International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Tricuspid Annular Diameter on Routine Chest CT to Detect Significant Tricuspid Regurgitation

Sana Asfiya, A. Y. Lakshmi

Abstract: ***Introduction: Tricuspid regurgitation (TR) is a relatively common abnormality. Due to its widespread use, CT may offer a new route for initial detection of moderate to severe TR, those who may be potential candidates for tricuspid repair. Aims and objectives: Aim: To assess the ability of tricuspid annular diameter measurements derived from CECT chest in predicting TR seen on echocardiography. Objectives: 1. To measure tricuspid annular diameter on routine noncardiac contrast enhanced chest CT 2.To determine the grade of severity of TR on 2d-ECHO. 3. To correlate CT and 2d- ECHO findings of significant TR. 4. To determine whether CT can be useful in detecting significant TR. Materials and Methods: This is a prospective study conducted in the Department of Radiology, SVIMS, Tirupati during the study period of 18 months from March 2021-June 2022 on consecutive patients referred to the Department of Radiology for CECT chest. Results: A total of 75 individuals were included in the study. The overall prevalence of significant (moderate or severe) TR was 14.6%. Specificity was 96.88% and sensitivity was 72.7%. Positive predictive value was 79.9% and negative predictive value was 95.41%. Summary-Measurement of the diameter of tricuspid valve annulus on regular chest CT can predict moderate to severe TR at a cut point of 40.5 mm. On routine contrast-enhanced CT scans of the chest, the tricuspid annular diameter can be evaluated, and if it is higher than the threshold, additional 2d ECHO evaluation should be advised. Conclusion: This study proposes that routine CECT scans of the chest can be used to quantify tricuspid annular diameter. Further 2D-ECHO testing should be advised when the tricuspid annular diameter is at or above the threshold in order to confirm the diagnosis, grade, and discriminate between the various forms of TR.***

Keywords: tricuspid annular dilation; tricuspid annulus; tricuspid regurgitation; tricuspid valve; valve diameter

1. Introduction

In 82–86% of people, Tricuspid regurgitation (TR) is a common observation [1, 2]. TR is typically insignificant clinically and mild [3]. Significant TR (moderate to severe) can, however, significantly influence a person's functional level [1]and those who are impacted have a higher mortality risk [4]

There are numerous causes of TR, which can be generically characterised as functional, organic, or idiopathic. The most frequent type of TR is functional (fTR), which accounts for about 80% of occurrences [3]

Functional fTR, also known as secondary TR, is mainly brought on by tricuspid annular dilatation, which results from higher tricuspid pressures brought on by left heart illness, right heart dysfunction, or pulmonary hypertension.

Organic TR can result from a number of tricuspid valve intrinsic disorders or diseases that directly impact the valve, like myxomatous degeneration or congenital disease (Ebstein anomaly, atrioventricular defects) and acquired conditions (endocarditis, rheumatic disease, and valvular interference by intracardiac device leads. [3]

Physiological TR is said to be present in 60–90% of patients who undergo echocardiography, and its incidence rises with age, depending on the series. TR is mainly insignificant or mild. In the Framingham research, 15% of men and 18% of women had mild or more TR by colour Doppler [2]. Only 1.2% of patients in a large database of more than 60, 000 echocardiograms were reported to have severe TR. In the USA, it is estimated that 1.6 million individuals have moderate-to-severe TR [5-7]. Despite this, for a variety of reasons only 4000-8000 tricuspid valve procedures are carried out annually [6, 8]. Historically, it was believed that treating the underlying mitral or aortic valve illness would cure fTR, and the tricuspid valve received less focus. Since then, it has been understood, nevertheless, that TR does not go away once the left heart valve is corrected and that direct tricuspid valve correction is also necessary [9]. Studies on individuals who underwent prior mitral valve replacement (without tricuspid valve operation) years ago have indicated that up to 43% of patients still have severe residual TR. Additionally, non-severe TR that is left untreated is likely to become severe TR [14] and post-left heart surgery, more severe TR is linked to higher long-term mortality [1, 15]. Older age and more severe TR at the time of surgery are the factors that put patients at risk for progression to severe TR following cardiac surgery [14]. The long-term mortality of TR has significantly improved with early therapy, especially when the condition is asymptomatic [4, 8]. In order to address the failure of the tricuspid valve either separately or at the time of left heart surgery, early incidental diagnosis or diagnosis before any form of left heart surgery may be crucial, especially when of greater severity.

In recent times, echocardiographic examination of the tricuspid valvular structure prior to surgery includes measurement of the tricuspid annular size [3, 18]. In addition to measuring the tricuspid annular diameter, the severity of TR is commonly rated on echocardiography utilising the tricuspid valve morphologic assessment, color-flow imaging, hepatic vein assessment, regurgitant volumes, and regurgitant orifice areas. One requirement for surgical repair of the tricuspid valve is that the annular diameter be > 40 mm, which can be measured using the apical four-chamber view [3, 19].

In the past, CT has had little to no impact on the identification or diagnosis of TR. The widespread usage and accessibility of CT, however, may present a novel method for the early detection of moderate to severe TR, individuals who may be candidates for tricuspid repair. We propose that substantial TR seen on echocardiography correlates with a straightforward measurement of the tricuspid annular

diameter on standard noncardiac CT. This study's goal is to evaluate how well tricuspid annular diameter measurements from noncardiac (non-ECG-gated) chest CT correlate with the predictions of TR observed on echocardiography performed.

2. Materials and Methods

The study was conducted after approval by the Institutional Thesis Protocol Approval Committee and Institutional Ethics Committee and written informed consent from each patient was obtained before the study.
This study was conducted on patients who are referred to the Department of Radiology for CECT chest for various indications as advised by physicians from various other departments and with concurrent echocardiography done at the Department of Cardiology, during the time frame of March 2021 to June 2022 at SVIMS, Tirupati.

Aim
To determine how well TR detected on 2D echocardiography may be predicted by tricuspid annular diameter measures obtained from noncardiac (non-ECG-gated) chest CT.

Objectives
1) To measure tricuspid annular diameter on routine noncardiac contrast enhanced chest CT.
2) To do echocardiography to determine the grade of severity of tricuspid regurgitation.
3) To correlate CT and echocardiography findings of significant tricuspid regurgitation.
4) To determine whether CT can be useful in predicting significant tricuspid regurgitation.

Inclusion Criteria
1) Patients with noncardiac contrast enhanced CT of the chest performed with IV contrast agent, for a broad range of indications like chestpain, sepsis, cough, shortness of breath, weight loss, fever.
2) Patients in whom concurrent echocardiography is performed within 24hrs of CT, for evaluation of cardiac function or for structural evaluation.

Exclusion Criteria
1) Patients not willing to participate in study
2) Patients with other valvular abnormalities
3) Patients in whom tricuspid valve cannot be evaluated due to prosthetic heart valves causing metal artefacts
4) Patients in whom concurrent echocardiography is not performed within 24hours of CT.
5) Patients with incomplete echocardiograms in which the tricuspid valve is not evaluated.
6) Patients allergic to non-ionic iodinated contrast agents in whom contrast enhanced CT of the chest cannot be done.
7) Patients with contraindications to non-ionic iodinated contrast agents.

CT Image Acquisition-
Non-cardiac CT scans were obtained without the use of ECG gating on a 128-slice SIEMENS CT. (Somatom Definition AS+, SIEMENS Healthcare, Germany). Images are obtained during single breath hold at end-inspiration without regard for patient heartrate.

Type of contrast medium injected-iodinated non-ionic contrast agent (IOHEXOL) with a strength of 300mg Iodine/ml.
Amount of contrast medium injected at a rate of 2ml/s.

Images are obtained at 45-55 seconds after contrast injection to obtain venous phase imaging.

Acquisition Parameters-
The 128-MDCT acquisition parameters are as follows: helical mode, 80 × 0.5 mm; rotation time 0.3 second; tube voltage 120kVp; minimum tube current, 20 mA; maximum tube current, 150 mA.

Images are reconstructed in axial plane with a slice thickness of 0.6mm.

CT Image Analysis
CT images are reviewed on a dedicated Syngo Acquisition workplace workstation

Axial images on the CECT chest are taken into consideration for measuring the tricuspid annular diameter.
On a single axial CT picture, where the distance between the right atrioventricular groove and the interventricular septum is greatest, the tricuspid annulus diameter is measured.

From the inner edge of the right atrioventricular groove to the interventricular septum, the tricuspid annular diameter is measured.

When the leaflets of the tricuspid valve could be seen, the line is drawn perpendicular to the interventricular septum and perpendicular to the long axis of the right heart.

The innermost point of the right atrioventricular groove is chosen when uncertainty about the right atrioventricular groove's position results from motion artefacts. A millimetre measurement is made and recorded as a whole number. Fractional measurements are rounded to the nearest whole number.

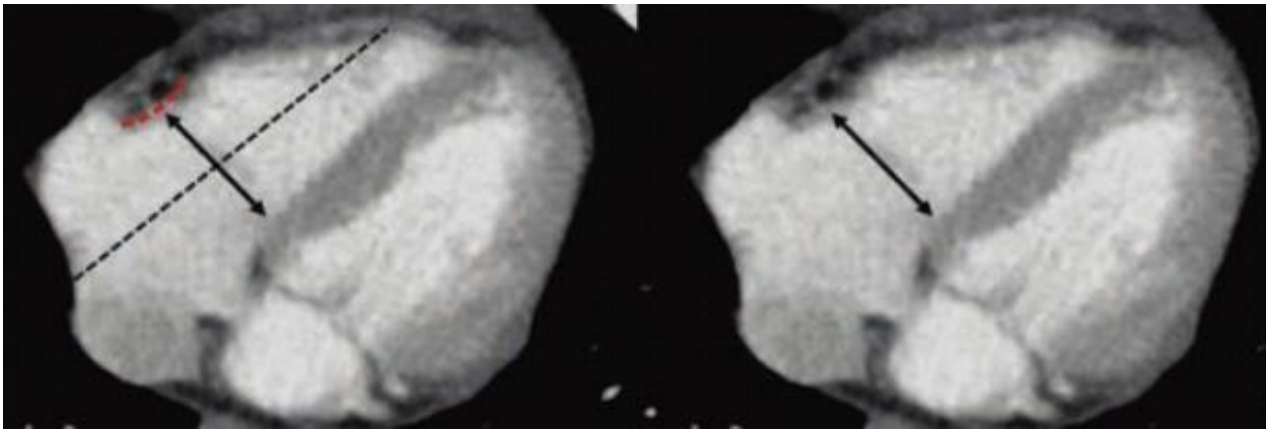

Figure 1: Tricuspid annular diameter measurement on CECT chest.

right atrioventricular groove (RAVG) is selected (red curved dashed line) as shown in first column. Next, the tricuspid annular diameter is measured (arrow) from the innermost portion of RAVG to interventricular septum. This line is perpendicular to the long axis of the right heart and interventricular septum (straight dashed line).

Echocardiographic Technique-
Echocardiography is performed within 24hrs of CT on ACUSON SC 2000 [SIEMENS ULTRASOUND SYSTEMS, SIEMENS HEALTHCARE, GERMANY] machine.

Echocardiographic Analysis-
Echocardiography analysis is done using a combination of qualitative and quantitative parameters.

Qualitative parameters included tricuspid valve morphology, presence or absence of TR. Quantitative parameters included the parameters for assessment of hemodynamic consequences of TR which are RV size, RA size, IVC size, RV ejection fraction, color flow mapping of TR, TR jet velocity on continuous wave Doppler, RV Systolic Pressure, vena contracta diameter and hepatic vein inflow.

TR was graded by a combination of these parameters according to American Heart Association and American College of Cardiology guidelines.

The grade of TR was reported as either “no regurgitation, ” “mild, ” “moderate, ” or “severe. ”

Grades of No regurgitation or mild regurgitation on ECHO are considered to be non-significant.

Grades of Moderate regurgitation or Severe regurgitation are considered to be significant.

3. Statistical Analysis

Data entry was done using M. S. Excel and statistically analysed using Statistical package for social sciences (SPSS Version 16) for M. S Windows. Descriptive statistical analysis was carried out to explore the distribution of several categorical and quantitative variables.

Categorical variables were summarized with n (%), while quantitative variables were summarized by mean ± S. D. All results were presented in tabular form and are also shown graphically using bar diagram or pie diagram as appropriate.

The difference in the two groups was tested and categorical variables tested by chi square test.

A Receiver Operator Characteristic (ROC) curve is used to show the diagnostic ability.

P-value less than 0.05 considered to be statistically significant.

4. Results

After taking into consideration the inclusion and exclusion criteria, a total of 75 patients were included in the study.

Mean age group of the patients included in our study was 51.91 +/-10.18 years. Out of 75 patients who were included in the study, 39 patients were males (52%) and 36 patients were females (48%).

Morphology of tricuspid valve on 2d echocardiography was found to be normal in all the patients included in the study.

Mean Tricuspid annular diameter as measured on CT was 36.39 mm +/-3.8mm
Tricuspid regurgitation was found to be present in 37 patients included in the study 49.3%.
Mean RA size as measured on 2d ECHO was 39.81cm +/-4.3 cm
Mean RV size as measured on 2d ECHO was 35.91cm +/-3.7 cm
IVC size was normal </=2cm in 70 patients (93.3%) and dilated IVC >2cm was found in 5 patients (6.7%).
Colour flow mapping of TR showed non-significant tricuspid regurgitation, that is nil TR / mild TR in 64 patients (85.4%) and significant TR, that is moderate to severe TR in 11 patients (14.7%).

Mean TR jet velocity was 2.870 m/s with a standard deviation of +/-0.4459. Mean RVEF was 57.28 % with a standard deviation of +/-5.341. Mean RVSP was 33.88 mmHg with a standard deviation of +/-8.555. Mean Venacontracta diameter was 3.917 with a standard deviation

of +/-2.0024. There was found to be normal hepatic vein Doppler in 39 patients (52%), systolic dominance pattern of hepatic vein Doppler was found in 25 patients (33.7%), systolic blunting pattern of hepatic vein Doppler was found in 8 patients (10.7%), systolic reversal pattern of hepatic vein Doppler was found in 3 patients (4%). There was no TR in 38 out of 75 patients included in the study. Mild degree of TR was found in 26 patients, Moderate degree of TR was found in 6 patients and severe degree of TR was found in 3 patients.

Age was found to be statistically significant variable for TR with a Chi-Square value of 41.73 and p value of 0.001. Gender was found to be statistically significant variable for TR with a Chi-square value of 12.85 and p value of 0.02.38.5% of males and 61.5% of females had mild degree of TR.12.5% of males and 87.5 % of females had moderate degree of TR.33.3% of males and 66.7% of females had severe degree of TR.

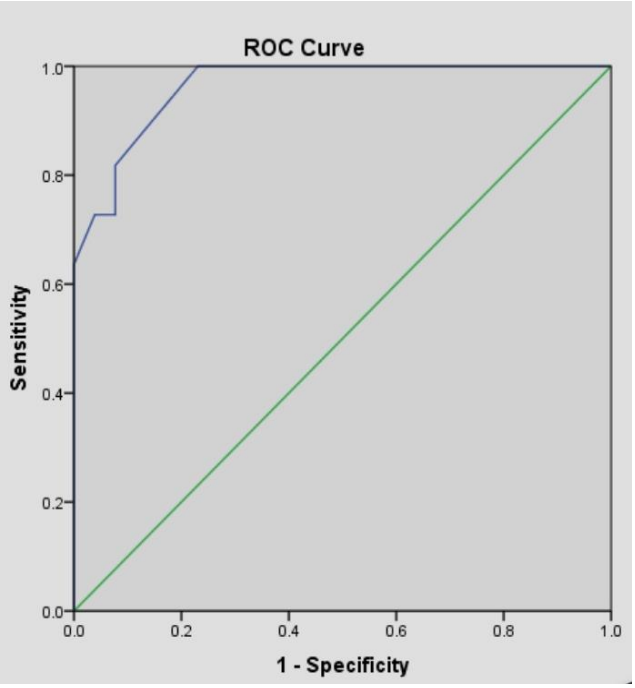

Figure 2: Graph shows ROC for CT tricuspid annular diameter in prediction of significant tricuspid regurgitation, AUC = 0.963.

Based on the ROC results, an optimum CT tricuspid annular diameter cut point of 40.5 mm was chosen for predicting moderate to severe TR. A CT value < 40.5 mm was classified as negative, whereas ≥ 40.5 mm was classified as positive. Using the ≥ 40.5 mm cut point, the prediction accuracy reached an AUC of 0.963 (95% CI, 0.911–1.000).

5. Discussion

The tricuspid valve has even been referred to as "the forgotten valve" [25]. Due to a number of variables, including as it is often an asymptomatic condition [9] and the relatively high surgical mortality when treating late symptomatic severe cases [8], TR has been neglected.

Another explanation is that TR is mostly caused by left-sided cardiac illness, and it was believed that once the underlying disease was treated, the condition would go away without the need for tricuspid valve surgery. However, there has been a tendency toward paying more attention to surgical and percutaneous intervention on the tricuspid valve due to the realization that untreated TR can continue following left heart surgery and can have a major influence on a person's functional capacity and survival.

Despite the increasing awareness of the clinical importance of TR, it is still only seldom diagnosed on echocardiography when a possible left heart condition is being investigated or a right heart failure is being assessed [26, 27]. The majority of these tricuspid repairs are performed together with left heart valve surgery [8]. The majority of these tricuspid repairs are carried out concurrently with procedures on the left heart valve [8]. Underdiagnosis and greater death rates for surgery conducted in late severe TR are contributing factors in the significantly reduced number of surgical procedures performed for solitary TR. However, U. S. [3] and European guidelines [28] support repair in patients with severe symptomatic TR undergoing left heart surgery as well as in those with silent progressing severe TR, emphasising the importance of early diagnosis in those without clinical symptoms.

Increased interest in the diagnosis and treatment of TR may be reflected in recent patterns of yearly increases in the number of tricuspid surgeries, which was reported to have more than doubled between 2003 and 2014 [29], and increased focus on transcatheter tricuspid valve therapies [30]. We think that the initial detection of TR in those who are asymptomatic can be aided by chest computed tomography, potentially providing a novel route for an early diagnosis. According to certain research, surgical mortality rates decrease when procedures are carried out early in the course of a disease [7, 8, 31, 32].

The tricuspid valve, the largest of the native cardiac valves, is functionally dynamic, able to change size and shape depending on the load presented to it [19]. This allows the tricuspid valve to dilate in response to the increased right heart loads. When it does dilate, it dilates primarily in the septal-to-lateral and anterior-to-posterior directions [35–37]. With this dilation comes dysfunction of the valve leaflets and ultimately TR. Dilatation of the valve in the septal-to-lateral direction is easily measured on echocardiographic or cross-sectional four-chamber views of the heart.

Despite the fact that this measurement does not accurately reflect the annulus' elliptical form, it is nevertheless one of the key measurements of the tricuspid valve on echocardiography, which aids in management. TR is actually divided into four grades (A, B, C, and D) according to American Heart Association and American College of Cardiology guidelines, with the more severe grades C and D being characterised in part by a tricuspid annulus measuring more than 40 millimetres on the four-chamber echocardiographic view [3].

The widespread usage and accessibility of CT, however, may present a novel method for the early detection of moderate to severe TR, individuals who may be candidates for tricuspid repair. This study was undertaken to assess the

ability of routine noncardiac (non-ECG-gated) chest contrast-enhanced CT to predict TR.

In our study, out of 75 patients who were referred for CECT chest, tricuspid annular diameter measured on CT was <41mm in 65 individuals and >/41mm in 10 individuals. Out of 65 individuals who had tricuspid annular diameter <41mm on CECT chest, 2D ECHO showed no TR & mild TR in 62 individuals and moderate to severe degree of TR in 3 individuals. Out of 10 individuals who had tricuspid annular diameter >41mm, 2D ECHO showed no TR & mild TR in 2 individuals and moderate to severe degree of TR in 8 individuals.

In our study, A total of 8 of 10 (80%) of CT-predicted positive cases had significant TR by echocardiography. A total of 62 of 65 (95.3%) of CT-predicted negative cases had nonsignificant TR by echocardiography.

Using this cut point, the specificity was 96.88% (95% CI-89.16% to 99.62%), the sensitivity was 72.7% (95% CI-39.03 to 93.98%).

Overall prevalence of significant TR was 14.6%.

Positive predictive value was 79.91% and Negative predictive value was 95.41%.

Surprisingly, the accuracy of the negative prediction was 95.41%. Similar to research done by Singh JP, Evans JC, Levy D, et al [2] that have revealed female sex to be a clinical determinant of TR, this study found that the prevalence of moderate to severe TR was higher in women (18% in women vs 10% in males). This study opted to concentrate on the prediction of moderate to severe TR since these types of TR are frequently clinically quiet but are nevertheless widely regarded as relevant [20]. Because it is linked to progressive right ventricular failure, death, and dilation when untreated, moderate to severe TR is regarded as serious [1, 20]. When left heart function, cardiac chamber size, and pulmonary artery pressures were taken into account, Nath et al. [1] reported that patients with severe TR had a 1-year survival rate of 63.9% compared to 91.7% for those without TR, and that moderate to severe TR was linked to worse clinical outcomes and more cardiac events.

Significant TR has a negative impact on mortality in patients who have undergone or have recently undergone aortic surgery [21], mitral surgery [14], transcatheter aortic or mitral valvular intervention [22, 23], or had a left ventricle assist device implanted [24]. Additionally, it is well-known that TR is a condition that gets worse over time [1, 20]. TR has nevertheless mostly gone unnoticed.

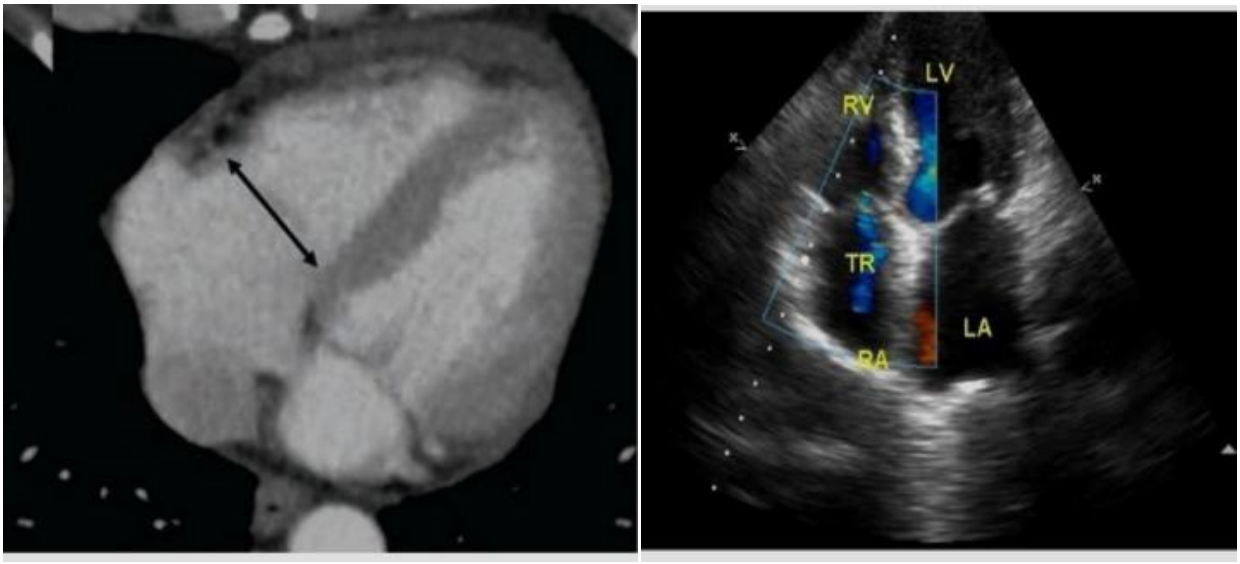

Figure 3: CECT chest (left) showing tricuspid annular diameter of 42mm, corresponding 2D-ECHO (right) in the same case showing mild regurgitation jet across tricuspid valve.

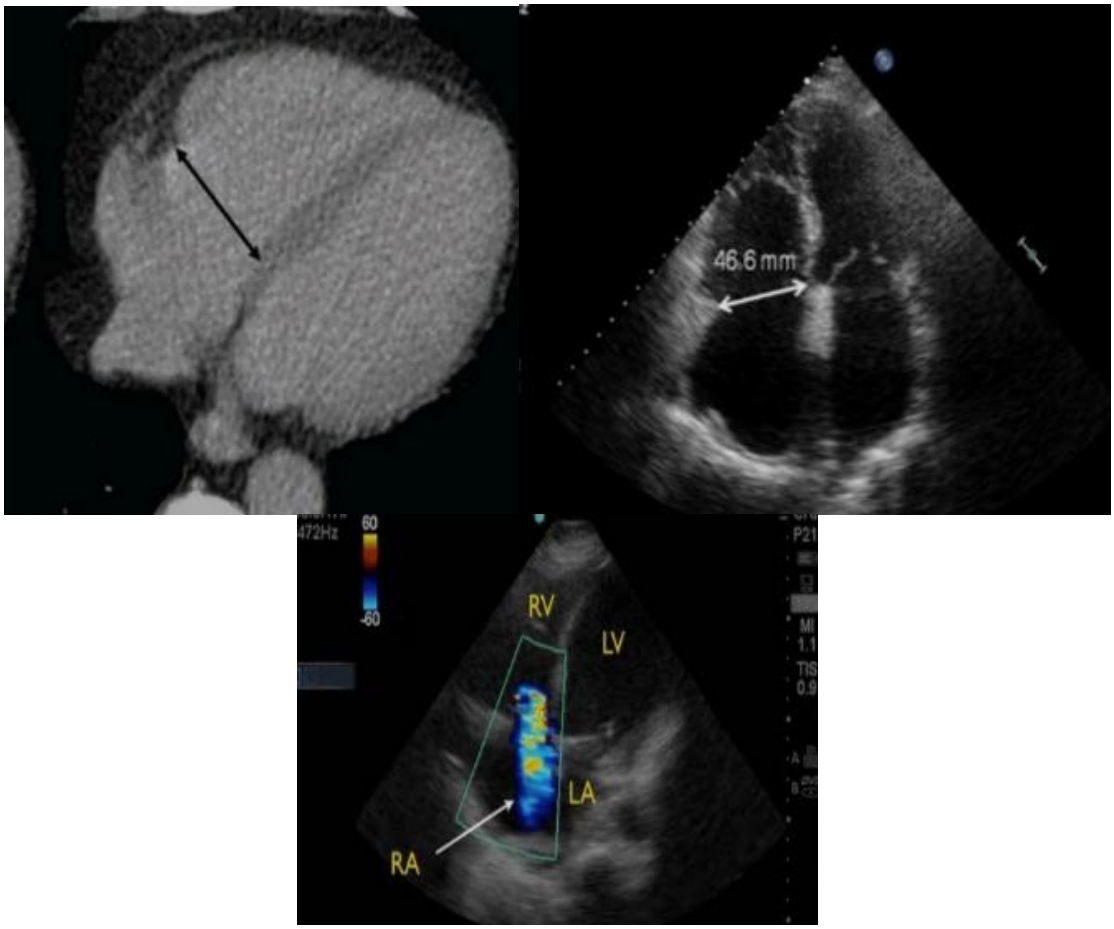

Figure 4: CECT chest (top left) showing CT tricuspid annular diameter of 45mm, corresponding 2D-ECHO (top right) in the same patient showing tricuspid annular diameter of 46.6mm and color Doppler (bottom left) evaluation of tricuspid valve showing significant tricuspid regurgitation jet from right ventricle into right atrium.

Early widespread TR detection would be necessary for early surgery. This is why our investigation concentrated on noncardiac CT rather than ECG-gated cardiac CT: the sheer volume of noncardiac chest CT images available gives the potential to detect TR in a substantially larger percentage of the population than cardiac CT angiography. The number of chest CT scans performed annually was estimated to be over 13 million in 2007 [33], and it is certainly higher today. This is an intriguing opportunity to identify TR in a large number of individuals in whom it might have previously gone undetected.

Tricuspid annular dilatation has evolved as a helpful TR marker on imaging. This is partly because functional TR typically manifests as tricuspid annular dilatation and makes up > 80% [3] of TR cases. This is because right ventricular pressure is high as a result of elevated left atrial pressure, pulmonary hypertension, and functional TR, which is mostly the result of underlying left heart disease [34].

Approximately 10% [3, 38] of TR cases are classed as idiopathic or organic because they are not functioning (i. e., due to an intrinsic abnormality of the valve as in rheumatic heart disease, valve prolapse, radiation, Ebstein anomaly, tumor, or vegetation). The prevalence of iatrogenic causes including damage from pacemaker leads or cardiac biopsies is also rising. The likelihood that certain kinds of TR will exhibit tricuspid annular dilatation is unknown.

This study demonstrates that, using a cut point of 40.5 mm, the tricuspid annulus can be assessed on transverse (axial) CT, and significant TR may be predicted with a high degree of accuracy. Our cut point of 40.5 mm complies with echocardiography recommendations, recommending a cut point of > 40 mm on the four-chamber view to determine the severity of TR. This is probably because the distance between the septal and lateral parts of the tricuspid annulus on axial imaging and the four-chamber distance is identical.

6. Limitations of the Study

A relatively small sample size, larger studies, including larger number of patients will show a better correlation between tricuspid annular diameter measured on CECT chest and grade of TR on echocardiography

Also, it was conducted at a tertiary care hospital that mainly caters to lower and middle socioeconomic strata, which is a subset of the general population, which thus underestimates the overall prevalence of significant TR

Inter-observer variability while doing echocardiographic analysis and in analysis of images obtained by CECT chest.

7. Conclusion

Assessment of the tricuspid valve annulus diameter on routine chest CT can predict significant (moderate to severe

degree) TR with a specificity of 96.88% and sensitivity of 72.7% using a cut point of 40.5 mm.

Measurements with a negative predictive value of 95.41% were below the cutoff.

This study concludes that routine contrast-enhanced CT scans of the chest can be used to quantify tricuspid annular diameter.

Further echocardiographic testing should be advised when the tricuspid annular diameter is at or above the threshold in order to confirm the diagnosis, properly grade, and discriminate between the various forms of TR.

References

[1] Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. J Am Coll Cardiol.2004 Feb 4; 43 (3): 405-9.
[2] Singh JP, Evans JC, Levy D, Larson MG, Freed LA, Fuller DL, et al. Prevalence and clinical determinants of mitral, tricuspid, and aortic regurgitation (the Framingham Heart Study. Am J Cardiol.1999 Mar 15; 83 (6): 897-902.
[3] Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP, Guyton RA, et al.2014 AHA/ACC Guideline for the Management of Patients With Valvular Heart Disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Circulation.2014 Jun 10; 129 (23): 2440-92.
[4] Topilsky Y, Khanna AD, Oh JK, Nishimura RA, Enriquez-Sarano M, Jeon YB, et al. Preoperative factors associated with adverse outcome after tricuspid valve replacement. Circulation.2011 May 10; 123 (18): 1929-39.
[5] Vassileva CM, Shabosky J, Boley T, Markwell S, Hazelrigg S. Tricuspid valve surgery: the past 10 years from the Nationwide Inpatient Sample (NIS) database. J Thorac Cardiovasc Surg.2012 May; 143 (5): 1043-9.
[6] Fender EA, Zack CJ, Nishimura RA. Isolated tricuspid regurgitation: outcomes and therapeutic interventions. Heart.2018 05; 104 (10): 798-806.
[7] Stuge O, Liddicoat J. Emerging opportunities for cardiac surgeons within structural heart disease. J Thorac Cardiovasc Surg.2006 Dec; 132 (6): 1258-61.
[8] Alqahtani F, Berzingi CO, Aljohani S, Hijazi M, Al-Hallak A, Alkhouli M. Contemporary Trends in the Use and Outcomes of Surgical Treatment of Tricuspid Regurgitation. J Am Heart Assoc.2017 22; 6 (12).
[9] Tornos Mas P, Rodríguez-Palomares JF, Antunes MJ. Secondary tricuspid valve regurgitation: a forgotten entity. Heart.2015 Nov; 101 (22): 1840-8.
[10] Porter A, Shapira Y, Wurzel M, Sulkes J, Vaturi M, Adler Y, et al. Tricuspid regurgitation late after mitral valve replacement: clinical and echocardiographic evaluation. J Heart Valve Dis.1999 Jan; 8 (1): 57-62.
[11] Izumi C, Iga K, Konishi T. Progression of isolated tricuspid regurgitation late after mitral valve surgery for rheumatic mitral valve disease. J Heart Valve Dis.2002 May; 11 (3): 353-6.
[12] Matsuyama K, Matsumoto M, Sugita T, Nishizawa J, Tokuda Y, Matsuo T. Predictors of residual tricuspid regurgitation after mitral valve surgery. Ann Thorac Surg.2003 Jun; 75 (6): 1826-8.
[13] Takano H, Hiramatsu M, Kida H, Uenoyama M, Horiguchi K, Yamauchi T, et al. Severe tricuspid regurgitation after mitral valve surgery: the risk factors and results of the aggressive application of prophylactic tricuspid valve repair. Surg Today.2017 Apr; 47 (4): 445-56.
[14] Goldstone AB, Howard JL, Cohen JE, MacArthur JW, Atluri P, Kirkpatrick JN, et al. Natural history of coexistent tricuspid regurgitation in patients with degenerative mitral valve disease: implications for future guidelines. J Thorac Cardiovasc Surg.2014 Dec; 148 (6): 2802-9.
[15] Kelly BJ, Ho Luxford JM, Butler CG, Huang CC, Wilusz K, Ejiofor JI, et al. Severity of tricuspid regurgitation is associated with long-term mortality. J Thorac Cardiovasc Surg.2018 03; 155 (3): 1032-8
[16] Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP, Fleisher LA, et al.2017 AHA/ACC Focused Update of the 2014 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 Clinical Practice Guidelines. Circulation.2017 06 20; 135 (25): e1159-e1195.
[17] Vahanian A, Alfieri O, Andreotti F, Antunes MJ, Barón-Esquivias G, Baumgartner H, et al. Guidelines on the management of valvular heart disease (version 2012). Eur Heart J.2012 Oct; 33 (19): 2451-96.
[18] Mitchell C, Rahko PS, Blauwet LA, Canaday B, Finstuen JA, Foster MC, et al. Guidelines for Performing a Comprehensive Transthoracic Echocardiographic Examination in Adults: Recommendations from the American Society of Echocardiography. J Am Soc Echocardiogr.2019 01; 32 (1): 1-64.
[19] Zoghbi WA, Adams D, Bonow RO, Enriquez-Sarano M, Foster E, Grayburn PA, 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 04; 30 (4): 303-71.
[20] Lamers WH, Virágh S, Wessels A, Moorman AF, Anderson RH. Formation of the tricuspid valve in the human heart. Circulation.1995 Jan 1; 91 (1): 111-21.
[21] Lama P, Tamang BK, Kulkarni J. Morphometry and aberrant morphology of the adult human tricuspid valve leaflets. Anat Sci Int.2016 Mar; 91 (2): 143-50.
[22] Fukuda S, Saracino G, Matsumura Y, Daimon M, Tran H, Greenberg NL, et al. Three-dimensional geometry of the tricuspid annulus in healthy subjects and in patients with functional tricuspid regurgitation: a real-time, 3-dimensional echocardiographic study. Circulation.2006 Jul 4; 114 (1 Suppl): I492-8.
[23] Ton-Nu TT, Levine RA, Handschumacher MD, Dorer DJ, Yosefy C, Fan D, et al. Geometric determinants of functional tricuspid regurgitation: insights from 3-dimensional echocardiography. Circulation.2006 Jul 11; 114 (2): 143-9.

[24] Hahn RT. State-of-the-Art Review of Echocardiographic Imaging in the Evaluation and Treatment of Functional Tricuspid Regurgitation. Circ Cardiovasc Imaging.2016 Dec; 9 (12): e005332.
[25] Mahmood F, Kim H, Chaudary B, Bergman R, Matyal R, Gerstle J, et al. Tricuspid annular geometry: a three-dimensional transesophageal echocardiographic study. J CardiothoracVascAnesth.2013 Aug; 27 (4): 639-46.
[26] Topilsky Y, Khanna A, Le Tourneau T, Park S, Michelena H, Suri R, et al. Clinical context and mechanism of functional tricuspid regurgitation in patients with and without pulmonary hypertension. Circ Cardiovasc Imaging.2012 May 1; 5 (3): 314-23.
[27] Prihadi EA, Delgado V, Leon MB, Enriquez-Sarano M, Topilsky Y, Bax JJ. Morphologic Types of Tricuspid Regurgitation: Characteristics and Prognostic Implications. JACC Cardiovasc Imaging.2019 03; 12 (3): 491-9.
[28] Rogers JH, Bolling SF. The tricuspid valve: current perspective and evolving management of tricuspid regurgitation. Circulation.2009 May 26; 119 (20): 2718-25.
[29] Paranon S, Acar P. Ebstein's anomaly of the tricuspid valve: from fetus to adult: congenital heart disease. Heart.2008 Feb; 94 (2): 237-43.
[30] Simula DV, Edwards WD, Tazelaar HD, Connolly HM, Schaff HV. Surgical pathology of carcinoid heart disease: a study of 139 valves from 75 patients spanning 20 years. Mayo Clin Proc.2002 Feb; 77 (2): 139-47.
[31] Waller BF, Howard J, Fess S. Pathology of tricuspid valve stenosis and pure tricuspid regurgitation-- Part III. Clin Cardiol.1995 Apr; 18 (4): 225-30.
[32] Pritchett AM, Morrison JF, Edwards WD, Schaff HV, Connolly HM, Espinosa RE. Valvular heart disease in patients taking pergolide. Mayo Clin Proc.2002 Dec; 77 (12): 1280-6.
[33] Baseman DG, O'Suilleabhain PE, Reimold SC, Laskar SR, Baseman JG, Dewey RB. Pergolide use in Parkinson disease is associated with cardiac valve regurgitation. Neurology.2004 Jul 27; 63 (2): 301-4.
[34] Topilsky Y, Maltais S, Medina Inojosa J, Oguz D, Michelena H, Maalouf J, et al. Burden of Tricuspid Regurgitation in Patients Diagnosed in the Community Setting. JACC Cardiovasc Imaging.2019 03; 12 (3): 433-42.
[35] Medvedovsky D, Aronson D, Gomberg-Maitland M, Thomas V, Rich S, Spencer K, et al. Tricuspid regurgitation progression and regression in pulmonary arterial hypertension: implications for right ventricular and tricuspid valve apparatus geometry and patients outcome. Eur Heart J Cardiovasc Imaging.2017 Jan; 18 (1): 86-94.
[36] Pinamonti B, Dragos AM, Pyxaras SA, Merlo M, Pivetta A, Barbati G, et al. Prognostic predictors in arrhythmogenic right ventricular cardiomyopathy: results from a 10-year registry. Eur Heart J.2011 May; 32 (9): 1105-13.
[37] Utsunomiya H, Itabashi Y, Mihara H, Berdejo J, Kobayashi S, Siegel RJ, et al. Functional Tricuspid Regurgitation Caused by Chronic Atrial Fibrillation: A Real-Time 3-Dimensional Transesophageal Echocardiography Study. Circ Cardiovasc Imaging.2017 Jan; 10 (1): e004897.