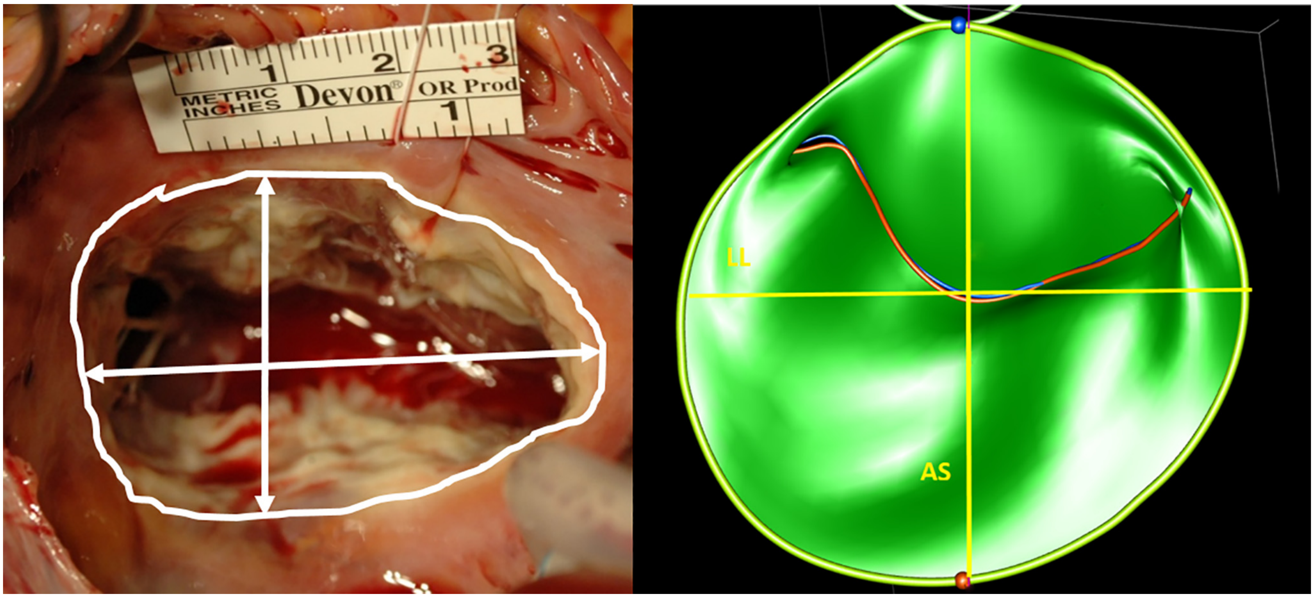

FIGURE E1. Intraoperative picture of the tricuspid valve (*left panel*) with measurements used in the analysis. *Right panel* shows annular measurements obtained from the echocardiographic analysis.