Original Article

Accuracy of Lone Three-dimensional Transthoracic Echocardiography in Tricuspid Valve Function and Geometry Assessment: Implication for Preoperative Evaluation of Transcatheter Tricuspid Valve Therapies

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Abstract

Introduction: Tricuspid regurgitation (TR) is associated with high rate and poor prognosis in patient undertreated. In recent years, transcatheter tricuspid valve interventions (TTVI) appears like a valuable option in high risk surgical candidates in presence of suitable anatomy. Screening phase with transthoracic, thansoesophageal echocardiography, and cardiac computed tomography (CT) are necessary select patients. **Purpose:** The aim of the study is to compare different imaging modalities as three-dimensional (3D) transthoracic echocardiography (TTE), transesophageal echocardiography (TOE) and ECG-gated cardiac CT for the definition of tricuspid valve (TV) function and geometry assessment. **Materials and Methods:** Twenty-one (age 79 ± 7 years, female 72%) patients under screening for transcatheter treatment of TR were prospectively enrolled in the study and underwent TTE, TOE, and cardiac CT. All measurements were performed in double blind by three different operators and compared. **Results:** In the comparison between 2D/3D TTE and 2D/3D TOE, no statistically significant differences were found regarding the evaluation of the valve anatomy, the site of regurgitation, and the underlying mechanism (TTE vs. TOE: 3D septo-lateral diam 45.8 ± 4,92 vs. 45.87 ± 4,98 mm, $P = 0.87$; 3D antero-posterior diam 43.5 ± 4,58 vs. 43.5 ± 4,53 mm, $P = 0.59$; Circularity index 0,75 ± 0,08 vs. 0,76 ± 0,08, $P = 0.98$). When comparing 3D TTE and cardiac CT, no differences were recorded in terms of TV area 17.58 ± 3 versus 17.71 ± 4,3 cm^2, $P = 0.1$; perimeter 14.89 ± 1,6 versus 14.29 ± 1 cm, $P = 0.5$ and diameters. Similarly, in the study of right ventricular dimensions, obtained through 3D volumetric reconstruction, TTE was not statistically different to Cardiac CT. **Conclusions:** The present series shows how a lone 3D TTE has a good reliability in the definition of TV function, leaflet characteristics, and geometry when compared with second level imaging modalities and may be safely used to select optimal candidates for complex TTVI.

Keywords: Three-dimensional echocardiography, transcatheter tricuspid valve interventions, tricuspid regurgitation, tricuspid valve

Introduction

Tricuspid valve (TV) regurgitation is an emerging disease with the recognition of a large amount of population affected still undiagnosed and untreated. Almost 1.6 million of cases are estimated to be present in the U. S. A.[1]

For a long time, a neglected and passive structure, the TV was often called "the forgotten valve,". It has recently gained a strong focus from the medical population and attention due to the association of the tricuspid regurgitation (TR) itself with a reduced survival. Several conditions are associated with TR and play a special role in patient prognosis and outcome as right ventricle (RV) shape and function, TV anatomy and annulus, and status of pulmonary circulation.

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Last edition of European guidelines encouraged surgical correction in symptomatic patients affected by isolated TR and focus on RV dilation of a marker of advance disease.[2] transcatheter tricuspid valve interventions (TTVI) has been recently proposed as valuable option to deal with TR when the patients is deemed at high risk for open heart surgery.[3,4] In this field, several techniques maybe applied and considered according TR etiology, location of may jet, leaflet motility and gap between them, anular dilation, and presence of leads which may impinge the valve.[5-8] Devices on the market or under investigation for the treatment of TR may be classified as (1) coaptation device, (2) annular device, and (3) replacement device (orthotopic or etherotopic prosthesis).[9,10] Choosing the most suitable therapeutic strategy for each patient needs an accurate echocardiographic screening phase aimed to correctly define in deep at the anatomic features as annular dimensions and shape, leaflet characteristics, jet features, RV dimensions and motility.[11-13] In this setting, transesophageal echo represents the gold standard both to describe valve function an anatomy and guide TTVI.[14-16] Nevertheless, TOE is an invasive test with potential complication which may be avoided with accurate transthoracic echo. Emerging technique of advanced transthoracic echocardiography (TTE) aims to reproduce all accuracy of TOE in a rapid, easy, and noninvasive approach.[17,18]

The primary aim of this prospective and observational study was to evaluate, in patients with severe TR candidates for percutaneous treatment of TR, (1) the accuracy of TTE when compared with transesophageal one in three-dimensional analysis of valve morphology, geometry, and annular characteristics; (2) reliability of the three-dimensional transthoracic echocardiogram in the evaluation of annular geometry compared to computed tomography (CT) (gold standard); secondary objective was the effectiveness of the percutaneous intervention in terms of reduction of TR and improvement in quality of life (New York Heart Association [NYHA] class and symptoms of decompensation).

Materials and Methods

General population

Twenty-one patients referred to San Camillo Forlanini Cardiac Surgery Department with a diagnosis of at least severe symptomatic TR were consecutively enrolled. All patients underwent two- and three dimensional transthoracic echocardiographic study (TTE) at the time of enrollment for diagnosis purposes and subsequently underwent two dimensional (2D) and three-dimensional (3D) Transesophageal echocardiography study (TOE). Moreover, an ECG-gated cardiac CT was performed for the study of the annular parameters and coronary anatomy. The local Heart Team evaluated the patient's features and eligibility criteria for percutaneous treatment of TR when excluded for of any surgical option. Surgical risk stratification was performed by the calculation of the EUROSCORE II, TriSCORE, and evaluation of comorbidities as advanced age, frailty scales, previous cardiac interventions, and status of RV and pulmonary circulation.

Following criteria were adopted. Inclusion criteria:

- Age ≥18 years
- Diagnosis of severe TR
- NYHA Class II or RV failure signs

Exclusion criteria:

- -Life expectancy <1 year
- Recent myocardial infarction/stroke (<1 month)
- Transthoracic or transesophageal echocardiographic window not adequate for three-dimensional reconstructions
- Inadequate CT images to perform reconstruction

All measurements were performed in double-blind by three different operators, one for each method listed (TTE, TOE, and CT). At the end of data collection, the same was examined by a dedicated single operator (not involved in the previous ones).

Reconstruction of tricuspid annulus on cardiac CT was carried out through the software 3 Mensio 3 (Pie Medical Imaging, Maastricht, The Netherlands).

Echocardiographic protocol

All patients underwent 2D, Doppler, and 3D TTE and TOE. Echocardiographic studies were performed with Vivid E95 Echo Machine (GE Vingmed, Horten, Norway), equipped with 4Vc (TTE) and 6VT-D (TOE) probes. Acquisitions of the regurgitant jet with color Doppler method were obtained from RV inflow, parasternal short axis, apical 4-chamber, and apical 4-chamber RV focused windows regarding the transthoracic examination; from the midesophageal 4 chambers and RV inflow-outflow views, deep esophageal, TV focused transgastric short axis, and transgastric long axis for the RV regarding transesophageal one. The recordings were carried out on three (five in patients with atrial fibrillation) consecutive cycles during respiratory apnea to minimize respiratory variability.

At the end of the two-dimensional and Doppler examination, three-dimensional full volume images for the RV from the apical four chamber view RV focused and apical four chamber conventional for the left ventricle (LV), 4D TV focused zoom images with and without color were acquired for the study of the TV on an average of 3 beats.

All images were then reprocessed offline using dedicated software EchoPAC 203 (GE Vingmed, Horten, Norway), volume measurement was carried out using the 4D AutoRVQ software package. Grading of TR was obtained through evaluation of qualitative, semi-quantitative, and quantitative parameters as per the recommended protocol.

The measurement of the tricuspid annulus was performed by two-dimensional examination from the RV focused apical view (TTE) and mid-esophageal four chambers view (TOE) into end diastole (frame before the closure of TV).

Three-dimensional examination was obtained from the 3D atrial view and multiplanar reconstruction (MPR) reconstructions acquired respectively by the RV focused window (TTE) and mid-esophageal four chambers view (TEE) in end-diastole.

Statistical analysis

Statistical analysis was performed by applying the descriptive statistical methods for the study population at baseline. Continuous normally distributed variables were presented as means ± standard deviation; nonnormally distributed data were presented as medians and ranges interquartile range (25th and 75th percentiles). The categorical variables were presented as numbers (%). Differences between groups were compared using the *t*-test Student's test and Shapiro–Wilk test for normally distributed variables and the Mann–Whitney U test for asymmetric variables. Categorical variables were summarized as numbers and percentages of subjects in each category.

Adverse events were analyzed in proportion to the number of patients. The observed mortality rates were described as rates (%). Early mortality rates were described using the means of descriptive statistics. All deaths for unknown reasons were considered as cardiac death. All P values reported were considered statistically significant if <0.05. IBM SPSS Statistics 26.0 (Armonk, NY, USA: IBM Corp) was used for all analyses statistics.

Results

Baseline population

The baseline demographic and clinical features are reported in Table 1 and Graph 1. The mean age of the population is 79 ± 7 and 15 patients were of female sex (72% of the general population).

The majority of patients (86%) showed marked limitations of physical activity or hearth failure symptoms at rest (NYHA III-IV). Sixteen patients of the study cohort (76%) have had at least one hospitalization for heart failure in the 12 months prior to enrollment.

All patients had a nonnegligible surgical risk with an average EUROSCORE II of 7.14 ± 5.3% and an average TRISCORE of 4.9 ± 0.9%. Furthermore, 38% of patients had already undergone open heart surgery for CABG, aortic and/or mitral valve replacement, mitral valve repair surgery.

Transthoracic echocardiographic features of the population at baseline

The baseline echocardiographic characteristics of the population are shown in Table 2 and Graph 2. Most patients presented a preserved left ventricular systolic function and left ventricular dimensions (average LV ejection fraction % 59 ± 7, average LV end-diastolic diameter 49 ± 6, average LV end-diastolic volume 113 ± 31), with slightly reduced average global longitudinal strain (GLS) values (average GLS-16.38 ± 3). The median value of left atrial volume and right atrial area suggested marked biatrial dilatation common to most patients.

Table 1: Baseline population (*n*=21)

Variable	Whole population (*n*=21), *n* (%)
Age (year) ± SD[a]	79±7
Sex, male	6 (28)
Diabetes	61 (15)
Hypertension	21 (100)
Dyslipidemia	8 (38)
Smoker	3 (14)
AF	15 (71)
Hospitalization for HF	16 (76)
NYHA[b] III–IV	18 (86)
Previous MI	2 (9.5)
Previous stroke	1 (5)
CKD	10 (48)
Dialysis	1 (5)
COPD[c]	7 (33)
Pheripheral arteriopathy	3 (14)
LV EF (%) ± SD[a]	59±7
Previous cardiac surgery	8 (38)
Previous endocarditis	1 (5)
EuroSCORE II (%) ± SD[a]	7.14±1.3
TriSCORE (%) ± SD[a]	6.9±0.9
CIED	8 (38)
Furosemide	18 (85)
Beta blockers	10 (47)
ACE inhibitors	5 (24)
Aldosterone antagonist	9 (42)

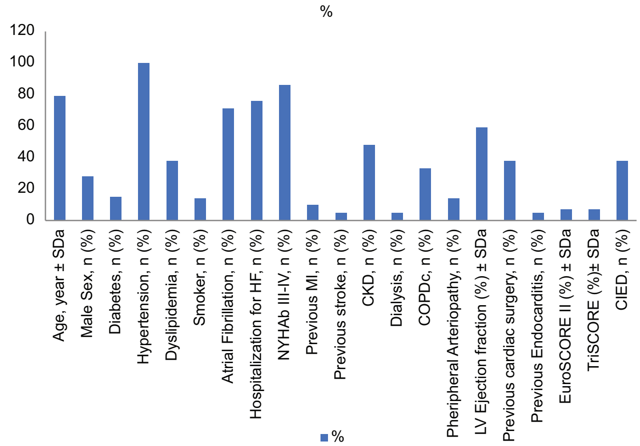
[a]SD standard deviation, [b]NYHA New York Heart Association, [c]COPD Chronic obstructive pulmonary disease. SD=Standard deviation, HF=Heart failure, NYHA=New York Heart Association, CIED=Cardiac impiantable electronic device, LV=Left ventricle, CKD=Chronic kidney disease, COPD=Chronic obstructive pulmonary disease, MI=Myocardial infarction, AF=Atrial fibrillation, EF=Ejection fraction, ACE=Angiotensin-converting enzyme inhibitor

As regards right volumetrics, the median value of right ventricular end diastolic volume and right ventricular end systolic volume indicates right ventricular enlargement. Respectively, 42% and 52% of patients present reduced longitudinal and radial systolic function, compared to values of mean FAC % (42 ± 8), mean RV GLS (−15 ± 7), and 3D EF (54 ± 10) only slightly reduced.

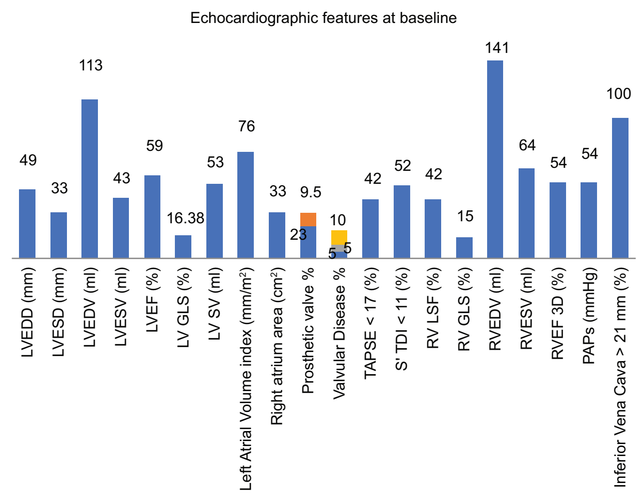
Pulmonary hypertension (average PAPs 54 ± 10) and caval plethora (average value 24 mm) were found in all patients.

Transthoracic echocardiographic characterization of tricuspid regurgitation at baseline

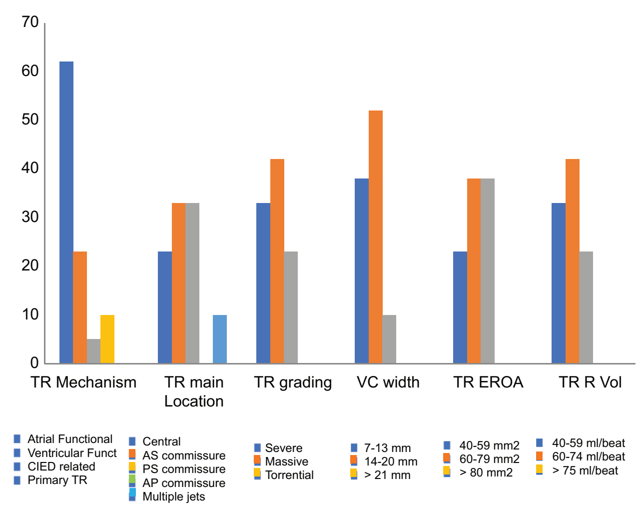
All patients enrolled present a baseline ≥ severe TR (inclusion criterion). In 34% of patients, regurgitation was assessed as severe, in 43% as massive, and finally in 23% as torrential. Regarding etiology, in 86% of the cases (18 pts), mechanism underlying the failure was considered to be a functional cause (respectively, 73% atrial functional TR and 27% ventricular functional TR), only one case (5%) was described as cardiac impiantable electronic device related and 2 cases (9%) were related to probable organic etiology.



Graph 1: Baseline population ($n = 21$)



Graph 2: Baseline echocardiographic characteristics of population ($n = 21$)



Graph 3: Echocardiographic characterization of tricuspid regurgitation at baseline ($n = 21$)

Regarding localization of jet regurgitation, none of the patients presents a jet in the anteroposterior commissural site (unfavorable anatomical site for a possible Triclip implant), in 33% of cases the regurgitation jet is located equally in the anteroseptal and posteroseptal commissural site, a smaller number of patient in the middle site of valve (24%); only in 10% of cases were multiple jets of comparable size identified [Figure 1 and Graph 3] [Table 3].

Table 2: Baseline echocardiographic characteristics of population (n=21)

Variable	Whole population (n=21), n (%)
LVEDD (mm) ± SD[a]	49±6
LVESD (mm) ± SD[a]	33±5.75
LVEDV (mL) ± SD[a]	113±31
LVESV (mL) ± SD[a]	43±13
LVEF (%) ± SD[a]	59±7
LV GLS (%) ± SD[a]	−16.38±3
LV SV (mL) ± SD[a]	53±13
Left atrial volume index (mm/m^2) ± SD[a]	76±37
Right atrium area (cm^2) ± SD[a]	33±9
Prostetic aortic valve	5 (23)
Prostetic mitral valve	2 (9.5)
Mitral regurgitation ≥ moderate	1 (5)
Mitral stenosis ≥ moderate	0
Aortic stenosis ≥ moderate	1 (5)
Aortic regurgitation ≥ moderate	2 (9.5)
TR ≥ moderate	21 (100)
TAPSE (mm) ± SD[a]	17±3.94
TAPSE <17 mm	9 (42)
S'- TDI (cm/s) ± SD[a]	10±2.1
S' - TDI <11 (cm/s)	11 (52)
RV - LSF (%)±SD[a]	42±8
RV GLS (%)±SD[a]	−15±7
RVEDV (mL) ± SD[a]	141±27
RVESV (mL) ± SD[a]	64±18
RVEF 3D (%) ± SD[a]	54±8
PAPs (mmHg) ± SD[a]	54±10
TAPSE/PAPs	0.33±0.09
IVC (mm)	24±5
IVC >21 (mm)	21 (100)

[a]SD standard deviation. TR=Tricuspid regurgitation, SV=Systolic volume, SD=Standard deviation, LV=Left ventricle, GLS=Global longitudinal strain, RV=Right ventricle, RVEDV=RV end diastolic volume, RVESV=RV end SV, RVEF=RV ejection fraction, LVEF=LV ejection fraction, LSF=Longitudinal shortening fraction, LVEDD=LV end-diastolic diameter, LVESD=LV end systolic diameter, LVEDV=LV end-diastolic volume, LVESV=LV essential societal variables, TAPSE=Tricuspid annular plane systolic excursion, IVC=Inferior vena cava, 3D=Three dimentional, TDI=Tissue doppler imaging, PAPs=Pulmonary systolic artery pressure

Comparative analysis between two-dimensional/three-dimensional transthoracic and two-dimensional/three-dimensional transesophageal echocardiography

In the comparison between 2D and 3D transthoracic and transesophageal echocardiograms, no statistically significant differences emerged regarding the evaluation of valve anatomy, site of regurgitation, and underlying mechanism.

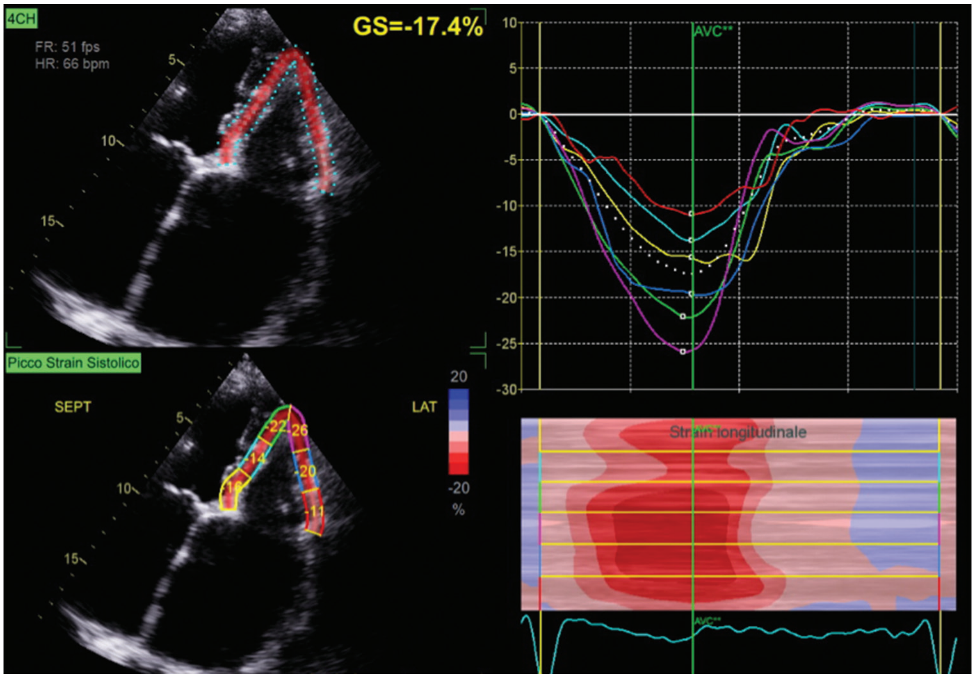


Figure 1: Right ventricle-global longitudinal strain

Data relating to the study of the tricuspid annulus obtained through 2D analysis (septolateral-SL and anteroposterior-AP diameter) and 3D analysis (SL, AP diameter, maximum and minimum diameter, annular area and annular perimeter, and circularity index) were comparable to the data obtained in double blind from transesophageal examination (no statistically significant differences, $P > 0.05$). Similarly, substantial overlap emerges from the data between the two methods for the data relating to the study of valve anatomy/deformation (valve area, tenting area, and coaptation height). However, as regards the severity of regurgitation, the two methodics are comparable in terms of measurement of proximal isovelocity surface area (PISAr) (2D), vena contracta (VC) width (2D), and VC3D. The only statistically significant differences were found in the measurement of effective regurgitant orifice area (EROA) ($P = 0.02$) and regurgitant volume ($P = 0.007$) with values bordering between massive (TTE) and severe (TOE), placing this at favor of greater performance of the transthoracic examination in assessing severity of regurgitation [Figure 2 and Graph 4] [Table 4].

Comparative analysis between three-dimensional transthoracic echocardiography and cardiac computed tomography

From the double-blind comparison between 3D TTE and Cardiac CT, no statistically significant differences emerged regarding anatomy and deformation of the annulus study (area, perimeter, maximum diameter, and minimum diameter). Similarly, in the study of the dimensions of the RV, obtained through three-dimensional volumetric reconstruction with dedicated 4D RVQ software, 3D TTE was found to be noninferior compared to cardiac CT in the measurement of ventricular diameters (basal right ventricular diameter- [RVD] 1 and mid right ventricular diameter-RVD2 and RL; $P > 0.05$) [Figure 3 and Table 5].

Efficacy and safety outcomes in treated patients

Among 21 patients participating in this study, 6 patients, after careful evaluation and selection by the Heart Team, underwent the percutaneous TR treatment considered most suitable based on the etiology of regurgitation, characteristics and location of jet regurgitation and the extent of annular dilatation. The remaining 15 patients were the candidates to medical therapy for therapeutic optimization, where possible, with subsequent re-evaluation or due to unfavorable anatomical characteristics.

Therefore, three patients underwent percutaneous valve repair with Triclip implant, one patient was treated with Cardioband, and finally two patients underwent TricValve implant [Table 6].

In patients undergoing percutaneous treatment for TR, despite the small number of cases analyzed, there was a statistically significant reduction in the NYHA class ≥1 grade at 30 days. In all patients was documented a reduction in severity of regurgitation ≥1° and in the EROA (although not statistically significant), on the contrary, there was an important reduction regarding regurgitation volume in postprocedural phase and during follow-up ($P = 0.03$). No intra- and periprocedural complications were observed; in early follow-up, however, one death was recorded [Table 7 and Graph 5].

Discussion

Interest in the study of tricuspid valvular anatomy and annulus has recently increased due to the recognition of the poor prognosis associated with TR and the development of new

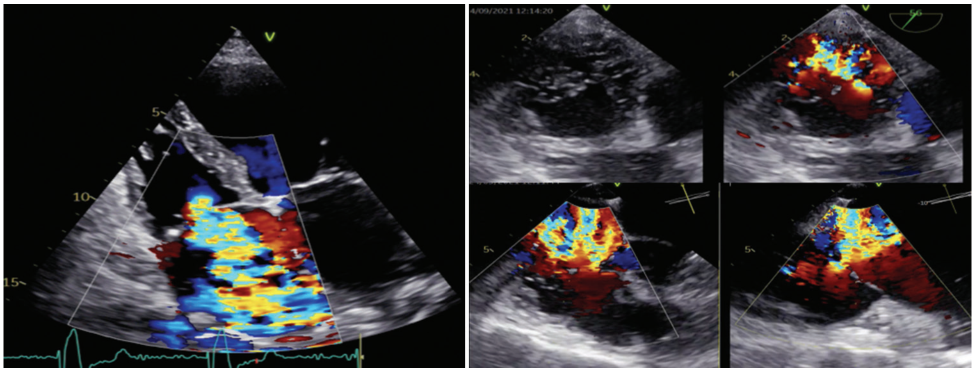


Figure 2: Massive tricuspid regurgitation with prevalent jet localized in the antero-septal area: TTE apical window right ventricle focused 4 chambers view; Transesophageal echocardiography (TOE) (left) transgastric short axis view (top) and mid-esophageal 4-chamber view with multiplanar reconstruction (MPR) (bottom)

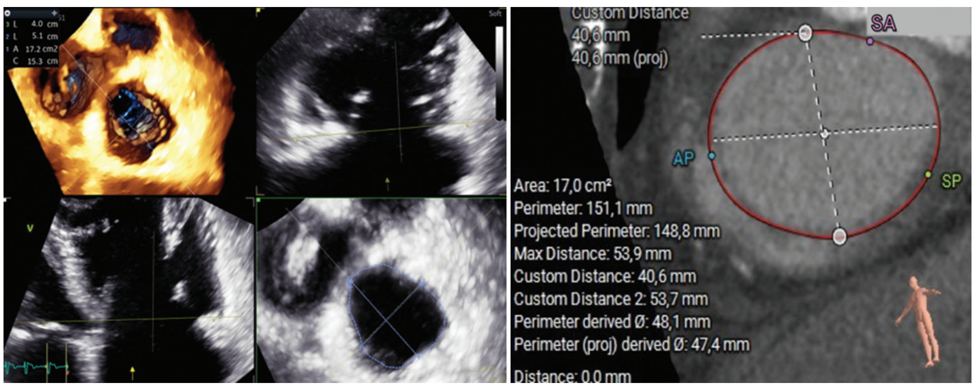
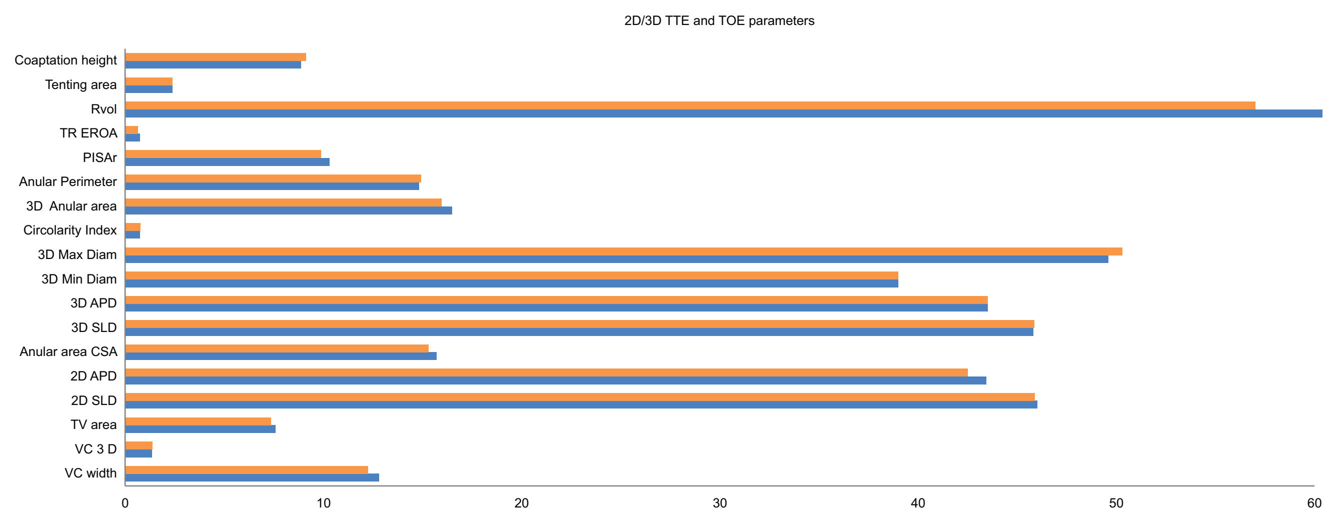


Figure 3: Study of the tricuspid annulus. Three dimensional transthoracic echocardiography reconstruction of the valve annulus with related measurements (right); study of the tricuspid annulus on cardiac computed tomography (left). Both measurements were taken in end-diastole



	VC width	VC 3 D	TV area	2D SLD	2D APD	Anular area CSA	3D SLD	3D APD	3D Min Diam	3D Max Diam	Circolarity Index	3D Anular area	Anular Perimeter	PISAr	TR EROA	Rvol	Tenting area	Coaptation height
ETE	12.26	1.36	7.35	45.88	42.5	15.3	45.87	43.5	39	50.31	0.76	15.97	14.93	9.87	0.64	57	2.38	9.12
ETT	12.8	1.35	7.59	46	43.43	15.7	45.8	43.5	39	49.6	0.75	16.48	14.82	10.31	0.74	60.4	2.37	8.87

Graph 4: Comparison of two dimensional and three dimensional transthoracic echocardiography and Transesophageal echocardiography (TOE) parameters ($n = 19$)

percutaneous repair techniques for the treatment of patients with severe TR at high surgical risk. Although there is not yet a standardized preprocedural work-up, the measurement of the ring during the selection and screening phase of patients

Table 3: Transthoracic echocardiographic characterization of tricuspid regurgitation at baseline (*n*=21)

Variable	Whole population (*n*=21), *n* (%)
Secondary TR	18 (86)
Atrial functional TR	13 (62)
Ventricular functional TR	5 (23)
CIED related TR	1 (5)
Primary TR	2 (9,5)
TR main location central	5 (23)
TR main location antero-septal commissure	7 (33)
TR main location postero-septal commissure	7 (33)
TR main location antero-posterior commissure	0 (0)
TR multiple jets	2 (9.5)
TR PISA ± SD[a]	10.4±1.82
Severe TR	7 (33)
Massive TR	9 (42)
Torrential TR	5 (23)
TR VC width 7–13 (mm)	8 (38)
TR VC width 14–20 (mm)	11 (52)
TR VC width ≥21 (mm)	2 (9.5)
TR EROA 40–59 (mm2)	5 (23)
TR EROA 60–79 (mm^2)	8 (38)
TR EROA ≥80 (mm^2)	8 (38)
TR regurgitation volume 45–59 (mL)	7 (33)
TR regurgitation volume 60–74 (mL)	9 (42)
TR regurgitation volume ≥75 (mL)	5 (23)

CIED=Cardiac impiantable electronic device, TR=Tricuspid regurgitation, EROA=Effective regurgitant orifice area, PISA=Proximal isovelocity surface area, SD=Standard deviation, VC=Vena contracta

candidates for percutaneous treatment is crucial in the rule-in/rule-out process for a specific interventional treatment; this measurement is currently carried out with both transthoracic and transesophageal echocardiography (both methods considered indispensable in this phase), with the finding of sometimes discordant values between the two methods linked to the relationship between scanning angle and spatial anatomical orientation (view dependent).

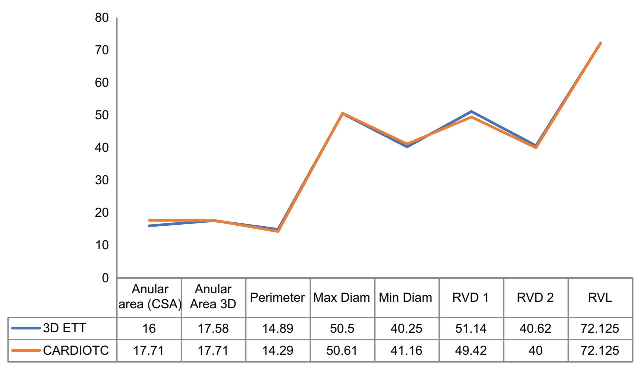
Current guidelines recommend performing end-diastolic tricuspid annulus measurements using two-dimensional TTE from the apical four-chamber window. However, although two-dimensional echocardiography is useful in the study of the tricuspid apparatus, numerous studies have demonstrated its inferiority compared to three-dimensional echocardiography,[22,23] due to the non-planar elliptical morphology of the annulus which makes correct alignment of the scanning plane difficult with respect to the annular spatial orientation.

Recognition of the limitations of two-dimensional echocardiography in the analysis of such complex valve anatomy has led to increased interest in using three-dimensional echocardiography as a more accurate alternative; however, there is not yet a shared standardized approach or specific cut-offs for the three-dimensional analysis of the ring. Finally, numerous studies have compared two- and three-dimensional

Table 4: Comparison of two dimensional and three dimensional TTE and trans-esophageal echocardiographic parameters (*n*=19)

Variable	TTE	TOE	*P*
TR VC width (mm)	12.8	12.26	0.24
TR VC 3D (cm^2)	1.35	1.362	0.26
TV area (cm^2)	7.59	7.35	0.9
2D SL tricuspid annular diameter in 4 chamber view (mm)	46	45.88	0.08
2D AP tricuspid annular diameter (mm)	43.43	42.5	0.08
Tricuspid anular area 2D (CSA) (cm^2)	15.704	15.3	0.89
3D SL diameter (mm)	45.87	45.875	0.87
3D AP diameter (mm)	43.56	43.5	0.59
3D minimum diameter (mm)	39.06	39	0.80
3D maximum diameter (mm)	49.625	50.31	0.17
Circularity index (diam minimum/maximum)	0.75	0.76	0.98
Tricuspid anular area 3D (cm^2)	16.48	15.97	0.77
Tricuspid anular perimeter (cm)	14.82	14.93	0.54
PISA r (mm)	10.31	9.875	0.23
TR EROA (cm^2)	0.74	0.64	0.02
TR regurgitant volume (mL/beat)	60.4	57	0.007
TV tenting area (cm^2)	2.375	2.38	0.76
TV coaptation height (mm)	8.875	9.125	0.59

TR=Tricuspid regurgitation, TV=Tricuspid valve, EROA=Effective regurgitant orifice area, PISA=Proximal isovelocity surface area, SL=Septolateral, AP=Anteroposterio, 3D=Three dimensional, VC=Vena contracta, 2D=Two-dimensional, TTE=Transthoracic echocardiography, TOE=Transesophageal echocardiography, CSA=Cross sectional area



Graph 5: Three dimensional transthoracic echocardiography versus cardiac computed tomography: Comparison of annular and ventricular parameters (*n* = 12)

echocardiography to transthoracic or transesophageal echocardiographic evaluation (single-acquisition approach); However, at present, there is very little knowledge about the differences in the measurement of three-dimensional annular parameters between 3D TTE and 3D TOE.

Analysis of results: Transthoracic echocardiography (TTTE) versus toe subgroup

Our study, aimed at comparing these two methods, has confirmed how both 2 D TTE and 2 D TOE, although with overlapping derived values, lead to a significant underestimation of the annular diameters, not taking into account the nonplanar

Table 5: Three dimensional TTE versus cardiac computed tomography: Comparison of annular and ventricular parameters (*n*=12)

Variable	TTE	CardioCT	*P*
Tricuspid anular area (CSA) (cm^2)	16	17.71	0.1
Tricuspid anular area 3D (cm^2)	17.58	17.71	0.19
Tricuspid anular perimeter (cm)	14.89	14.29	0.5
Maximum diameter (mm)	50.5	50.61	0.19
Minimum diameter (mm)	40.25	41.16	0.28
RVD 1 (mm)	51.14	49.42	0.5
RVD 2 (mm)	40.62	40	0.7
RVLD (mm)	72.125	72.125	0.8

RV=Right ventricle, RVD=RV diameter, RVLD=RV longitudinal diameter, 3D=Three dimensional, TTE=Transthoracic echocardiography, CSA=Cross sectional area, CT=Computed tomography

Table 6: Percutaneous treatments used for tricuspid regurgitation

Percutaneous treatments used for TR (number of patients; %)	Description
TEER (*n*=3; 50%)	Minimally invasive procedure that treats valve regurgitation by using transvenous approach, without the need for cardiopulmonary bypass or cardiac surgery. A catheter is inserted through the femoral vein to access right heart, then 1 or more clips with 2 arms are delivered to capture and hold the leaflets together[19]
Direct TV anuloplasty (*n*=1; 17%)	Catheter-delivered annular reduction system that mimics the surgical annuloplasty approach. It consist of a direct, sutureless, and adjustable surgical-like Dacron band. The device is inserted through a transfemoral access, and up to 17 anchors are deployed on the atrial side of the anterior and posterior annulus to fix the device. A size adjustment tool is advanced over a wire, and the band is then cinched, providing a reduction of the anteroposterior and septolateral diameters[20]
Etherotopic TV implantation (*n*=2; 33%)	Transcatheter implantation of stent valves in a heterotopic positon into the IVC and SVC to prevent caval backflow and mitigate systemic venous congestion. CAVI can be single (IVC only) or bicaval, depending on anatomic suitability. 2 different devices have been used for CAVI: Nondedicated balloon-expandable devices commonly used for transcatheter aortic valve replacement and dedicated self-expandable CAVI devices[21]

TEER=Transcatheter edge to edge repair, IVC=Inferior vena cava, SVC=Superior vena cava, CAVI=Caval valve implantation, TR=Tricuspid regurgitation, TV=Tricuspid valve

morphology and often D-shaped of the ring and often limiting the measurement of the maximum diameter which is interpreted in such methods as the septo-lateral (it is instead remembered that the maximum annular deformation in functional regurgitation is reached in the posterior location).

On the contrary, both TTE and TOE three-dimensional acquisitions allow correct spatial orientation of the ring and more accurate measurements of the septo-lateral, antero-posterior, maximum and average diameters; in this case it is interesting to note how in our study these values appear to be superimposable between the two methods since no statistically significant differences emerged from the comparative analysis of the 3D TTE and 3D TOE annular parameters.

Finally, drawing attention to a nontrivial aspect that emerged from the comparison between the two methods, it should be underlined that the only statistically significant differences concern the quantification of regurgitation and specifically the evaluation of EROA and Regurgitation Volume. In fact, higher estimation of these two parameters was found on TTE: this finding is attributable to the fact that since EROA and RVol are two derived parameters (through the principle of mass conservation), their calculation first involves the quantification of the PISAr, TR velocity, and TR VTI measurements which are all strongly influenced by the correct alignment of the Doppler on the regurgitation and which are therefore more correctly obtainable from the transthoracic approach. This therefore suggests a greater sensitivity of the TTE in the quantification of regurgitation, with the finding of massive insufficiency values at the TTE underestimated instead at the TOE as severe.

Analysis of results: Three-dimensional transthoracic echocardiography versus cardiac-computed tomography subgroup

Three-dimensional assessments of the annulus and right chambers can then be obtained from echocardiography, cardiac resonance imaging, and cardiac CT, however the costs, the relatively limited access to the methods in some centers and the need for protocols dedicated to the right heart with nonnegligible acquisition and post processing times, in addition to the use of contrast and radiation, restrict the field of application of these imaging methods to selected patients[18] and on the basis of the planned percutaneous treatment. In clinical practice, TTE represents the most used imaging technique in the evaluation of patients with valvular pathologies, so our study aimed to evaluate the diagnostic accuracy of 3D TTE compared to cardiac CT (currently considered as gold standard) in the evaluation not only of annular diameters but also of right ventricular geometry. From the double-blind analysis of the annular measurements, no statistically significant differences emerged between the 3d TTE annular reconstructions (area, perimeter, major, and minor diameter) obtained with the 3D MPR technique compared to those obtained with CardiacCT with 3-Mensio software dedicated to TV. Similarly, the diameters obtained through the three-dimensional study of the right ventricular volumetry show good overlap with those obtained from CardiacCT with negligible bias. Therefore, three-dimensional echocardiography represents a reliable method in measuring the right chambers and annular dimensions.

Table 7: Efficacy and safety outcomes in treated patients (n=6)

Variable	Pre	Post	*P*	Trend
NYHA class	2.8±0.4	1.4±0.5	0.0255	<
NYHA class III–IV, *n* (%)	6 (100)	0	<0.05	<
TR severity (grading 1–6) ± SD[a]	4.8±0.7	2.6±1.2	0.156	<
EROA (cm^2) ± SD[a]	0.64±0.23	0.36±0.19	0.0716	<
TR regurgitant volume ± SD[a]	57.2±10	36±15	0.0342	<
30 days mortality, *n* (%)	-	1 (15)	-	=
Intraprocedural complication	-	0	-	

[a]SD standard deviation. NYHA=New York Heart Association, TR=Tricuspid regurgitation, EROA=Effective regurgitant orifice area, SD=Standard deviation

Analysis of results: subgroup subjected to percutaneous treatment

All patients undergoing treatment reported a clear improvement in dyspnea and congestion symptoms at the 30-day follow-up; with reduction of NYHA class >1°, improvement in quality of life and functional capacity. The improvement in symptoms was also associated with echocardiographic evidence of a reduction in regurgitation >1°, with statistical significance relating to the extent of the regurgitation volume. The procedures carried out (Triclip, Cardioband and TricValve) also proved to be safe, as they were carried out in the absence of intra/periprocedural complications. Finally, one death was recorded at the 30-day follow-up

Conclusions

Our study showed that three-dimensional transthoracic approach, less invasive than the transesophageal method, can be used for an overall periprocedural evaluation of patients with TR candidates for percutaneous treatment, allowing an accurate study of the characteristics of regurgitation through MPR reconstructions (entity, localization), valvular and annular anatomy, right chamber dimensions, and right ventricular function. All these advantages lead to a reduction in time, costs, and above all risks for patients who are inherently fragile with often hepato-renal impairment, coagulopathy, and cardiogenic cirrhosis in advanced stages.

Despite the high diagnostic sensitivity and specificity of three-dimensional TTE, second-level imaging methods (CT, magnetic resonance imaging) still remain the technique of choice for patients with a poor transthoracic acoustic window or candidates for annular repair techniques that require evaluation of additional anatomical parameters (e.g., right coronary course in patients candidates for annuloplasty).

Ethical statement

The study was approved by the Institutional Ethics Committee of San Camillo Hospital, Rome.

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Conflicts of interest

There are no conflicts of interest.

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