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Tricuspid annular diameter and right ventricular volume on preoperative cardiac CT can predict postoperative right ventricular dysfunction in patients who undergo tricuspid valve surgery☆,☆☆

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ABSTRACT

Background: We investigated the predictive value of preoperative computed tomography (CT)-derived tricuspid annular and right ventricular (RV) parameters for postoperative RV dysfunction in patients undergoing tricuspid valve (TV) surgery.

Methods: We retrospectively reviewed clinical, transthoracic echocardiography (TTE), and CT data of 100 consecutive patients who underwent cardiac CT and subsequently received TV surgery. Preoperative cardiac CT and TTE parameters were analyzed, including TV annulus diameter and RV size. Univariate and multivariate logistic regression analyses were performed to identify significant predictors for postoperative RV dysfunction, both in the entire study population and in the subgroup of patients without preoperative RV dysfunction.

Results: Postoperative RV dysfunction occurred in 46% of all patients. In the multivariate logistic regression analysis, longer TV annulus diameter (>29.3 mm/m^2 on four-chamber view; (odds ratio [OR] 3.56, 95% confidence interval [CI] 1.13–11.24), larger RV volume (RV end-diastolic volume/body surface area > 128.8 ml/m^2) on CT (OR 3.85, 95% CI 1.24–11.98) and presence of preoperative RV dysfunction on TTE (OR 11.96, 95% CI 2.8–50.99) were independent predictors for postoperative RV dysfunction in the entire study population ($P < 0.05$). Among patients without preoperative RV dysfunction, longer TV annulus diameter (OR 4.02, 95% CI 1.20–13.41) and larger RV volume on CT (OR 6.09, 95% CI 1.87–19.80) were independent predictors for postoperative RV dysfunction ($P < 0.05$).

Conclusions: Preoperative assessment of cardiac CT imaging–based TV annular diameter and RV volume can provide independent information for predicting postoperative RV dysfunction in patients undergoing TV surgery.

1. Introduction

With the increasing prevalence of valvular heart disease (VHD), the clinical importance of right-side valve diseases such as tricuspid regurgitation (TR) has been gradually increasing [1,2]. Although TR is a common echocardiographic finding present in 80–90% of normal individuals, increasing TR severity is associated with worse survival [3]. Approximately 80% of significant TR cases are functional and related to tricuspid valve (TV) annular dilation and leaflet tethering in the setting of right ventricle (RV) remodeling due to pressure and/or volume overload [4]. The prevalence of TR is steadily increasing, even long after successful surgical correction of a left-sided valve abnormality [5–9]. The development of TR leads to a vicious cycle propagating further RV dilatation and dysfunction, more tricuspid annular dilatation, leaflet tethering, and consequently, worsening of TR [10].

According to 2014 AHA/ACC guideline for the management of patients with VHD, indications for TR surgery are 1) patients with severe TR undergoing left-sided valve surgery, 2) patients with ≥mild functional TR at the time of left-sided valve surgery with either TV annular dilation (>40 mm or 21 mm/m^2) or prior evidence of right heart failure, and 3) reoperation for isolated TV surgery for persistent symptoms due to severe TR in patients who have undergone previous left-sided valve

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surgery without severe pulmonary hypertension or significant RV systolic dysfunction [11]. Not only the severity of TR, but also other factors such as TV annulus diameter, RV function, and pulmonary hypertension are regarded as important factors for treatment planning.

Assessment of RV systolic function in patients with TR is a critical component of preoperative planning, because impaired RV systolic function negatively impacts functional and survival outcomes following TV surgery [4,12]. Moreover, predicting and monitoring postoperative RV function are also critical for patient management, because the presence of refractory RV dysfunction after cardiac surgery is associated with high in-hospital mortality [13]. Evaluation of RV function with transthoracic echocardiography (TTE) or transoesophageal echocardiography can be suboptimal in some patients due to poor acoustic windows, technical limitations, and dynamic changes in RV loading conditions. Cardiac magnetic resonance imaging (CMR) can provide more accurate assessment of RV volumes and systolic function, as well as annular dimension and the degree of leaflet tethering. However, considering practical issues such as concomitant arrhythmia and poor compliance for CMR of patients with TR, evaluation of RV and TV annulus by computed tomography (CT) can offer a useful alternative. Nevertheless, the value of preoperative cardiac CT parameters for the prediction of postoperative outcome has not yet been described. We hypothesized that TV annulus diameter and RV volume measured on cardiac CT would have value for prediction of postoperative RV systolic dysfunction in patients undergoing TV surgery.

We investigated the predictive value of cardiac CT-derived TV annular and RV parameters for postoperative RV dysfunction in patients who undergo TV surgery.

2. Materials and methods

2.1. Patients

The Institutional Review Board of our institution approved this retrospective study, and informed consent was waived. We retrospectively searched the cardiac CT database of our institution for cases performed between January 2013 and August 2015. Among 712 consecutive patients who had VHD and also underwent cardiac CT during this period, we included 152 patients who underwent subsequent TV surgery after CT (Fig. 1). At our institution, cardiac CT is routinely performed at following situations; 1) when a patient with history of previous valve surgery is scheduled to receive redo-cardiac surgery, or 2) a patient is suspected to have prosthetic valve dysfunction, or 3) echocardiography is inconclusive in a patient with suspected or known VHD. Otherwise, CT is indicated a patient with VHD is scheduled to receive subsequent valve surgery, mainly for coronary artery evaluation. We excluded 45 patients who had undergone previous TV surgery before CT, because TV annulus morphology was thought to have changed due to prior surgery, six patients who had TV disease as intrinsic abnormality without left-side VHD, and one patient who had no postoperative TTE exam. Therefore, a total of 100 patients (62 women and 38 men; mean age 61.5 ± 11.9 years) were included in the study population.

2.2. CT acquisition protocol

All CT scans were performed with a dual-source CT scanner (SOMATOM Definition Flash; Siemens Healthcare, Forchheim, Germany). Scans were performed with the retrospective electrocardiogram-gated acquisition mode without electrocardiogram-based tube current modulation to allow valves to be imaged during the entire cardiac cycle. Scans were performed using the triple-phase injection method for adequate enhancement of the right heart chamber, because many of patients with left-sided VHD have a TV abnormality. From raw data sets, images were generated using iterative reconstruction (sinogram affirmed iterative reconstruction, SAFIRE) with a medium kernel (I36f), and the reconstruction slice thickness was 0.75 mm with 0 .5 mm increments. For all patients, 10 transverse datasets were reconstructed every 10% of the cardiac cycle (0–90% of RR interval with 10% increment). Reconstructed images were transferred to an image server and analyzed using dedicated software (Aquarius iNtuition, Ver. 4.4.11, TeraRecon, San Mateo, CA, USA). Mean dose-length product of cardiac CT was 754.6 ± 357.3 mGy·cm.

2.3. CT image analysis

All CT analyses were performed by two radiologists who were blinded to clinical information and TTE results. Using multiplanar reformatted images, assessment of TV consisted of measurement of TV annulus diameter and evaluation of TV annular shape (Fig. 2). Diameter of the TV annulus was measured on diastole showing maximal dimensions, in the three following ways: 1) maximal diameter on a four-chamber view (TAD_{4ch}), 2) maximal diameter on a long axis view (TAD_{LA}), and 3) average diameter derived from the area of the TV annulus on an en-face (short axis) view (TAD_{avg}). An en-face view of TV annulus was made by adjusting the axis on the four-chamber view and long axis view to show the basal attachment of each leaflet on a single plane [14]. For evaluation of TV annular shape, TV annulus sphericity was calculated by dividing the minimal TV annulus diameter by the maximal TV annulus diameter on an en-face view. RV volume was

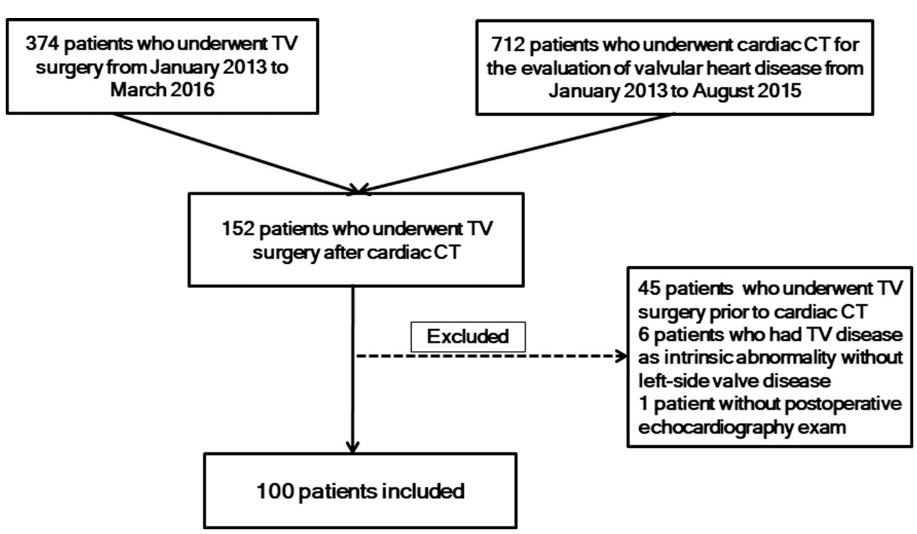

Fig. 1. Flow diagram of the study population. TV, tricuspid valve; CT, computed tomography.

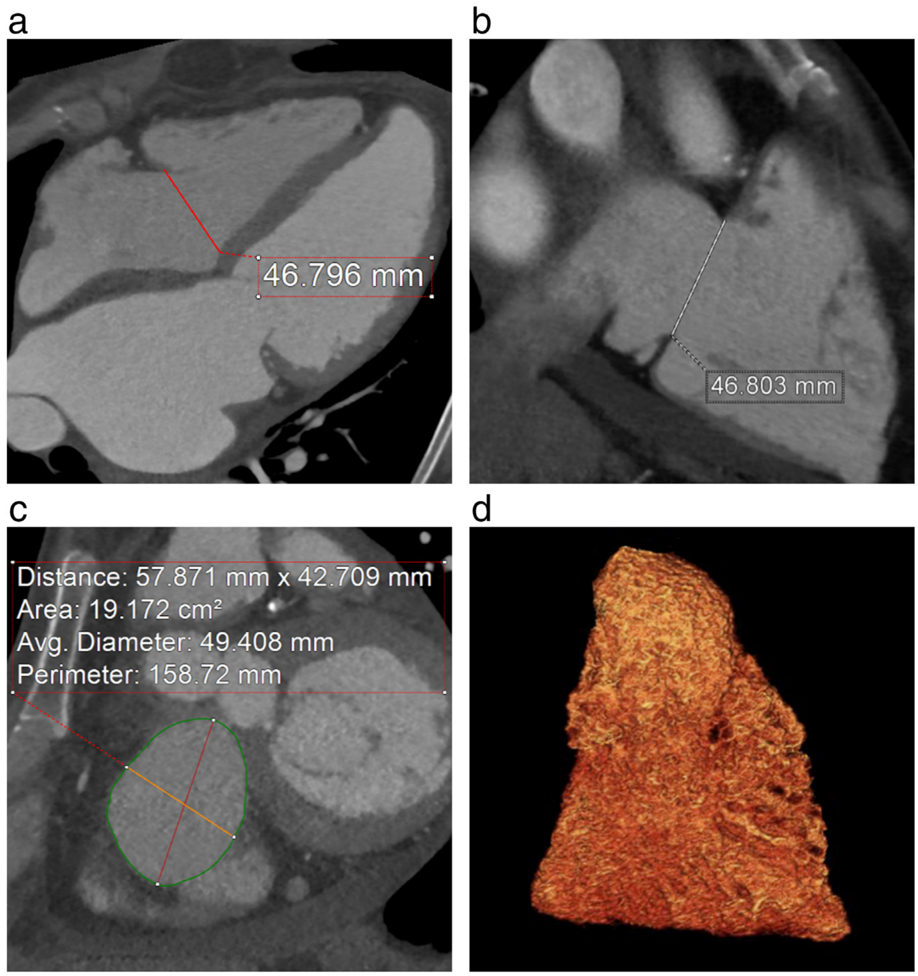

Fig. 2. An example of CT analysis in a 61-year-old female patient with no preoperative RV dysfunction and with the occurrence of postoperative RV dysfunction. She underwent cardiac CT before mitral valve surgery due to severe degenerative mitral regurgitation. (A) Four-chamber view and (B) long-axis view CT images show dilated TV annulus (26.6 mm/m^2 on both views). (C) En-face view CT image demonstrates an average diameter of the TV annulus of 29.9 ml/m^2 and a sphericity of 0.737 (minimal diameter [42.7 mm] divided by maximal diameter [57.9 mm]). (D) RV end-diastolic and end-systolic volumes by CT were measured to be 155.7 ml/m^2 and 101 ml/m^2 (not shown), respectively. On preoperative TTE, moderate tricuspid regurgitation was noted with a TV annulus diameter of 37 mm, a RV end-diastolic area of 18.9 cm^2 and a RV systolic pressure of 68 mm Hg. Preoperative RV-FAC was 35.7%. The patient underwent mitral ring annuloplasty with concomitant TV annuloplasty, and RV-FAC measured on postoperative TTE was 27.7%. CT, computed tomography; RV, right ventricle; TV, tricuspid annulus; TTE, transthoracic echocardiography; FAC, fractional area change.

quantified using cardiac CT with a semiautomatic three-dimensional region-growing method, both on end-diastolic and end-systolic phases [15,16]. The endocardial border was delineated using an attenuation-based thresholding method. The threshold was manually adjusted until the appearances matched visual assessment. The papillary muscles and trabeculations were excluded from RV volume. End-diastolic and end-systolic volume (EDV and ESV) were measured, and stroke volume (SV) was calculated as [EDV-ESV]. RV ejection fraction (RVEF) was defined as [RVSV/RVEDV]. For TV annular and RV volume parameters, indexed values by body surface area (BSA) were used for analysis (TAD_{4ch}/BSA, TAD_{LA}/BSA, TAD_{avg}/BSA, RVEDVi, RVESVi, and RVSVi).

2.4. Transthoracic echocardiography

All patients underwent comprehensive, preoperative, two-dimensional TTE within a median of 2.5 days (25th to 75th percentile, 1–22.5 days) from their CT exam and postoperatively a median of 6 days (25th to 75th percentile, 5–7 days) after TV surgery. Severity of TR was graded semi-quantitatively from color and continuous wave Doppler data using a multiparametric approach: none or trivial (0–1+), mild (2+), moderate (3+), or severe (4+) [17,18]. The TV annulus diameter was measured in end-diastole in the apical four-chamber view (TAD_{TTE}) [18]. The RV systolic pressure gradient (RVSP) was calculated from the maximum velocity of the TR jet according to the modified Bernoulli equation [19]. RV function was assessed using tricuspid annular plane systolic excursion (TAPSE), TV lateral annular systolic velocity (TV S′) by tissue Doppler imaging, and RV fractional area change (RV-FAC). All these measurements were performed in accordance with current ASE guidelines [20]. Abnormal cutoffs for RV function parameters were as follows: FAC < 35%, TAPSE < 1.7 cm, and TV annular velocity (S′) < 9.5 cm/s. Presence of RV dysfunction was comprehensively defined, as having >50% of the available RV function parameters below the lower cutoff; RV function was considered normal if <50% of these parameters were abnormal [21].

2.5. TV surgery indication

TV surgery was considered when there was severe TR on preoperative TTE or mild/moderate TR with TV annular dilatation (≥40 mm) by TTE or CT or in the presence of pulmonary hypertension [11].

2.6. Data analysis

Clinical data were collected from medical records. Preoperative TTE data were TR severity, TAD_{TTE}, RVSP, presence of severity of concomitant mitral regurgitation, presence of RV dysfunction, RV-FAC, left ventricular end-diastolic dimension, and left ventricular ejection fraction. Postoperative TTE data included the presence of RV dysfunction and RV-FAC after surgery.

2.7. Statistical analysis

Statistical analyses were performed using computerized statistics programs (MedCalc for Windows, version 11.5.0.0; MedCalc Software, Mariakerke, Belgium, and R version 3.3.3, R Foundation for Statistical Computing, Vienna, Austria). Details regarding the statistical analysis are described in Supplemental methods. Normally distributed data were identified using the Shapiro-Wilk W test. Continuous variables were presented as mean ± standard deviation and were compared using the independent *t*-test for normally distributed data or the Mann-Whitney *U* test for non-normally distributed data. Comparison of clinical, CT, and TTE variables between patients with and without postoperative RV dysfunction was performed using chi-square test or Fisher's exact test for categorical variables or independent *t*-test or Mann-Whitney test for continuous variables. Univariate and multivariate logistic regression analyses were performed to assess associations between clinical variables, cardiac CT/TTE parameters, and postoperative RV dysfunction (Supplemental methods). We constructed two models for multivariate logistic regression analysis (one model with CT parameters and another with TTE parameters) and compared c-statistic of the receiver operating characteristic curve of each logistic regression analysis model to identify the model with the higher predictability. For subgroup analysis, logistic regression analysis was performed in patients without preoperative RV dysfunction. Probability values <0.05 were considered statistically significant.

3. Results

3.1. Baseline characteristics

Baseline clinical characteristics are summarized in Supplemental Table 1. Postoperative RV dysfunction occurred in 46 patients (46%). There were no significant differences in demographic characteristics of patients with and without postoperative RV dysfunction. The dose-length product of cardiac CT was 745.8 ± 338.4 mGy·cm.

3.2. TTE data and CT analysis results

When comparing CT image analysis results according to TR severity, patients with severe TR showed longer TAD than patients with mild to moderate did (Supplemental Fig. 1). CT-measured TV annulus diameter on all three axes tended to be larger than TAD_{TTE}/BSA (Supplemental Figs. 2 and 3). Inter-observer variability between two readers was excellent for TAD_{avg}/BSA (intraclass correlation coefficients 0.891, 95% confidence interval [CI] 0.836–927). There was a positive correlation between CT-measured TV annulus diameter and RV volume on CT (not shown, $r = 0.362$–0.368, $P < 0.05$).

Patients with postoperative RV dysfunction had more frequent severe TR grade, longer TAD_{TTE}, larger RV-EDA and RV-ESA, and more frequent preoperative RV dysfunction on TTE, compared to those without postoperative RV dysfunction ($P < 0.05$, Table 1). On postoperative TTE, patients with postoperative RV dysfunction showed higher RVSP and lower RV-FAC ($P < 0.05$). In patients with postoperative RV dysfunction, TAD_{4ch}/BSA on CT was significantly longer than that of those without postoperative RV dysfunction ($P < 0.05$), but TV annulus sphericity was not significantly different between the two groups ($P = 0.4315$). RVEDVi, RVESVi, and RVSVi on CT were significantly larger in patients with postoperative RV dysfunction than in those without postoperative RV dysfunction ($P < 0.05$). No significant difference was observed in RVEF between the two groups ($P > 0.05$).

3.3. Predictive value of cardiac CT-derived parameters

Based on univariate logistic regression for the prediction of postoperative RV dysfunction, severe TR, longer TAD_{TTE}, higher RVSP, larger EDA and ESA of RV, lower TV S′ and presence of preoperative RV dysfunction on preoperative TTE, as well as longer TV annulus diameter (TAD_{4ch}/BSA and TADavg/BSA) and larger RV volume (RVEDVi, RVESVi, RVSVi) on preoperative cardiac CT were significant predictors of occurrence of postoperative RV dysfunction (Supplemental Table 2). Optimal cutoff values for continuous variables to predict postoperative RV dysfunction are shown in Supplemental Table 3.

We constructed two prediction models for postoperative RV dysfunction based on the multivariate logistic regression analysis, each model based on the TV annular and RV parameters from CT and TTE, respectively (Table 2). TAD_{4ch}/BSA > 29.3 mm/m^2, RVEDVi > 129.3 ml/m^2 and presence of preoperative RV dysfunction on CT were significant independent predictors for postoperative RV dysfunction (Model 1). TAD_{TTE} > 40 mm was a significant independent predictor in Model 2, whereas RV-EDA > 18.7 cm^2 was not significant. The c-statistic of Model 1 was higher than that of Model 2, without statistical significance.

3.4. Subgroup analysis of patients with no preoperative RV dysfunction

Twenty-seven patients (27%) showed preoperative RV dysfunction on TTE. Among 73 patients without preoperative RV dysfunction, postoperative RV dysfunction occurred in 22 patients (30.1%). Univariate logistic regression analysis showed that larger TV annulus diameter and RV volume measured on CT were significant predictors for postoperative RV dysfunction ($P < 0.05$, Supplemental Table 2). None of TTE parameters including TR severity, TV annular and RV parameters was not significant predictors in this subgroup. Optimal cutoff values for continuous variables to predict postoperative RV dysfunction in this subgroup are shown in Supplemental Table 3. Multivariate logistic regression analysis models revealed that TV annulus diameter measured on CT (TAD_{4ch}/BSA > 29.3 mm/m^2) and RV volume (RVEDVi>128.8 ml/m^2) were independent predictors for postoperative RV dysfunction (OR 4.02 [95% CI 1.20–13.41] and OR 6.09 [95% CI 1.87–19.80]; $P = 0.0237$ and $P = 0.0027$, respectively).

4. Discussion

Our study demonstrates that TV annulus diameter and RV volume measured on preoperative cardiac CT can predict postoperative RV dysfunction in patients undergoing TV surgery. In the entire study population, TV annulus diameter and RV volume measured on CT, and TV annulus diameter, preoperative RVSP and preoperative RV dysfunction on TTE, are significant independent factors for prediction of postoperative RV dysfunction. In patients without preoperative RV dysfunction, only TV annulus diameter and RV volume measured on CT are significant predictors. TAD_{4ch}/BSA > 29.3 mm/m^2 and RVEDVi > 128.8 ml/m^2 on cardiac CT represent cutoff values for prediction of postoperative RV dysfunction.

Current guideline for VHD suggests consideration of TV surgery for TV annular dilation > 40 mm or 21 mm/m^2 in functional TR at the time of left-sided valve surgery because TV annular dilatation indicates persistent TR [11]. The guideline recommends that TV annulus diameter be measured on the four-chamber view of TTE (TAD_{TTE} in our study). However, TV annulus diameter on TTE might not represent actual annular dilatation, because TV annulus shape is diverse, as proven by the wide range of sphericity of TV annulus on CT and agreements between TAD_{TTE} and tricuspid annular diameter on CT measured in our study.

A few recent studies have investigated the utility of cardiac CT in TV disease, and most reported that TV annulus diameter on cardiac CT had significant correlation with RV volume and TR severity [14,22–24]. Instead of correlations between CT-derived values and severity of TR, we

Table 1
Comparison of CT and TTE parameters between patients with and without postoperative RV dysfunction.

	All patients ($n = 100$)	No postoperative RV dysfunction ($n = 54$)	Postoperative RV dysfunction s ($n = 46$)	*P* value
CT parameter				
TV annulus				
TAD_{4ch}/BSA (mm/m^2)	27.0 ± 4.5	26.1 ± 4.0	28.0 ± 4.7	**0.0311**
TAD_{LA}/BSA (mm/m^2)	27.2 ± 4.8	26.5 ± 5.0	28.1 ± 4.5	0.0828
TAD_{avg}/BSA (mm/m^2)	27.4 ± 4.3	26.7 ± 3.3	28.3 ± 5.1	0.0746
Sphericity	0.783 ± 0.091	0.79 ± 0.106	0.776 ± 0.068	0.4315
RV parameters ($n = 98$)		($n = 53$)	($n = 45$)	
RVEDV/BSA (ml/m^2)	151 ± 65.1	127.1 ± 41.4	179.2 ± 76.3	**0.0001**
RVESV/BSA (ml/m^2)	82 ± 36.2	68.3 ± 19.5	98.3 ± 44.1	**0.0001**
RVSV/BSA (ml/m^2)	69 ± 35.8	58.8 ± 37.1	80.9 ± 41	**0.0029**
RV ejection fraction (%)	45.2 ± 9.2	45.4 ± 8.5	45.0 ± 9.9	0.8402
TTE parameter				
Preoperative TR grade				**0.0139**
Mild	25 (25)	19 (35.2)	6 (13)	
Moderate	32 (32)	18 (33.3)	14 (30.4)	
Severe	43 (43)	17 (31.5)	26 (56.5)	
Preoperative TR grade (binary)				**0.0121**
Mild to moderate	57 (57)	37 (68.5)	20 (43.5)	
Severe	43 (43)	17 (31.5)	26 (56.5)	
TV annulus				
TV annulus diameter (mm)	39.4 ± 6.4	38.11 ± 4.8	41.0 ± 7.5	**0.0245**
TV annulus diameter/BSA (mm/m2)	24.3 ± 4.2	23.6 ± 3.45	25.2 ± 5.0	0.0554
RV parameter				
RV-EDA (cm^2)	20.2 ± 7.4	17.7 ± 5.8	23.0 ± 8.1	**0.0004**
RV-ESA (cm^2)	12.0 ± 5.1	10.4 ± 3.8	13.9 ± 5.6	**0.0005**
RV-FAC (%)	41.1 ± 7.7	42.1 ± 6.8	39.8 ± 8.4	0.1474
TAPSE (cm)	1.7 ± 0.6	1.8 ± 0.4	1.6 ± 0.7	0.3880
TV S′ (cm/s)	10.2 ± 3.4	11.5 ± 3.6	9.2 ± 2.9	**0.0031**
Preoperative RVSP (mm Hg, $n = 99$)	52.6 ± 17.2	48.4 ± 14.3	57.6 ± 19.2 (n = 45)	**0.0095**
Preoperative RV dysfunction	271 (27)	3 (5.6)	24 (52.2)	<**0.0001**
Postoperative RVSP ($n = 93$)	44.7 ± 16.8	40.5 ± 15.5 ($n = 49$)	49.4 ± 17.1 ($n = 44$)	**0.0104**
Postoperative RV-FAC (%)	35.2 ± 8.6	37.4 ± 7.8	32.7 ± 8.8	**0.0066**
Other TTE parameters				
Mitral regurgitation				0.7105
No to trivial	28 (28)	16 (29.6)	12 (26.1)	
Mild	17 (17)	7 (13)	10 (21.7)	
Moderate	11 (11)	6 (11.1)	5 (10.9)	
Severe	44 (44)	25 (46.3)	19 (41.3)	
LV end-diastolic dimension (mm)	53.2 ± 97	54.0 ± 9.1	52.4 ± 10.3	0.4254
LV ejection fraction (%)	62.1 ± 9.5	62.2 ± 9.6	61.1 ± 9.5	0.887
Postoperative LV dysfunction	11 (11)	3 (5.6)	8 (17.4)	0.607

CT, computed tomography; TTE, transthoracic echocardiography; RV, right ventricle; TV, tricuspid valve; TAD; tricuspid annular diameter; 4ch, four-chamber; LA, long-axis; avg, average; BSA, body surface area; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; TR, tricuspid regurgitation; EDA, end-diastolic area; ESA, end-systolic area; FAC, fractional area change; TAPSE, tricuspid annular plane systolic excursion; RVSP, right ventricular systolic pressure; LV, left ventricle.
Bold values indicate statistical significance.

investigated the utility of cardiac CT-derived TV annular and RV volume parameters for predicting RV dysfunction in the early postoperative period, which can have a clinical importance for patient management.

Presence of preoperative RV systolic dysfunction is a crucial factor in surgical planning and a known predictor of postoperative RV dysfunction [11,25]. We consistently found the presence of preoperative RV

Table 2
Multivariate logistic regression model for prediction of postoperative RV dysfunction.

Variables	All patients (n = 100)		c-Statistic (95% CI)
	OR (95% CI)	P value	
Model 1			0.858 (0.773–0.921)
TAD_{4ch}/BSA on CT (>29.3 mm/m^2)	**3.56** (**1.13–11.24**)	**0.0306**	
RVEDV/BSA on CT (>128.8 ml/m^2)	**3.85** (**1.24–11.98**)	**0.0199**	
Severe TR on preoperative TTE	0.77 (0.25–2.44)	0.6620	
Preoperative RVSP (>50 mm Hg) on TTE	1.68 (0.55–5.13)	0.3642	
Preoperative RV dysfunction on TTE	**11.96** (**2.81–50.99**)	**0.0008**	
Model 2			0.834 (0.746–0.902)
TAD_{TTE} (>40 mm)	**2.93** (**1.02–8.44**)	**0.0461**	
RV-EDA on TTE (>18.7 cm^2)	2.571 (0.92–7.16)	0.0715	
Severe TR on preoperative TTE	1.03 (0.35–3.03)	0.9622	
Preoperative RVSP (>50 mm Hg)	2.06 (0.7–6.05)	0.1891	
Preoperative RV dysfunction on TTE	**11.12** (**2.78–44.5**)	**0.0007**	
Difference of c-statistic between Model 1 and Model 2	0.024	0.675	

RV, right ventricle; OR, odds ratio; CI, confidence interval; TAD; tricuspid annular diameter; 4ch, four-chamber; BSA, body surface area; CT, computed tomography; EDV, end-diastolic volume; TR, tricuspid regurgitation; TTE, transthoracic echocardiography; N/A, non-applicable; RVSP, right ventricular systolic pressure; EDA, end-diastolic area.
Bold values indicate statistical significance.

dysfunction to be a significant predictor of postoperative RV dysfunction with the highest predictability among the many variables in our study. However, assessment of preoperative RV dysfunction by TTE can be challenging and limited in some situations, making CMR the modality of choice. A recent study reported that preoperative CMR-derived RVEF lower than 46% was an independent predictor for cardiac death and major postoperative cardiac events in patients with severe functional TR [26]. In our study, RVEF based on CT measurement was not a significant predictor, with several possible underlying reasons. First, RVEF might not reflect RV systolic function in the presence of significant TR, because this parameter does not consider the regurgitant fraction of TR. Second, the reliability of volume measurements, including RVEF, can be reduced in cases with poor image quality, such as in the presence of concomitant arrhythmia during imaging acquisition, which can be problematic for both CT and CMR.

RV dilatation as a consequence of TR leads to RV systolic dysfunction, and large RV volume was as a significant independent predictor of postoperative RV dysfunction in the entire population and also in the subgroup of patients without preoperative RV dysfunction. We suggest several explanations for this result. First, we defined the presence of RV dysfunction using TTE parameters, which can be influenced by the severity of TR [27]. Therefore, preoperative RV systolic dysfunction can be masked when severe TR is present, and the masked RV systolic dysfunction has been revealed after corrective surgery for TR. Second, the timing of assessing postoperative RV dysfunction can affect the incidence of postoperative dysfunction. RV function can recover in the late postoperative period after TV corrective surgery in the setting of severe RV dilatation, rather than in immediate fashion [28]. In clinical situations, refractory RV failure has a low incidence, but results in high morbidity and mortality after cardiac surgery [13]. Therefore, preoperative identification of risk groups for RV dysfunction, early recognition of postoperative RV dysfunction, and timely treatment such as decreasing pulmonary vascular resistance and optimization of the ventricular performance are crucial for preventing refractory RV failure.

In addition to RV dysfunction, presence of pulmonary hypertension is an important factor for treatment planning in patients with TR. Increased pulmonary vascular resistance can alter afterload of RV, leading to RV dilatation and dysfunction [29,30]. In our study, RVSP on preoperative TTE was a significant predictor for postoperative RV dysfunction in the univariate logistic regression analysis, but not in the multivariate analysis. We assumed that this could be attributed to the close association between preoperative RVSP and RV parameters included in the multivariate analysis, which can be possibly explained by RV to pulmonary artery coupling [31].

While TR severity is known to be related to poorer prognosis, severe TR was not a significant independent predictor in our multivariate analysis. This result might be due to the observed positive correlation of TR severity with dilated TV annulus and large RV volume. Our findings support current guidelines where patients with a functional TR can consider TV surgery when the TV annulus is dilated, regardless of TR severity.

The results of the current study may contribute to expanding the role of cardiac CT in VHD. Generally, the purpose of preoperative coronary artery and comprehensive anatomic evaluation can be acceptable indications of cardiac CT before valve surgery, especially in patients who will be scheduled for reoperation. Besides, TV annular and RV volume parameters can be a useful quantitative predictor for postoperative outcome, based on our study results. Cardiac CT can be a useful modality for evaluation of TV and RV, considering the inherent limitations of TTE.

Our study has several limitations. First, we assessed the presence of RV dysfunction based on TTE, although CMR is considered the standard modality. A substantial portion of our study population could not undergo CMR because of concomitant arrhythmia and poor compliance for breath-holds during CMR. Therefore, we comprehensively assessed RV function with multiple TTE parameters, even though TTE can have considerable limitations for evaluation of RV volume and function [32]. Second, the reliability of CT measurements of TV annulus and RV volume can be reduced when image quality is poor. In our study, RV volume parameters were not measurable in two patients due to poor image quality caused by arrhythmia. Third, the potential hazard of radiation exposure by CT can be one of limitations.

5. Conclusion

Preoperative assessment of cardiac CT parameters can provide independent information for predicting postoperative RV dysfunction in patients undergoing TV surgery. TV annulus diameter and RV volume on preoperative cardiac CT represent useful predictors for postoperative RV dysfunction.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2019.03.002.

References

[1] H.K. Kim, S.P. Lee, Y.J. Kim, D.W. Sohn, Tricuspid regurgitation: clinical importance and its optimal surgical timing, Journal of Cardiovascular Ultrasound 21 (1) (2013) 1–9.
[2] C.J. Bruce, H.M. Connolly, Right-sided valve disease deserves a little more respect, Circulation 119 (20) (2009) 2726–2734.
[3] J. Nath, E. Foster, P.A. Heidenreich, Impact of tricuspid regurgitation on long-term survival, J. Am. Coll. Cardiol. 43 (3) (2004) 405–409.
[4] A. Shiran, A. Sagie, Tricuspid regurgitation in mitral valve disease incidence, prognostic implications, mechanism, and management, J. Am. Coll. Cardiol. 53 (5) (2009) 401–408.
[5] H.K. Kim, Y.J. Kim, K.I. Kim, et al., Impact of the maze operation combined with left-sided valve surgery on the change in tricuspid regurgitation over time, Circulation 112 (9 Suppl) (2005) I14–I19.
[6] J.J. Kwak, Y.J. Kim, M.K. Kim, et al., Development of tricuspid regurgitation late after left-sided valve surgery: a single-center experience with long-term echocardiographic examinations, Am. Heart J. 155 (4) (2008) 732–737.
[7] A. Porter, Y. Shapira, M. Wurzel, et al., Tricuspid regurgitation late after mitral valve replacement: clinical and echocardiographic evaluation, The Journal of Heart Valve Disease 8 (1) (1999) 57–62.
[8] P.H. Groves, R.J. Hall, Late tricuspid regurgitation following mitral valve surgery, The Journal of Heart Valve Disease 1 (1) (1992) 80–86.
[9] L.B. McGrath, L. Gonzalez-Lavin, B.M. Bailey, G.L. Grunkemeier, J. Fernandez, G.W. Laub, Tricuspid valve operations in 530 patients. Twenty-five-year assessment of early and late phase events, J. Thorac. Cardiovasc. Surg. 99 (1) (1990) 124–133.
[10] J. Mascherbauer, G. Maurer, The forgotten valve: lessons to be learned in tricuspid regurgitation, Eur. Heart J. 31 (23) (2010) 2841–2843 (1010).
[11] R.A. Nishimura, C.M. Otto, R.O. Bonow, et al., AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines, J. Am. Coll. Cardiol. 63 (22) (2014) e57–185.
[12] Y.J. Kim, D.A. Kwon, H.K. Kim, et al., Determinants of surgical outcome in patients with isolated tricuspid regurgitation, Circulation 120 (17) (2009) 1672–1678.
[13] T.K. Kaul, B.L. Fields, Postoperative acute refractory right ventricular failure: incidence, pathogenesis, management and prognosis, Cardiovasc. Surg. 8 (1) (2000) 1–9.
[14] P.J. van Rosendael, E. Joyce, S. Katsanos, et al., Tricuspid valve remodelling in functional tricuspid regurgitation: multidetector row computed tomography insights, Eur. Heart J. Cardiovasc. Imaging 17 (1) (2016) 96–105.
[15] L. Sugeng, V. Mor-Avi, L. Weinert, et al., Multimodality comparison of quantitative volumetric analysis of the right ventricle, J. Am. Coll. Cardiol. Img. 3 (1) (2010) 10–18.
[16] H.W. Goo, S.H. Park, Semiautomatic three-dimensional CT ventricular volumetry in patients with congenital heart disease: agreement between two methods with different user interaction, The International Journal of Cardiovascular Imaging 31 (Suppl. 2) (2015) 223–232.

[17] P. Lancellotti, L. Moura, L.A. Pierard, et al., European Association of Echocardiography recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation (native valve disease), European Journal of Echocardiography: The Journal of the Working Group on Echocardiography of the European Society of Cardiology 11 (4) (2010) 307–332.
[18] C. Joint Task, Force on the Management of Valvular Heart Disease of the European Society of, S. European Association for Cardio-Thoracic, A. Vahanian, et al., Guidelines on the management of valvular heart disease (version 2012), Eur. Heart J. 33 (19) (2012) 2451–2496.
[19] L.P. Badano, E. Agricola, L. Perez de Isla, P. Gianfagna, J.L. Zamorano, Evaluation of the tricuspid valve morphology and function by transthoracic real-time three-dimensional echocardiography, European Journal of Echocardiography: The Journal of the Working Group on Echocardiography of the European Society of Cardiology 10 (4) (2009) 477–484.
[20] R.M. Lang, L.P. Badano, V. Mor-Avi, et al., Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging, Journal of the American Society of Echocardiography: Official Publication of the American Society of Echocardiography 28 (1) (2015) 1–39 e14.
[21] E. Koifman, R. Didier, N. Patel, et al., Impact of right ventricular function on outcome of severe aortic stenosis patients undergoing transcatheter aortic valve replacement, Am. Heart J. 184 (2017) 141–147.
[22] M. Kabasawa, H. Kohno, T. Ishizaka, et al., Assessment of functional tricuspid regurgitation using 320-detector-row multislice computed tomography: risk factor analysis for recurrent regurgitation after tricuspid annuloplasty, J. Thorac. Cardiovasc. Surg. 147 (1) (2014) 312–320.
[23] N. Nemoto, J.R. Lesser, W.R. Pedersen, et al., Pathogenic structural heart changes in early tricuspid regurgitation, J. Thorac. Cardiovasc. Surg. 150 (2) (2015) 323–330.
[24] N. Funabashi, A. Kataoka, M. Uehara, et al., Relationship of maximum and minimum tricuspid valve annular diameter determined by 320-slice CT with right atrial and ventricular volume and estimated right ventricular systolic pressure, Int. J. Cardiol. 168 (4) (2013) 4578–4581.
[25] M.J. Schuuring, E.C. van Gulik, D.R. Koolbergen, et al., Determinants of clinical right ventricular failure after congenital heart surgery in adults, J. Cardiothorac. Vasc. Anesth. 27 (4) (2013) 723–727.
[26] J.-B. Park, H.-K. Kim, J.-H. Jung, et al., Prognostic value of cardiac MR imaging for preoperative assessment of patients with severe functional tricuspid regurgitation, Radiology 280 (3) (2016) 723–734 (151556).
[27] S.H. Hsiao, S.K. Lin, W.C. Wang, S.H. Yang, P.L. Gin, C.P. Liu, Severe tricuspid regurgitation shows significant impact in the relationship among peak systolic tricuspid annular velocity, tricuspid annular plane systolic excursion, and right ventricular ejection fraction, Journal of the American Society of Echocardiography: Official Publication of the American Society of Echocardiography 19 (7) (2006) 902–910.
[28] R.R. Desai, L.M. Vargas Abello, A.L. Klein, et al., Tricuspid regurgitation and right ventricular function after mitral valve surgery with or without concomitant tricuspid valve procedure, J. Thorac. Cardiovasc. Surg. 146 (5) (2013) 1126–1132 e1110.
[29] M. Skhiri, S.A. Hunt, A.Y. Denault, F. Haddad, [Evidence-based management of right heart failure: a systematic review of an empiric field], Rev. Esp. Cardiol. 63 (4) (2010) 451–471.
[30] F. Haddad, R. Doyle, D.J. Murphy, S.A. Hunt, Right ventricular function in cardiovascular disease, part II: pathophysiology, clinical importance, and management of right ventricular failure, Circulation 117 (13) (2008) 1717–1731.
[31] I. Sultan, A. Cardounel, I. Abdelkarim, et al., Right ventricle to pulmonary artery coupling in patients undergoing transcatheter aortic valve implantation, Heart (British Cardiac Society), 2018.
[32] L.G. Rudski, W.W. Lai, J. Afilalo, et al., Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography, Journal of the American Society of Echocardiography: Official Publication of the American Society of Echocardiography. 23 (7) (2010) 685–713; quiz 786–688.