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Three-Dimensional Transthoracic Echocardiographic Evaluation of Tricuspid Regurgitation Severity using Vena Contracta Area in Comparison with Volumetric Method

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ORIGINAL ARTICLE

Three-Dimensional Transthoracic Echocardiographic Evaluation of Tricuspid Regurgitation Severity using Vena Contracta Area in Comparison with Volumetric Method

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Abstract

Background: ***In clinical practice, tricuspid regurgitation (TR) is a valvular heart requirement that is frequent.***

Aim of the work: ***The objective is to utilize the 2D-determined EROA volumetric approach as a reference to establish 3D vena contracta area Cutoff values and ranges for (VCA) to differentiate TR grades, exceptionally mild and severe TR. Furthermore, to provide a standard calibration for TR grading, compare colour Doppler 2D regurgitant orifice area (ROA) and 3D VCA.***

Patients and methods: ***This study was done at the Cardiology Department of Al-Azhar University (Bab El-Sheriaa University Hospital) from February 2023 to October 2023. It included fifty consecutive patients; 31 patients had severe TR, and the other 19 had moderate TR.***

Results: ***As regards the 3D Echo-Doppler study Vena contract, the mean was (89.4 ± 38.5) mm2 with minimum 54 mm2 and maximum 300 mm2, also 3D Echo Doppler study Vena contract can be used to discriminate between patients with moderate and severe TR at a cutoff level of > 76 mm2, with 96.8% sensitivity, 89.5% specificity, PPV of 93.7 per cent and NPV of 94.4 per cent (AUC = 0.924 & p-value <0.001). Moreover, there was a High statistically significant (p <0.001) increase in the 3D ECHO study Vena contracta in patients with severe TR (median= 92, IQR 81-100) than in patients with moderate TR (median= 69, IQR 58-74).***

Conclusion: ***A practical and reliable indicator of TR severity is the 3D measurement of VC area. Another way to assess the degree of regurgitant regurgitation is to evaluate the VCA of a TR utilizing 3D colour Doppler echocardiography. When determining the severity of a TR, Three-dimensional direct planimetry from VCA is a dependable method that can be used in clinical settings.***

Keywords: 3D Echocardiography; vena contracta; Tricuspid Regurge

1. Introduction

In clinical practice, tricuspid regurgitation (TR) is a valvular heart requirement that is somewhat frequent.[1]

Regardless of left ventricular systolic function and pulmonary hypertension, severe tricuspid regurgitation is linked to a higher death rate.[2]

TR's detrimental effects have been steadily acknowledged. According to earlier research, the mortality rate associated with moderately or above TR is twice as high as that associated with mild or below TR.[3] TR's detrimental effects have been steadily acknowledged. According to earlier research, the mortality rate associated with moderately or above TR is twice as high as that associated with mild or below TR.[4]

As a result, measuring TR is a crucial first step in providing these patients with early treatment. In order to diagnose TR, echocardiography is the recommended test.5 Unfortunately, our objectives cannot be satisfied by conventional quantitative approaches like the two-dimensional (2D) proximal velocity surface area (PISA) method and the vena contracta width (VCW). There are now more options for quantifying TR thanks to the development of real-time three-dimensional (3D) echocardiography. A close association exists between the hemodynamic effects and the effective regurgitant orifice area (EROA).[5]

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Additionally, it can remove the assumptions about shape and size necessary for 2D PISA EROA and provide an accurate measurement of flow convergence by exploiting the advantages of 3D imaging.[6]

EROA, or effective regurgitant orifice area, has been extensively used and recommended for evaluating mitral regurgitation (MR) due to the irregular shape that defines the regurgitation of the tricuspid orifice with the decreased flow velocity of TR compared to MR. However, further investigation is necessary prior to implementing this approach in quantitative TR.[7]

By utilizing the 2D-determined EROA volumetric approach as a reference, the current work seeks to create 3D vena contracta area (VCA) ranges and cutoff levels to differentiate TR grades, exceptionally moderate and severe TR. Furthermore, to provide a standard calibration for TR grading, compare the colour Doppler 2D regurgitant orifice area (ROA) and 3D VCA.

2. Patients and methods

This prospective observational study was conducted at the Cardiology Department of Al-Azhar University (Bab El-Sheriya University Hospital) from February 2023 to October 2023. It included fifty consecutive patient candidates for TEE evaluation; 31 patients had severe TR, and the other 19 had moderate TR. They were enrolled in the study after obtaining their informed consent and after a full explanation of the purpose and nature of the study.

2.1.Inclusion criteria: Patients with tricuspid valve replacement (TR) confirmed by two-dimensional transthoracic echocardiography (TTE) at our hospital's echocardiography department; A proposal for doing either single-stage tricuspid valve surgery or a combination of mitral valve surgery and tricuspid valve surgery within a week, along with the presence of a noticeable region of flow convergence near the tricuspid valve in the four-chamber image.

2.2.Exclusion criteria: The following conditions must be present: no discernible proximal flow convergence region; mild or more severe pulmonary regurgitation or pulmonary stenosis; Intra-cardiac shunt, prosthetic tricuspid valve, limited visibility due to weak acoustic window, and individuals under the age of eighteen.

2.3. Methods:

All patients were subjected to the signed informed consent from each patient was obtained. Ethical approval was obtained from Al-Azhar University's Faculty of Medicine's Ethical and Research Committee. Detailed medical history taking. Detailed general and local clinical examination to detect predictors of severity of TR according to ESC/EACTS Valvular Heart Disease Guidelines was obtained. Resting twelve-lead surface electrocardiogram(ECG) and a long strip to detect heart rhythm and rate were obtained for all patients.

2.4.Echocardiography:

Two-Dimensional Echocardiography and Measurements: Every patient underwent an examination in the left lateral decubitus posture. Echocardiographic pictures were obtained from the conventional perspectives (apical four chambers, apical five chambers, apical two chambers, and parasternal long and short axes at the level of the great vessels). The American Society of Echocardiography's guidelines were followed to record and compute various cardiac chamber and ejection fractions.

A comprehensive TTE using (GE Healthcare Vivid-905) (GE et al. (Sector) 1.4-4.6 MHz for 2D) and (Volume 1.5-4.0 MHz; GE 4V-D Probe). Standard Echocardiographic measurements were obtained following the most recent EACVI guidelines Li et al.,[8] comprising the following: measurements of the aortic root, left atrium, left ventricle, right atrium, and right ventricle, either linearly or voluminously—comprehensive Doppler methods assessed valves other than the tricuspid valve. A comprehensive two-dimensional TTE and three-dimensional TTE assessment of TV were explained in dedicated measurements.

2.5.Two-Dimensional TTE:

Every patient underwent 2D imaging in the following viewpoints: the subcostal view, the apical 4-chamber views (Standard and Focused), the parasternal right ventricular inflow tract view (RVIT), and the parasternal short-axis view (SAX).

The following information was obtained in 2D echocardiography:

Assessment of TR severity: The TR grading included mild, moderate, and severe classifications according to:

Qualitative Doppler: Jet envelop character of the color flow, flow convergence zone, continuous wave Doppler.

Semi-quantitative: The PISA radius and the width of the Vena Contracta were measured. The PISA was zoomed in with the area of flow convergence, and the colour baseline shifted to 30.0 to 40.0 cm/sec. PISA radius was measured in the frame with peak velocity during systole using the hemispheric shape of flow convergence.

Quantitative: EROA: EROA= $2 \times \pi \times$ RPISA2 $\times$ Valiasing/Vmax, where RPISA is PISA radius (cm), Valiasing is the aliasing velocity of PISA (cm/s), and Vmax is the maximum speed (in cm/s) at which the continuous-wave Doppler TR signal can travel. Based on two-dimensional echocardiography, the American Society of Echocardiography and the European Association

of Echocardiography will evaluate the severity of the TR. Individuals will be categorized as having a moderate TR if their two-dimensional EROA is between 0.2 and 0.4 cm2, a severe TR if their EROA is more significant than 0.4 cm2, and a mild TR if their two-dimensional EROA is less than 0.2 cm2.

Regurgitant volume and Regurgitant fraction.

Recordings and computations were performed for various heart chamber volumes and fractions in compliance with the most recent EACVI/ASE of Echocardiography guidelines.[9]

2.6.These measurements have been taken:

The bi-plane Simpson method in two dimensions was used to assess the end-systolic and diastolic volumes of the left ventricle. Stroke volume divided by end-diastolic volume yielded the LV ejection fraction.

Using continuous-wave Doppler in several views, the most incredible velocity of tricuspid regurgitation and estimated systolic pulmonary artery pressure (ESPAP) were determined.

It was measured using an M-mode ultrasound technique from the apical four-chamber view, the tricuspid annular plane systolic excursion (TAPSE).

S wave velocity from apical four-chamber view in order to detect RV function.

2.7.Three-dimensional TTE:

For measuring the area of the vena contracta during tricuspid regurgitation. 3DE echocardiography was obtained with the GE Vingmed Ultrasound 4V probe. From the RV-focused apical view, direct mechanical planimetry of the regurgitant VCA has been carried out. Utilizing a single breath-hold of ECG gating that spans three to four consecutive cardiac cycles, 3DE datasets were acquired. By maximizing depth and optimizing sector width, temporal accuracy was maximized, and gain settings were optimized. The average rate for each frame was 27 ± 8 frames per second. The EchoPAC BT 12, manufactured by GE in Milwaukee, Wisconsin, was employed for offline analysis of all 3D datasets. Two orthogonal axes parallel to the regurgitant jet are aligned to measure VCA. Currently positioned at a right angle with the jet, the third plane is aligned with the regurgitant orifice, which is the most minor section of the jet. The VCA (vena contracta area) is then traced. A VCA measurement of ≥ 0.75 cm2 indicates severe tricuspid regurgitation. However, VCA may overstate the genuine regurgitant orifice area because complicated jets are unlikely to have a planer. Furthermore, when TR is not holosystolic, VC and VCA will overstate severity. Lastly, there is uncertainty over the VCA cutoff point for defining severe TR.

3. Results

Table 1. A description of every patient under study, including demographic information.

VARIABLES		STUDIED PATIENTS (N = 50)
AGE (YEARS)	Mean ± SD	56.9 ± 12.7
	Min - Max	25 – 76
SEX	Male	27 54%
	Female	23 46%
DM	No	24 48%
	Yes	26 52%
HTN	No	27 54%
	Yes	23 46%
SMOKING	No	31 62%
	Yes	19 38%
BMI (KG/M²)	Mean ± SD	30.1 ± 3.6
	Min - Max	21.4 – 37.3
BODY SURFACES AREA (M²)	Mean ± SD	1.88 ± 0.17
	Min - Max	1.58 – 2.19

Of the patients under study, 27 were male (54%) and 23 were female (46%), with an average age of 56.9 ± 12.7 years, a minimum aged of 25 years, and a maximum aged of 76 years. Of the patients under investigation, 26 (52%) had diabetes mellitus and 23 (46%) had hypertension. Of the patients analyzed, nineteen individuals (38%) were smokers. With a low of 21.4 kg/m2 and a maximum of 37.3 kg/m2, the mean BMI for all the patients under study was (30.1 ± 3.6) kg/m2. The standard deviation of the body surface area of all the patients under study was 1.88 ± 0.17 m2, ranging from 1.58 m2 to 2.19 m2.

Table 2. Description of all studied patients as regard 2D echo data.

VARIABLES			STUDIED PATIENTS (N = 50)
LV VOLU	LVEDV (ml)	Mean ± SD	166.3 ± 50.3
		Min - Max	96 – 245
	LVESV (ml)	Mean ± SD	107.5 ± 51.9
		Min - Max	34 – 210
EF% MODIFIED SIMPSON		Mean ± SD	39.6 ± 15.5
		Min - Max	17 – 70
GRADING THE SEVERITY OF	PISA Radius (cm)	Mean ± SD	0.9 ± 0.19
		Min - Max	0.5 – 1.3
	EROA (cm²)	Mean ± SD	0.47 ± 0.16
		Min - Max	0.2 – 0.9
	Regurgitant volume (ml)	Mean ± SD	49 ± 16
		Min - Max	18 – 80
	Regurgitant Fraction	Mean ± SD	45.8 ± 8.1
		Min – Max	26 – 60
RV SYSTOLIC FUNCTION	TAPSE (cm)	Mean ± SD	1.86 ± 0.27
		Min - Max	1.4 – 2.5
	S wave (cm/s)	Mean ± SD	10.04 ± 1.27
		Min - Max	7.4 – 13.1
	TRV (cm/s)	Mean ± SD	351 ± 55.7
		Min - Max	180 – 470
	ESPAP (mmHg)	Mean ± SD	48.5 ± 8.7
		Min - Max	30 – 65

The mean LVEDV was (166.3 ± 50.3) ml with minimum 96 ml and maximum 245 ml while the mean LVESV was (107.5 ± 51.9) ml with minimum 34 ml and maximum 210 ml. The mean EF modified Simpson was (39.6 ± 15.5) % with minimum 17% and maximum 70% and the mean PISA radius in all studied patients was (0.9 ± 0.19) cm with minimum 0.5 cm and maximum 1.3 cm. The mean ERORA was (0.47 ± 0.16) cm2 with minimum 0.2 cm2 and maximum 0.9 cm2 while the mean regurgitant volume in all studied patients was (49 ± 16) ml with minimum 18 ml and maximum 80 ml.

As regard regurgitant Fraction, the mean in all studied patients was (45.8 ± 8.1) % with minimum 26% and maximum 60% and the mean TAPSE was (1.86 ± 0.27) cm with minimum 1.4 cm and maximum 2.5 cm. The mean S wave was (10.04 ± 1.27) cm/s with minimum 7.4 cm/s and maximum 13.1 cm/s. The mean TRV was (351 ± 55.7) cm/s with minimum 180 cm/s and maximum 470 cm/s and finally and the mean ESPAP was (48.5 ± 8.7) mm Hg with minimum 30 mmHg and maximum 65 mmHg.

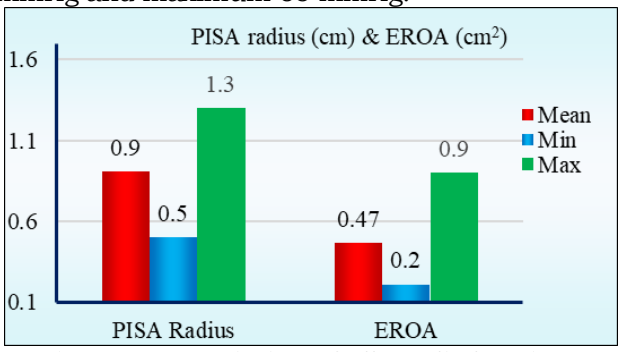

Figure 1. Description of all studied patients as regard PISA radius and ERORA.

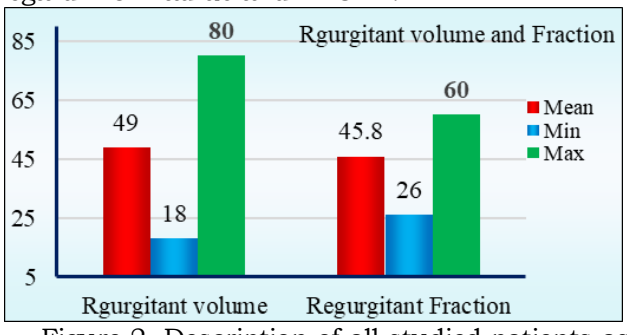

Figure 2. Description of all studied patients as regard regurgitant Volume and fraction.

Table 3. Description of all studied patients as regard 3D ECHO Doppler study Vena contracta.

VARIABLES		STUDIED PATIENTS (N = 50)
3D ECHO DOPPLER STUDY VENA CONTRACTA (MM^2)	Mean ± SD	89.4 ± 38.5
	Min - Max	54-300

3D ECHO Doppler study Vena contracta, the mean in all studied patients was (89.4 ± 38.5) mm2 with minimum 54 mm2 and maximum 300 mm2.

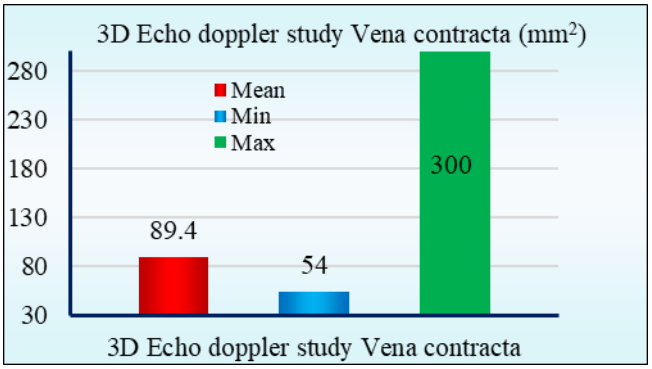

Figure 3. Description of all studied patients as regard 3D ECHO Doppler study Vena contracta.

Table 4. description of all studied patients as regard 2D ECHO classification of TR.

VARIABLES		STUDIED PATIENTS (N = 50)	
TR CLASSIFICATION AS REGARD 2D ECHO	Moderate	19	38%
	Severe	31	62%

As regard 2D ECHO classification of TR, there were 19 patients (38%) with moderate TR and 31 patients (62%) with severe TR.

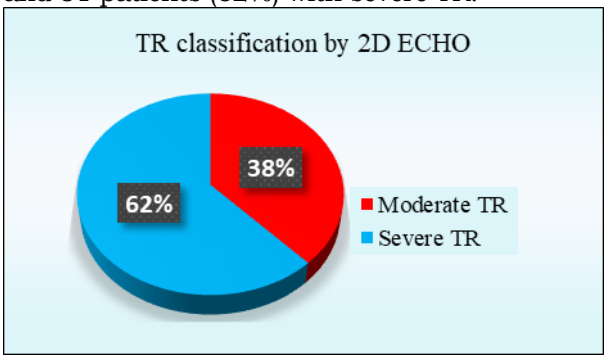

Figure 4. description of all studied patients as regard TR classification by 2D ECHO.

Table 5. Comparing patients with moderate to severe TR with respect to the Vena contracta 3D Echo Doppler study.

VARIABLES		MODERATE (N = 19)	SEVERE (N = 31)	MW	P-VALUE
3D ECHO DOPPLER STUDY VENA CONTRACTA (MM^2)	Median	69	92	44.5	< 0.001
	IQR	58 – 74	81 – 100		HS

MW: Mann-Whitney U Test; HS: p-value < 0.001 is considered high statistically significant.

IQR: Interquartile Range.

High statistically significant (p <0.001) increased 3D ECHO study Vena contracta in patients with severe TR (median=92, IQR 81-100) than it in patients with moderate TR (median= 69, IQR 58-74)

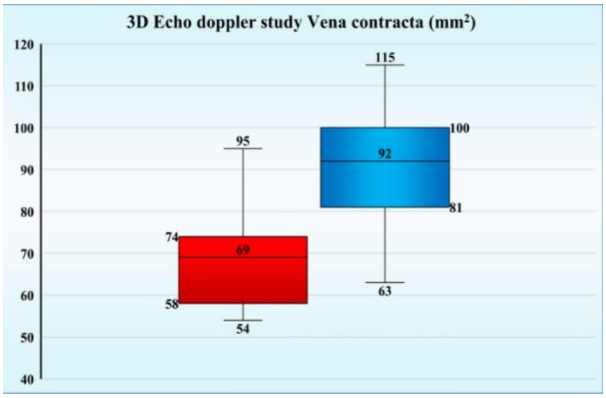

Figure 5. Comparing the 3D Echo Doppler study Vena contracta between individuals with moderate and severe TR.

Vena contracta can be utilized in a 3D Echo Doppler examination to distinguish between patients with moderate TR and patients with severe TR at a cutoff level of > 76 mm2, with 96.8% sensitivity, 89.5% specificity, PPV of 93.7 percent and NPV of 94.4 percent (AUC = 0.924 & p-value <0.001).

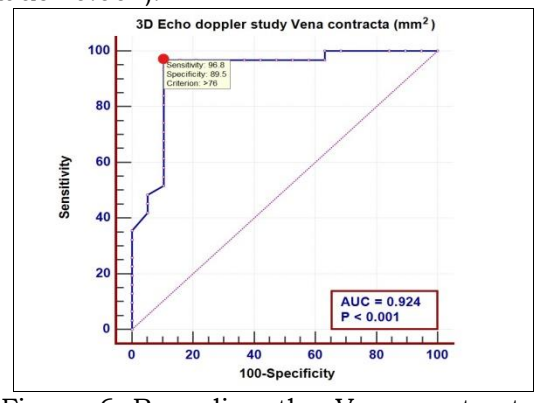

Figure 6 Regarding the Vena contracta 3D Echo Doppler study, the ROC curve between patients with mild TR and patients with severe TR.

4. Discussion

In the current study, regarding 3D ECHO Doppler study Vena contract, the mean in all studied patients was (89.4 ± 38.5) mm2 with a minimum of 54 mm2 and a maximum of 300 mm2.

In a study by Chouchani et al.,[10], The regurgitant orifice area was evaluated by PISA-EROA and 3D Doppler colour echocardiography in 95 patients with TR varying in severity. Three datasets were considered while determining the regurgitant orifice area in each patient using 3D Doppler colour echocardiography. Based on three independent measurements in each of the 95 patients, the mean of the three-dimensional VCA was 0.27 ± 0.14, 0.27 ± 0.13, and 0.29 ± 0.14 cm2, respectively.

In a study by Sugeng et al.,[11] 3D colour Doppler flow measurement measurements were compared to 2-dimensional approaches on 56 individuals to assess TR severity. The minimum and maximum diameters of the vena contracta were measured in this study using 3D colour Doppler echocardiography. 2D echocardiography was used to compare these diameters to vena contracta diameters. The 3D measured VC diameters (1.3 ± 0.6 vs. 0.7 ± 0.2 cm, P <.001) were substantially more significant than the 2D measured ones. VCAs were determined according to the vena vein diameters.

In comparison to 2D echo, these were also greater than 3D. Since no reconstruction techniques were employed in this investigation, VCAs were not identified by planimetry. Additionally, only patients with an adequate acoustic window were included in this study; those with atrial fibrillation were not.

In a study by Song et al.,[12] Fifty-two patients with different sinus rhythm and functional TR degrees were evaluated. This study employed 3-dimensional Doppler colour echocardiography to determine the effective regurgitant orifice area (EROA) using the PISA radius obtained from the 3D colour Doppler data set, along with measurements of vena contracta width and vena contracta area (VCA). In this work, reconstruction techniques were used to analyze the planimetry of the VCA. The average PISA-EROA, assessed using a 3D colour Doppler method, was 0.2 ± 0.2 cm2. The planimetry-based colour Doppler flow VCA value was significantly greater than that of PISA-EROA (0.61 ± 0.67 cm2 vs. 0.22 ± 0.22 cm2). The study needed patients who were in sinus rhythm to participate. Patients with definite organic deformation, restricted tricuspid valve motion, atrial fibrillation, or recurring premature beats were excluded. Using three-dimensional colour, Doppler echocardiography revealed a robust association between VCA and PISA EROA.

Comparing patients with moderate TR and those with severe TR about 3D Echo Doppler study Vena contracta, the current study found that patients with severe TR had a higher (3D ECHO study Vena contracta) than patients with moderate TR (median = 69, IQR 58-74) statistically significant increase (p <0.001).

Velayudhan et al.,[13] Multiple echocardiographic techniques were utilized to assess tricuspid regurgitation (TR) in ninety-three consecutive patients who underwent live three-dimensional (3D) and standard two-dimensional (2D) transthoracic echocardiography (TTE). 3D TTE was used to determine the TR vena contracta (VC) region by methodically and sequentially cropping the resultant 3D TTE dataset.

Notably, the VC area measurements of the severe TR group exhibited significant variability, ranging from 0.79 to 3.2 cm2. This suggests that this group could be further divided in a manner that allows for accurate predictions. With an

impressive negative predictive value of 95%, the cut point of 0.75 cm2 is highly effective in ruling out severe TR. However, it has a poor positive predictive value of 81.1% for severe TR due to its significant overlap with RJA's definition of moderate TR. The cut point of 1.0 cm2, which is more accurate, has a slightly lower negative predictive value (91.8%) for ruling out severe TR. However, it shows minimal overlap with the intermediate range assessed by RJA (positive predictive value for severe TR = 93.2%). A value of 1.0 cm2 may be the best choice for accurately identifying the most severe torrential tricuspid regurgitation (TR) while minimizing any overlap with moderate TR. However, a 3D transthoracic echocardiography (TTE) vena contracta (VC) area of 0.75 cm2 can also be used as a susceptible measurement to rule out severe TR.

4. Conclusion

Accurate and valid measures of tricuspid regurgitation severity include quantifying the area of the vena contracta using three-dimensional imaging. Another method to determine regurgitation severity is to examine the vena contracta area (VCA) of tricuspid regurgitation (TR) using three-dimensional colour Doppler echocardiography. The clinical application of 3D-guided straight planimetry of the vena contracta area (VCA) in tricuspid regurgitation (TR) is a reliable technique for assessing the severity of TR. When assessing the seriousness of TR, it is essential to consider this factor, especially in individuals whose severity falls within the borderline range according to conventional 2D measurements.

Disclosure

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Authorship

All authors have a substantial contribution to the article

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Conflicts of interest

There are no conflicts of interest.

References

1. Thomas KL, Jackson LR 2nd, Shrader P, et al. Prevalence, Characteristics, and Outcomes of Valvular Heart Disease in Patients With Atrial Fibrillation: Insights From the ORBIT-AF (Outcomes Registry for Better Informed Treatment for Atrial Fibrillation). J Am Heart Assoc. 2017;6(12):e006475.
2. Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. J Am Coll Cardiol. 2004;43(3):405-409.
3. Wang N, Fulcher J, Abeysuriya N, et al. Tricuspid regurgitation is associated with increased mortality independent of pulmonary pressures and right heart failure: a systematic review and meta-analysis. Eur Heart J. 2019;40(5):476-484.
4. Rodés-Cabau J, Hahn RT, Latib A, et al. Transcatheter Therapies for Treating Tricuspid Regurgitation. J Am Coll Cardiol. 2016;67(15):1829-1845.
5. Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for Noninvasive Evaluation of Native Valvular Regurgitation: A Report from the American Society of Echocardiography Developed in Collaboration with the Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr. 2017;30(4):303-371.
6. de Agustin JA, Viliani D, Vieira C, et al. Proximal isovelocity surface area by single-beat three-dimensional color Doppler echocardiography applied for tricuspid regurgitation quantification. J Am Soc Echocardiogr. 2013;26(9):1063-1072.
7. de Agustín JA, Marcos-Alberca P, Fernandez-Golfin C, et al. Direct measurement of proximal isovelocity surface area by single-beat three-dimensional color Doppler echocardiography in mitral regurgitation: a validation study. J Am Soc Echocardiogr. 2012;25(8):815-823.
8. Li L, Colen TM, Jani V, et al. Dynamic Systolic Changes in Tricuspid Regurgitation Vena Contracta Size and Proximal Isovelocity Surface Area in Hypoplastic Left Heart Syndrome: A Three-Dimensional Color Doppler Echocardiographic Study. J Am Soc Echocardiogr. 2021;34(8):877-886.
9. Badano LP, Kolias TJ, Muraru D, et al. Standardization of left atrial, right ventricular, and right atrial deformation imaging using two-dimensional speckle tracking echocardiography: a consensus document of the EACVI/ASE/Industry Task Force to standardize deformation imaging [published correction appears in Eur Heart J Cardiovasc Imaging. 2018 Jul 1;19(7):830-833.
10. Chouchani M, Michaelsen J, Langenbrink L, Piatkowski M, Altiok E, Hoffmann R. Quantification of tricuspid regurgitation area by 3-dimensional color Doppler echocardiography considering different clinical settings. Echocardiography. 2020;37(7):1120-1129.
11. Sugeng L, Weinert L, Lang RM. Real-time 3-dimensional color Doppler flow of mitral and tricuspid regurgitation: feasibility and initial quantitative comparison with 2-dimensional methods. J Am Soc Echocardiogr. 2007;20(9):1050-1057.
12. Song JM, Jang MK, Choi YS, et al. The vena contracta in functional tricuspid regurgitation: a real-time three-dimensional color Doppler echocardiography study. J Am Soc Echocardiogr. 2011;24(6):663-670.
13. Velayudhan DE, Brown TM, Nanda NC, et al. Quantification of tricuspid regurgitation by live three-dimensional transthoracic echocardiographic measurements of vena contracta area. Echocardiography. 2006;23(9):793-800.