Original Article

Echocardiographic parameters recommended for assessing the severity of tricuspid regurgitation: concordance and discordance

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Background: Current guidelines recommend integrating several echocardiographic indices to evaluate the severity of tricuspid regurgitation (TR). Discordance of indices, including qualitative and quantitative methods, commonly exists in practice. The discordance among these parameters has not yet been fully elucidated.

Methods: A total of 127 patients with recognizable TR jets without pulmonary regurgitation or intracardiac shunt were prospectively enrolled. We evaluated 8 parameters by 2-dimensional (2D) echocardiography: proximal iso-velocity surface area (PISA)–derived regurgitant volume (RVol), PISA-derived effective regurgitant orifice area (EROA), PISA radius, vena contracta width (VCW), color Doppler jet area, tricuspid valve annular diameter, inferior vena cava (IVC) diameter, and peak E wave. According to current guidelines, each echocardiographic parameter was determined to represent either severe or non-severe TR. A concordance score was calculated as the number of concordant parameters divided by 8, with a higher score reflecting better concordance. Data were further categorized into 3 subgroups: complete concordance (0 discordant parameters), high concordance (1–2 discordant parameters), and low concordance (3–4 discordant parameters).

Results: The mean concordance score was 81%±17% for the entire cohort. There were 48 (38%) patients with complete concordance, including 6 patients with severe TR. In contrast, the low concordance group (n=43, 34%) mostly comprised severe TR patients (36 patients). When considering only EROA, RVol, and VCW, concordance improved, with 98 patients (77%) in complete agreement.

Conclusions: Concordance seems limited when using echocardiographic parameters to assess TR severity. Applying only EROA, RVol, and VCW results in better concordance, as recommended by the current guidelines.

Keywords: Tricuspid regurgitation (TR); echocardiography; discordance

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Introduction

Current guidelines for valvular heart disease recommend integrating several echocardiographic indices to evaluate the severity of tricuspid regurgitation (TR) (1-3). These indices include qualitative and quantitative assessments of TR severity and several parameters that assess the hemodynamic consequences of TR. However, qualitative parameters can be discordant with quantitative ones, and even quantitative indices can have conflicting results, making it hard to differentiate severe from non-severe TR. Moreover, the rate of concordance between echocardiographic indices is still unknown. This study aimed to assess the extent to which different echocardiographic parameters recommended for assessing TR severity vary from each other.

Methods

A total of 127 patients with recognizable TR jets without pulmonary regurgitation or intracardiac shunt were prospectively enrolled. All patients were candidates for cardiac surgery, and had been undergoing diuretics therapy before transthoracic echocardiogram examination. At the time of enrollment, baseline clinical data were collected for each patient. Images were read by experienced echocardiographers who were blinded to the clinical data. A total of 8 parameters by 2-dimensional (2D) echocardiography were evaluated: proximal iso-velocity surface area (PISA)-derived regurgitant volume (RVol), PISA-derived effective regurgitant orifice area (EROA), proximal flow field (PISA radius), vena contracta width (VCW), color Doppler jet area, peak E velocity, tricuspid valve annular diameter, and inferior vena cava (IVC) diameter. The overall TR severity was graded according to integrated method as recommended in the current American Society of Echocardiography (ASE) guideline (2017) and the modified version by Zhan *et al.* (2,4). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Review Board and Ethics Committee of Zhongshan Hospital, Fudan University (No. B2018-117). Written consent was provided by all participants.

Echocardiography

A complete 2D transthoracic echocardiographic study was performed on the GE Vivid E95 system (GE Vingmed Ultrasound, Horten, Norway) with an M5Sc probe. Echocardiographic parameters were obtained according to the current guidelines (1-3): 3 consecutive cardiac cycle images were acquired in patients with sinus rhythm; in patients with atrial flutter, atrial fibrillation (Afib), or frequent premature beats, 6 consecutive cardiac cycle images were acquired. Peak tricuspid E wave velocity was measured at the leaflet tips from the apical 4-chamber view. Color Doppler jet area was calculated from the imaging view with the largest color Doppler jet, using a Nyquist limit of 50–60 cm/s. The VCW was measured in both the right ventricular (RV) inflow and apical 4-chamber views and averaged. The PISA radius was measured in zoomed right-ventricle focused 4-chamber view with a baseline Nyquist limit shift of 28 cm/s. Continuous-wave Doppler images across the tricuspid valve were acquired parallel to the color Doppler jet and then categorized based on their shape and density. The velocity-time integral (VTI) of TR and maximum velocity of TR were also determined by continuous-wave Doppler. The EROA was calculated using the PISA radius, peak TR velocity, and aliasing velocity. Per the current guidelines, tricuspid RVol was derived using PISA-EROA and the TR VTI. The pulmonary arterial systolic pressure (PASP) was calculated based on the maximum velocity of the continuous-wave Doppler signal of the functional tricuspid regurgitation (FTR) jet and the right atrial (RA) pressure estimate by IVC size and inspiratory collapsibility index. Tricuspid valve annular diameter was measured at diastole in an apical 4-chamber view. The IVC diameter was measured with its maximal dimension at 1–2 cm proximal to the junction of the IVC and RA. RV end-diastolic area (EDA) and end-systolic area (ESA) were measured in the apical 4-chamber view and indexed to body surface area (5). RV fractional area change (FAC) was calculated as (RV EDA − RV ESA)/RV EDA, with normal FAC ≥35%. RV end-diastolic volume and end-systolic volume were quantified using 4D AutoRVQ software package (GE Vingmed Ultrasound). RA volume was measured using 4D AutoLVQ software package (GE Vingmed Ultrasound). All echocardiographic measurements were made in triplicate and averaged.

Echocardiographic parameter agreement

According to current guidelines, each parameter for TR assessment was identified as severe or non-severe (*Table 1*). A concordance score was calculated as the number of concordant parameters divided by 8, with a higher score

Table 1 Parameters for TR severity assessment

Parameter	Severe TR definition
PISA-EROA	≥40 mm²
PISA–RVol	≥45 mL
VCW	≥7 mm
PISA radius	>9 mm
TA diameter	≥40 mm
IVC diameter	>2.5 cm
Color jet area	>10 cm²
Peak E velocity	>1 m/s

TR, tricuspid regurgitation; PISA, proximal iso-velocity surface area; EROA, effective regurgitant orifice area; RVol, regurgitant volume; VCW, vena contracta width; TA, tricuspid valvular annulus; IVC, inferior vena cava.

reflecting better concordance. Patients were further categorized into 3 subgroups: complete concordance (0 discordant parameters), high concordance (1–2 discordant parameters), and low concordance (3–4 discordant parameters). An analysis including only VCW, PISA-RVol, and PISA-EROA was conducted separately concerning the increasing emphasis on quantitative methods by guidelines. Discordance among quantitative methods was defined when at least 1 in 3 parameters mismatched.

Statistical analysis

The data analysis was performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean ± SD. Categorical variables were presented as absolute numbers and percentages. Continuous variables were analyzed using the Student's *t*-test. Categorical variables were analyzed using the χ^2 test. One way analysis of variance (ANOVA) with a post hoc Bonferroni test was used to compare the means of continuous variables among multiple groups. Univariate predictors and multivariate predictors of concordance scores were determined using linear regression analysis with backward elimination. Variables included in the model were age, gender, Afib, TR etiology, PASP, VCW, EROA, RVol, PISA radius, color Doppler jet area, peak E velocity, tricuspid valve annulus (TA) diameter, IVC diameter, RV end-diastolic volume index (EDVI), RV end-systolic volume index (ESVI), and right atrial volume index (RAVI). Those variables with a P<0.1 in the univariate analysis were included in the multivariate analysis. All tests were 2-tailed, and a P value <0.05 was considered statistically significant.

Results

Baseline clinical data are listed in *Table 2* for the entire cohort according to the degree of concordance. Except for age, there were no differences in the baseline clinical characteristics between the complete/high concordance group and the low concordance group. A large proportion of patients were diagnosed with Afib before the screening and most patients had secondary TR. More than 80% of participants were administrated with more than 40 mg furosemide per day. Patients in the complete/high concordance group were shown to have higher PASP (51±18 *vs.* 42±10 mmHg).

In our cohort, 44 patients (35%) had mild TR, 32 patients (25%) had moderate TR, and 51 patients (40%) had severe TR. The mean concordance score was 81%±17%. There were 43 (34%) participants with low discordance, 36 (28%) with high discordance, and 48 (38%) with complete discordance. There were only 6 participants with severe TR in the complete concordance group. In contrast, the low concordance group mostly comprised severe TR patients (36 patients) (*Figure 1A*). Moreover, mild TR patients had the highest concordance score, and there was a decrease in concordance with increasing severity of TR (*Figure 1B*).

Table 3 shows the percentage of each echocardiographic parameter defined as non-severe or severe according to the current guidelines. In our cohort, non-severe TR was more common than severe TR regarding each parameter. *Figure 2* demonstrates the percentage of each parameter grouped by the multiparametric method. In patients grouped as non-severe TR, most echocardiographic parameters were non-severe except for TA diameter, which overestimated TR severity in about 32% of patients (24 in 76 patients). However, peak E velocity and IVC diameter were found to underestimate the TR severity in about half of patients grouped as severe TR.

For the primary TR in our cohort, there was 1 participant with Ebstein anomaly, 11 with degenerative disease (9 prolapse, 2 flail), 1 for whom the cause was thoracic trauma, and 32 with rheumatic heart disease (with morphological change in tricuspid valve, concomitant with or without left heart disease). A total of 4 participants were diagnosed with cardiac implantable electronic device (CIED)-induced TR. For the secondary TR (morphologically normal tricuspid valves), there were 4 participants with atrial secondary

Table 2 Baseline characteristics and echocardiographic parameters

Characteristics and parameters	Total (n=127)	Complete/high concordance group (n=84)	Low concordance group (n=43)	P value
Demographics				
Age, years	59±11	61±11	57±9	0.045
Female	83 (65.4)	54 (64.3)	29 (67.4)	0.724
BMI, kg/m^2	22.2±3.8	22.2±4.2	22.5±2.7	0.928
Hypertension	30 (23.6)	19 (22.6)	11 (25.6)	0.710
Diabetes mellitus	7 (5.5)	5 (6.0)	2 (4.7)	0.761
Atrial fibrillation	84 (66.1)	53 (63.1)	31 (72.1)	0.311
NYHA class III–IV	98 (77.2)	67 (68.4)	31 (72.1)	0.330
Elevated SCR	25 (19.7)	18 (21.4)	7 (16.3)	0.490
Elevated ALT	40 (31.5)	29 (34.5)	11 (25.6)	0.305
TR etiology and morphology				
Primary	49 (38.6)	32 (38.1)	17 (39.5)	–
Secondary	78 (61.4)	52 (61.9)	26 (60.5)	0.875
Eccentric jet	65 (51.2)	46 (54.8)	19 (44.2)	0.259
TR severity				
Mild	44	44	0	–
Moderate	32	25	7	–
Severe	51	15	36	0.000
Echocardiographic measurements				
PASP, mmHg	48±16	51±18	42±10	0.000
RA volume index, mL/m^2	81±89	76±102	92±55	0.340
RV EDA index, cm^2/m^2	13.7±5.6	12.7±5.7	15.8±4.8	0.003
RV ESA index, cm^2/m^2	7.9±3.6	7.6±3.7	8.6±3.2	0.151
RV EDV index, mL/m^2	71±31	68±29	78±33	0.098
RV ESV index, mL/m^2	38±19	36±18	43±22	0.100
EROA, cm^2	0.51±0.67	0.42±0.78	0.67±0.34	0.048
RVol, mL	34.34±33.68	27.8±37.6	47.1±18.8	0.002
VCW, cm	0.60±0.32	0.51±0.33	0.78±0.18	0.000
PISA radius, cm	0.73±0.35	0.63±0.35	0.91±0.25	0.000
E velocity, m/s	0.88±0.29	0.80±0.28	1.01±0.27	0.000
TA diameter, cm	39.3±8.8	38.3±9.3	41.1±6.0	0.051
Jet area, cm^2	10.03±7.58	9.1±8.3	11.8±5.7	0.059
IVC diameter, cm	1.91±0.70	1.75±0.73	2.21±0.55	0.000

Data are presented as mean ± standard deviation, n (%), or number. BMI, body mass index; NYHA, New York Heart Association; SCR, serum creatinine; ALT, alanine aminotransferase; TR, tricuspid regurgitation; PASP, pulmonary arterial systolic pressure; RA, right atrium; RV, right ventricle; EDA, end diastolic area; ESA, end systolic area; EDV, end diastolic volume; ESV, end systolic volume; EROA, effective regurgitant orifice area; RVol, regurgitant volume; VCW, vena contracta width; PISA, proximal iso-velocity surface area; TA, tricuspid valvular annulus; IVC, inferior vena cava.

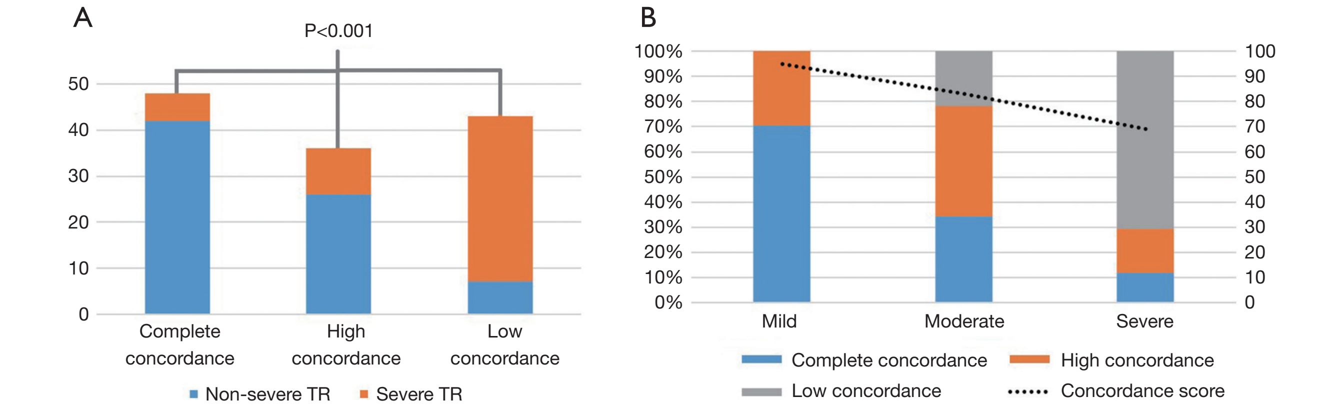

Figure 1 The relationship between concordance levels and TR severity. (A) The numbers of non-severe and severe TR patients in low, high, and complete concordance groups. (B) The percentage of each concordance group in mild, moderate, and severe TR patients and overall trend in concordance score. TR, tricuspid regurgitation.

Table 3 The percentage of each echocardiographic parameter as severe or non-severe

Parameter	Non-severe, %	Severe, %
VCW	80	47
EROA	75	52
RVol	95	32
PISA radius	94	33
Peak E	92	35
Jet area	88	39
TA diameter	70	57
IVC	94	33

VCW, vena contracta width; EROA, effective regurgitant orifice area; RVol, regurgitant volume; PISA, proximal iso-velocity surface area; TA, tricuspid valvular annulus; IVC, inferior vena cava.

TR (with isolated Afib), 26 with ventricular secondary TR (manifested by leaflet tethering without Afib), and 48 with mixed secondary TR (with Afib and leaflet tethering). There was no difference in concordance score between patients with primary or secondary TR (81±18 *vs.* 81±17; P=0.9) or with and without eccentric jets (82±18 *vs.* 81±17; P=0.7). However, when comparing the categories of mild, moderate, and severe TR, there was a better concordance in the mild and severe TR patients in primary TR than in secondary TR (*Figure 3*). Although the concordance score had no statistical differences among patients with or without Afib, the overall concordance was slightly better in the non-Afib patients (80±17 *vs.* 84±18; P=0.29) (*Figure 4*). When considering only EROA, RVol, and VCW, concordance improved with 98 patients (77%) in complete agreement. The improvement was most evident in the severe TR group, with 27 patients (56%) reaching complete concordance (*Figure 5*).

The univariate and multivariate predictors of concordance score are listed in *Table 4*. The multivariate predictors of concordance score include only PISA radius, EROA, and peak E velocity.

Discussion

The primary finding of this study is the wide variance among guideline-recommended echocardiographic parameters for TR assessment. A complete agreement of echocardiographic parameters appeared in only 38% (n=48) of participants. About 34% (n=43) of patients in our cohort were determined to have 3–4 parameters discordant. Previous studies have demonstrated the limitations in the echocardiographic evaluation of TR severity. Firstly, echocardiographic measurement is objective and varies among observers (6). Secondly, significant TR variations can be observed over the respiratory cycle, which makes a single echocardiographic measurement unreliable (7). Thirdly, different vendors and technical settings can affect the echocardiographic measurement (8,9). Our study highlights another challenge echocardiographers face when assessing TR severity: discordance among parameters. In the multivariate analysis, the concordance score was related to TR severity parameters, including peak E wave, EROA,

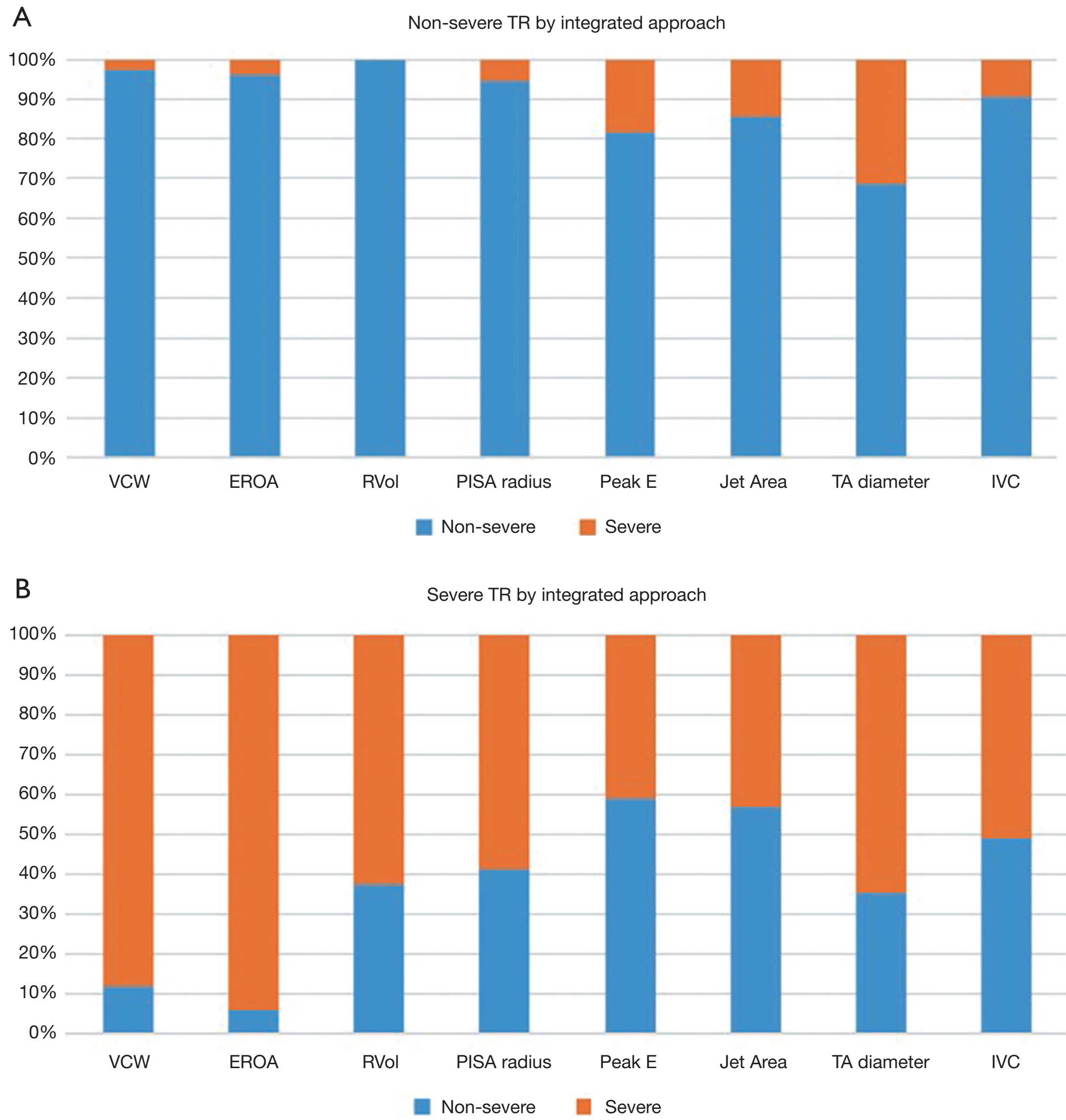

Figure 2 The percentage of each echocardiographic parameter reflective of either non-severe or severe tricuspid regurgitation. VCW, vena contracta width; EROA, effective regurgitant orifice area; RVol, regurgitant volume; PISA, proximal iso-velocity surface area; TA, tricuspid valve annulus; IVC, inferior vena cava; TR, tricuspid regurgitation.

RVol, and PISA radius. Moreover, there was an increasing trend of discordance as TR severity intensified, with severe TR patients having the lowest concordance score. Such inconsistency decreases the diagnostic confidence of clinicians, promoting the adoption of ambiguous diagnoses (moderate to severe TR), and leading to the late referral and management of severe TR patients (1,10).

Another important finding of the current study is that TA diameter overestimated TR severity in 30% of "non-severe" patients in our cohort and the concordance score was slightly higher in the non-Afib group, though without statistical significance. This could be explained by the pathophysiology of atrial functional TR. In atrial functional TR, The RV assumes a triangular shape with dilation confined to the inflow basal region (11,12), where eccentric posterior-directed TR and annular dilatation are prominent (13). The eccentric jet may complicate PISA-derived TR

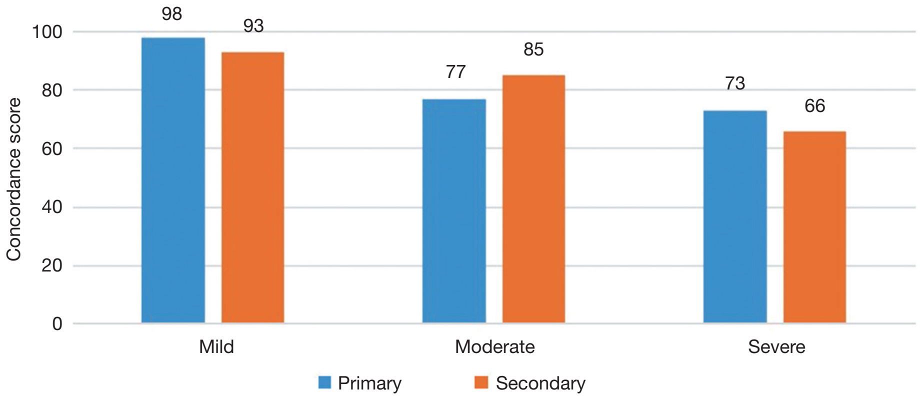

Figure 3 Concordance score in primary and secondary tricuspid regurgitation.

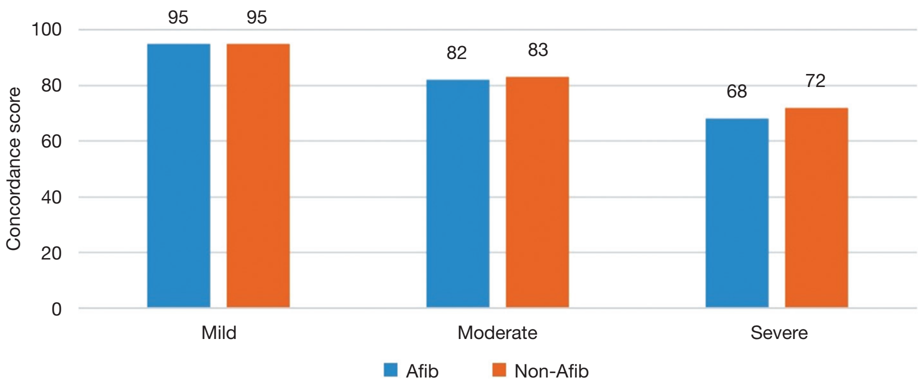

Figure 4 Concordance score according to the severity of tricuspid regurgitation in patients with atrial fibrillation and without Afib. Afib, atrial fibrillation; Non-Afib, not atrial fibrillation.

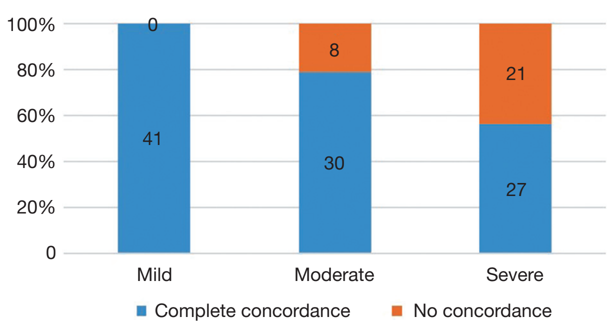

Figure 5 The percentage of patients with complete concordance or without concordance according to quantitative methods (including PISA-EROA, PISA-RVol, and VCW). PISA, proximal iso-velocity surface area; EROA, effective regurgitant orifice area; RVol, regurgitant volume; VCW, vena contracta width.

measurements and add to the discordance. In addition, in the early phase of atrial functional TR without significant RV remodeling, whether TA enlargement is sufficient to cause significant atrial functional TR is still controversial (12,14,15), which is consistent with our finding that a significant minority of patients with dilated TA have non-severe TR.

Comparisons of selected parameters for TR severity quantification have been reported in previous studies. Chen *et al.* reported a moderate correlation between VCW and EROA (16). In their study, EROA failed to correlate with the jet area, even in selected patients without Afib. In contrast, Yang *et al.* reported a good correlation between VCW, EROA, and jet area (17). A weak correlation between EROA and TA diameter was reported by Kim *et al.* (18). Several echocardiographic parameters have been compared

Table 4 Linear regression analysis for predictors of higher concordance score

Parameter	Univariate predictors				Multivariate predictors			
	B	β	95% CI	P value	B	β	95% CI	P value
Age	0.002	0.114	−0.001 to 0.005	0.201				
PASP	0.002	0.191	0.000 to 0.004	0.031	0.001	0.133	0.000 to 0.003	0.08
VCW	−0.227	−0.410	−0.316 to −0.138	<0.001				
EROA	−0.041	−0.157	−0.085 to 0.005	0.078	0.314	1.196	0.198 to 0.431	<0.001
RVol	−0.001	−0.284	−0.002 to −0.001	0.001	−0.005	−0.983	−0.008 to −0.003	<0.001
PISA-radius	−0.184	−0.364	−0.267 to −0.100	<0.001	−0.224	−0.441	−0.348 to −0.100	<0.001
Color jet area	−0.005	−0.219	−0.009 to −0.001	0.013				
Peak E	−0.255	−0.430	−0.349 to −0.160	<0.001	−0.159	−0.261	−0.250 to −0.069	0.001
TA	−0.006	−0.289	−0.009 to −0.002	0.001				
IVC	−0.081	−0.326	−0.123 to −0.039	<0.001				
RV EDVI	−0.001	−0.170	−0.002 to 0	0.056				
RV ESVI	−0.001	−0.152	−0.003 to 0	0.089				
RAVI	0	−0.107	−0.001 to 0	0.232				

PASP, pulmonary arterial systolic pressure; VCW, vena contracta width; EROA, effective regurgitant orifice area; RVol, regurgitant volume; PISA, proximal iso-velocity surface area; TA, tricuspid valve annulus; IVC, inferior vena cava; RV EDVI, right ventricular end-diastolic volume index; RV ESVI, right ventricular end-systolic volume index; RAVI, right atrial volume index.

with CMR to devise a diagnostic scheme without depicting the concordance among echocardiographic parameters (4). The concordance among mitral regurgitation severity parameters was reported by Uretsky *et al.* (19). So far, our study is the first to compare multiple TR parameters simultaneously, and it illustrates the wide variance among guideline-recommended TR parameters.

There could be several reasons for the widespread discordance among guideline-recommended TR severity parameters in our study. Some of these parameters reflect the structural changes related to TR, such as TA and IVC diameters; some characterize different hemodynamic aspects of TR, including the severity of the valvular lesion (VCW and EROA), RVol, and PISA radius. Some parameters, such as peak E wave and jet area, are unnecessarily associated with severe TR. Thus, discordance happens when integrating these parameters regarding different aspects of TR, especially in patients with significant TR.

Disturbed loading conditions could be a potential reason for the discordance among different TR severity parameters. In our cohort, all patients were undergoing radical diuretic therapy (daily dose of furosemide ≥40 mg in more than 80% of patients). In these patients, reduced effective circulating blood volume resulted in better compliance of the RA, and accounted for the underestimation of IVC diameter and peak E velocity in the severe TR group (*Figure 2*). Moreover, patients in the low concordance group had lower PASP. Thus, insufficient atrioventricular driving pressure may result in the underestimation of some parameters, like PISA-radius and jet area (*Figure 2*).

Lastly, our study should be considered a valuable supplement to the existing guidelines. Quantitative methods, such as EROA, VCW, and RVol, are recommended for assessing TR severity when discrepancies are present in qualitative parameters. However, it remains uncertain whether these quantitative measurements contribute significantly to a definitive diagnosis of TR severity. Our research offers evidence of the frequent discordance and reinforces the notion that quantitative methods should be employed whenever feasible to achieve a clear TR diagnosis.

Limitation

All participants in this study were candidates for cardiac surgery, presented with clinical or subclinical congestive heart failure [New York Heart Association (NYHA) III–IV in 77.2%], and were being administrated with diuretics. As a result, our conclusions may be limited to this specific population, who require the utmost care in TR grading before further intervention. Hepatic vein systolic flow reversal was not included because of the common existence of Afib in our cohort. Although 3-dimensional (3D) echocardiography can provide better evaluation of tricuspid annulus, it is limited by image quality and is in need of a reference value in TR patients (20). This study did not include 3D or Doppler-derived RVol and regurgitant fraction, as these measurements are not commonly used in clinical practice (21). Qualitative evaluation of the leaflet morphology such as large leaflet coaptation gap, leaflet perforation, and flail leaflet can be very useful to help determine whether TR is severe when there is discrepancy in quantitative data. The added value of the qualitative evaluation of the leaflet morphology in addition to quantitative parameters should be investigated in future studies. In this study, TR severity was graded solely by 2D echocardiography, and the use of more advanced imaging techniques, such as 3D echocardiography or cardiac magnetic resonance, might allow for a better definition of TR severity. It is hard to explain the multivariate model of concordance score in our study, and a larger study population is required to verify our findings.

Conclusions

Concordance seems limited when using echocardiographic parameters to assess TR severity. The discordance is worse in severe TR without the existence of valuable clinical predictors. Applying only quantitative methods, PISA-EROA, PISA-RVol, and VCW, results in better concordance, and is recommended in the current guidelines. These findings highlight the challenges faced by echocardiographers when assessing the severity of TR using integrative methods and support the idea that quantitative methods should be performed whenever possible to reach a clear TR diagnosis.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-3/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the Review Board and Ethics Committee of Zhongshan Hospital, Fudan University (No. B2018-117). Informed consent was provided by all participants.

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