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Role of Cardiac MRI in Evaluation of Tricuspid Valve Dysfunction

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Abstract

Background: Tricuspid valve dysfunction, and precisely tricuspid regurgitation, is very frequently encountered among cardiac patients with a complex pathophysiology and extended unfavorable complications.

Aim of Study: The purpose of this study is to investigate the accuracy of cardiac MRI in Tricuspid valve dysfunction in comparison to two-dimensional transthoracic echocardiography (2D echo).

Patients and Methods: This prospective study included 56 cardiac patients, who were evaluated for tricuspid valve dysfunction group. All were investigated by 2D transthoracic echo and cardiac MRI which was done maximally at a week interval after echo. Agreement between echocardiography and MRI as regard valve morphology, area, mean pressure gradient, regurgitation fraction and volume as well as right and left ventricular volumes and function were calculated.

Results: There is significant strong positive correlation between MRI and echo as regard tricuspid valve area (r=0.991, p<0.001) and mean pressure gradient (r=0.996 p<0.001). The two methods were significantly (r=0.991, p<0.001). Cohen's kappa agreement test was done to calculate agreement between MRI and echocardiography for morphological and functional Tricusped valve assessment. There is strong agreement (k=0.8, p<0.001) between MRI and echo as regard: Regurgitant jet area and regurgitation fraction while, moderate agreement in cusp thickness and regurgitant jet location (k=0.78,0.61 p=0.003). Leaflet mobility shows weak agreement (k=0.58, p=0.001) and there was no agreement regarding cusp calcification. There was strong positive correlation between echo and MRI as regard right and left ventricles ejection fraction in tricuspid valve disease (r=0.93, p=0.01 & r=0.87, p=0.003 respectively).

Conclusion: MRI is an accurate method for evaluation of tricuspid valve dysfunction with good correlation with echo.

Key Words: *Cardiac MRI, reliability – Tricuspid – Dysfunction – Stenosis – Regurgitation.*

Introduction

THE impact of Right sided cardiac valve dysfunction has been overlooked for years compared to left sided cardiac valve dysfunction. However, recently there is increasing concern about right sided cardiac valve dysfunction. Tricuspid regurgitation (TR) is frequently encountered and can cause functional impairment and survival reduction, especially if coexist with left-sided valvular disease. TR status also anticipates to poor outcomes in the setting of postsurgical and post-interventional procedures for the aortic and mitral valves [1-3]. Tricuspid regurgitation occurs secondary to dilated right ventricle resulting in enlargement of the valve's ring-like base. These conditions include heart failure, infective endocarditis, rheumatic heart disease, carcinoid syndrome, degeneration of the valve's supporting connective tissue and congenital heart defects. Tricuspid stenosis (TS) most frequently caused by rheumatic heart disease leading to hardening and thickening of valve leaflets thus limiting forward blood flow [4,5].

Echo is the gold standard imaging modality for the evaluation of chronic valvular stenosis and regurgitation, including explanation of the mechanism as well as quantifying its severity and impact on cardiac function [6-9]. Over the past two decades,

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Abbreviations:

MRI : Magnetic Resonance Imaging.
CMR : Cardiac Magenetic Resonance.
2D echo : Two-Dimensional Echocardiography.
SSFP : Steady State Free Procession.
ICC : Intraclass Correlation Coefficient.
VHD : Valvular Heart Diseases.
LV : Left ventricle
RV : Right ventricle.
TR : Tricuspid Regurgitation.
TS : Tricuspid Stenosis.
SD : Standard deviation.
EDV : End Diastolic Volume.
ESV : End Systolic Volume.
SV : Stroke Volume.
EF : Ejection Fraction.
SPSS : Statistical Package of social sciences.
T : Tesla
TE : Echo Time.
TR : Repition Time.

Cardiac MR has been introduced as an alternative modality to echo for assessment of valvular heart disease (VHD). Despite the fact that echo is the first-line imaging modality for imaging VHD, CMR can now provide a full assessment in many cases. Using variable sequences, CMR gives a wealth of information on valve anatomy and enables analysis of the severity of the valve dysfunction [10-12].

CMR imaging has distinctive advantageous features: It does not depend upon adequate acoustic windows, and less operator dependent for invaribley obtaining good quality images for interpretation . CMR provides excellent spatial resolution and, with ECG gating, has improved temporal resolution, which approximates echocardiography. When compared to multi-slice computerized tomography, CMR lacks ionizing radiation, thus provides safe lengthy examination [11,13,14].

Cardiac MRI offers a useful modality to evaluate myocardial structure, anatomy and function, because of its good spatial resolution. The cine sequences, and particularly steady-state free-precession (SSFP), allow excellent blood–myocardium delineation and contrast (Fig. 1), increasing its reliability of the quantification of cardiac chambers volume and function. Also, phase contrast cine sequences can directly assess the flow and evaluate severity of cardiac valves stenosis and regurgitation [1,11].

CMR is the gold-standard method for RV volumes and function evaluation. Moreover, CMR allows imaging of the pulmonary valve and RV outflow tract with precision not available with 2D echo. The complicated anatomy of the RV makes volumetric analysis by echo challenging. So, CMR is the preferred method for RV,TV and pulmonary valve disease evaluation [8,10,15].

While MRI is currently routinely used to evaluate regurgitant valve lesions, the available data relating to stenotic lesions, especially tricuspid and mitral valves, are limited [16-18].

The purpose of this study is to investigate the accuracy of cardiac MRI in Tricuspid valve dysfunction in comparison to two-dimensional transthoracic echocardiography (2D echo).

Patients and Methods

This prospective study included fifty six cardiac patients, their ages between 55 years and 76 years (mean = 62±7.2 Ys.). The study was conducted at Cardiology and Radiology Departments of Mansoura University Hospitals at the period from January 2015 till January 2018, cardiac patients referred from Cardiology Department and its out-patient clinic of Mansoura University Hospitals to the Radiology Department to perform cardiac MRI based upon echocardiographic abnormal findings. The patients underwent MRI within maximum one-week interval from the echocardiography. Post-processing was done by a radiologist who is blind to echocardiography report. The patients were classified into isolated tricuspid regurgitation, mixed regurgitation and stenosis and isolated tricuspid stenosis. Witten informed consent was obtained from all patients. The ethical committee (IRB)approved the study.

Methods:

Echocardiography technique:

Transthoracic echocardiography was performed on commercially available ultrasound machines with a transducer of 2-4 MHz in Cardiology Department of Mansoura University Hospitals. For the tricuspid valve: Parasternal long axis, right chamber view, parasternal short axis views at the level of aortic valve and apical 4 chamber view with both grey scale, M-mode, color and power Doppler studies.

These views were used to obtain the following parameters:

- Evaluation of valve morphology as cusps thickness, degree of calcification, and leaflets mobility.
- Valve stenosis: Valve area and mean pressure gradient were evaluated.
- Valve regurgitation: Regurgitation was graded as none, mild, moderate and sever according to visual grey scale, color and power Doppler evaluation based on an integrative assessment including color jet area and eccentricity and chamber dilatation.
- Evaluation of RV and LV ejection fraction.

MRI technique:

All cardiac MRI examinations were performed using (1.5 T Ingenia Philips Medical Systems, Best the Netherlands) equipped with dedicated cardiac MR software. All patients were in sinus rhythm during the examination, no sedation was used. Imaging was performed supine with the patient positioned in a 6-element phased array surface coil. All images were ECG gated and were performed with breath hold. Examination was done with the urinary bladder empty to ensure comfort in the supine position with head first. Head phones were used to reduce repetitive gradient noise, thus allow the patients to hear instructions including breath hold.

The MRI protocol included:

A- *Imaging acquisition:* Scout views in the three orthogonal planes without breath holding. Planning vertical long axis image from the axial orthogonal image at the level of the left ventricle. Planning the horizontal long axis view from the vertical long axis view. Planning the short axis view from the horizontal long axis view.

Sequences used:

1- ECG-gated 2, 3, 4 chamber and short axis SSFP cine sequences.

2- ECG-gated Phase contrast cine sequences at the level of tricuspid and pulmonary valve, proximal main pulmonary artery.

Breath-holding techniques were used to minimize respiratory motion artifacts. Examination time was about 30 seconds for each sequence and about 20-40 minutes for justification of planimetry.

For SSFP cine sequences (Fig. 1) we used matrix of 256 x 160-192, FOV:300-400mm, Flip angle: 45, slice thickness: 5-8mm, Gap: 0mm. TR: 3.5ms, TE: minimum, views per segment: 8.

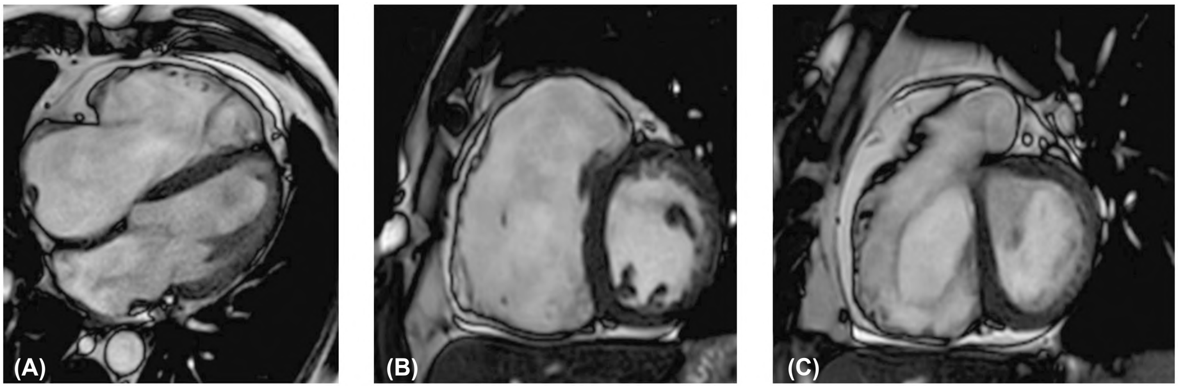

Fig. (1): SSFP images: (A): 4-chamber image. (B): Short axis image with dilated RV. (C) Short axis at the level of tricuspid valve.

For phase contrast cine sequences, we used matrix of 256 x 160-224, FOV:200-300mm, Flip angle: 25, slice thickness: 5mm, Gap: 0mm. TR: 12ms, TE: minimum, views per segment: 4-8 and standard protocols for morphology and function assessment [19].

B- *Image Interpretation:* Cardiac MRI data were evaluated by a concurrence of two radiologists who were blinded to the echocardiographic data, using cardiac analysis tool pack on Philips extended workstation (EWS) View Forum. Valve morphology (including thickness, calcification and mobility) was evaluated. Valve area, mean pressure gradient, regurgitant jet (location and area), regurgitation fraction and volume as well as right and left ventricular volumes and function were calculated.

A region of interest (ROI) was drawn to include tricuspid valve and a histogram of velocity versus pixel number displayed. A pixel cutoff for peak velocity was used to generate a velocity-time curve for 1 cardiac cycle. The process was repeated for Pulmonary artery and Aorta in all slices for indirect calculation of regurgitant volume and fraction.

Statistical analysis: Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. Significance of the obtained results was judged at the 5% level. Kappa agreement: Was used for identification of reliability between MRI & ECHO with the following grading; Kappa value: 0-0.2 none, 0.21-0.39 minimal, 0.40-0.59 denote weak agreement, 0.60-0.79 moderate agreement & 0.80-0.90 strong agreement, >0.9 almost perfect agreement.

Inter class Correlation Coefficient and correlation coefficient analyzed for agreement between methods. For each pair of values, limits of agreement were assessed by evaluating the mean difference (bias) and the standard deviation of the differences using the Bland-Altman plot which was used to visually assess agreement between the methods. N.B: p is significant if 0. 05 at confidence interval 95%.

Results

This prospective study included fifty six cardiac patients, their ages ranged from 55-76 years with a mean (mean = 62±7.2 Ys.), 36 females and 20 males. Twenty six patients (46.4%) had associated rheumatic heart disease, while 20 (36.5%) had associated dilated cardiomyopathy.

Patients were classified into 3 groups, isolated tricuspid regurgitation (no=36, 64.3%) (Fig. 2), mixed regurgitation and stenosis (n=10, 17.85%), and isolated tricuspid stenosis (n=10, 17.85%).

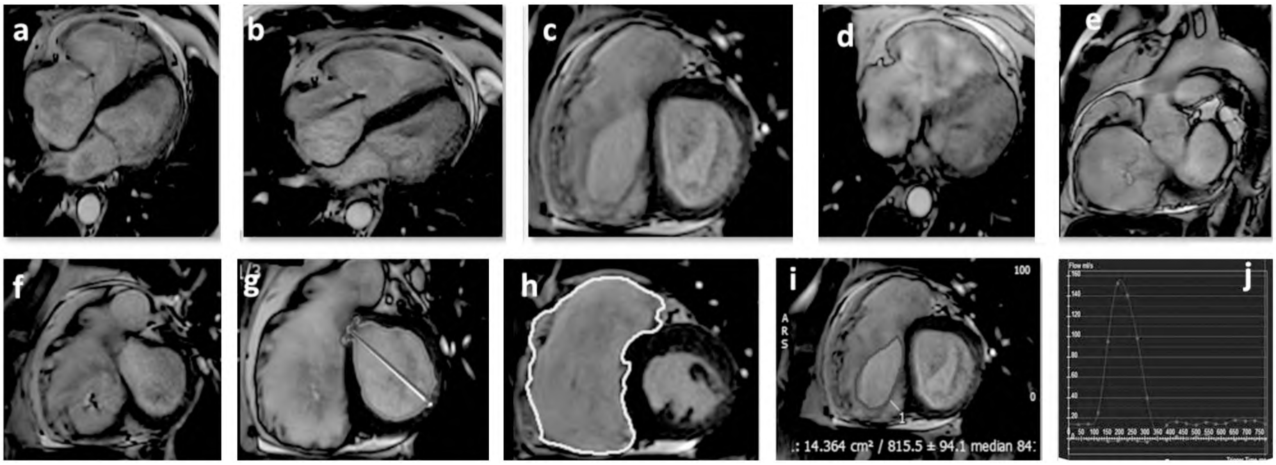

Fig. (2): Moderate tricuspid regurgitation with severely impaired right ventricular function and mildly impaired left ventricular function. (A,B): 4-chamber SSFP image showing central signal void jet regurgitant into the right atrium. (C): Short axis SSFP image of both ventricles as the level of tricuspid and mitral valves showing dilated right ventricle, mildly thickening tricuspid valve cusps. (D): Phase contrast magnitude image through the tricuspid valve showing central regurgitant jet with jet area ~ 0.22cm^2. (E,F): Short axis SSFP images shows dilated right ventricle and signal void regurgitant jet across the tricuspid valve. (G): Short axis SSFP image showing marking of the endocardial contour of the LV for its volumes and function evaluation. H: Short axis SSFP image showing marking of the endocardial contour of the RV for its volumes and function evaluation. (I): Short axis SSFP image at the level of the tricuspid valve for planimetry which showed that the tricuspid valve area measured about 14.4 cm^2. (J): Time flow curve at the level of the pulmonary artery for calculation of the forward flow through pulmonary artery which then allowed evaluation of the regurgitant volume.Forward flow (pulmonary artery stroke volume) = 41ml. Regurgitation fraction ~ 44 %.Regurgitant volume ~ 32ml. By analysis, the LV volumes and function: EDV: 130ml, ESV: 67 ml, SV: 63 ml, EF: 48%. RV volumes and function: EDV: 308ml, ESV: 235ml, SV: 73ml, EF: 23.7%. There was associated minimal pericardial effusion.

The mean, median, standard deviation (SD), minimum and maximum values by echo and MRI and correlation between both methods as regard tricuspid valve area and mean pressure gradient (in cases of isolated TS) are illustrated in Table (1).

There is significant strong positive correlation between MRI and echo as regard tricuspid valve area (r=0.991, p<0.001) and mean pressure gradient (r=0.996, p<0.001). The two methods are significantly correlated, (r=0.991, p<0.001).

Cohen's kappa agreement test was used to calculate agreement between MRI and echocardiography for morphological and functional Tricusped valve assessment. There is strong agreement (k=0.8, p<0.001) between MRI and echo as regard: Regurgitant jet area and regurgitation fraction while, moderate agreement in cusp thickness and regurgitant jet location as well as regurgitant volume (k=0.78,0.61, p=0.003). Leaflet mobility shows weak agreement (k=0.58, p=0.001) and there was no agreement regarding cusp calcification

Ventricular function analysis:

Analysis of the left and right ventricular volumes including EDV, ESV, SV and function including EF with the mean, median. Standard deviation, minimum and maximum values are illustrated in Tables (3,4). Correlation between MRI and echo as regard LV and RV ejection fraction is shown in Table (5).

There was strong positive correlation between echo and MRI as regard right and left ventricles ejection fraction in tricuspid valve disease (r=0.93, p=0.01 & r=0.87, p=0.003 respectively).

Table (1): Interclass correlation between echo and MRI of tricuspid valve area and mean pressure gradient.

Tricuspid valve dysfunction (n=56)	MRI Mean ± SD Median Min/max	ECHO Mean ± SD Median Min/max	ICC
Overall valve area (cm^2)	9.0±5.8 12.0 (2.0-15.0)	9.53±6.06 13.0 (2.0-16.0)	r=0.991 p<0.001*
Valve area in isolated TR (n=36) (cm^2)	11.8±2.44 13 (5-15)	12.5±2.51 13.5 (5.5-16)	
Mean pressure gradient in isolated TS (n=10)	0.97±1.65 0.0 (0.0-3.4)	1.11±1.9 0.0 (0.0-4.2)	r=0.996 p<0.001*

ICC: Interclass correlation co-efficient.
p: Probability. *Statistically significant (p<0.05).

Table (2): Kappa agreement analysis between ECHO & MRI in evaluation of Tricuspid valve disease.

Tricuspid Valve Dysfunction (n=56,%)	MRI	ECHO	Test of significance	Agreement
1- *Cusp thickness:*				
Normal	16 (28.6)	24 (42.9)	p=0.12	Kappa=0.781
Mild thickening	24 (42.9)	24 (42.9)		p=0.003 *
Moderate thickening	16 (28.6)	8 (14.3)		
2- *Cusp calcification:*				
None	53 (94.6)	47 (83.9)	p=0.07	Kappa=0.09
Present	3 (5.3%)	9 (16)		p<0.001 *
3- *Leaflet mobility:*				
Normal	34 (71.4)	40 (71.4)	p=0.3	Kappa=0.58
Hypermobile	22 (28.6)	16 (28.6)		p<0.001 *
4- *Regurgitation jet location:*				
None	8 (14.3)	8 (14.3)	p=0.01 *	Kappa=0.61
Small central	16 (28.6)	32 (57.1)		p=0.003 *
Variable	16 (28.6)	8 (14.3)		
Large central/eccentric	16 (28.6)	8 (14.3)		
5- *Regurgitation jet area:*				
None	8 (14.3)	8 (14.3)	p=0.3	Kappa=0.80
Mild	16 (28.6)	24 (42.9)		p<0.001 *
Moderate	24 (42.9)	16 (28.6)		
Severe	8 (14.3)	8 (14.3)		
6- *Regurgitation fraction:*				
None	3 (5.4)	9 (16%)	p=0.3	Kappa=0.84
Mild	28 (50)	27 (48.2%)		p<0.001 *
Moderate	15 (26.8)	11 (19.6)		
Severe	10 (17.9)	9 (16)		
7- *Regurgitation volume:*				
None	6 (10.7%)	8 (14.2%)	p=0.8	Kappa=0.749
Mild	30 (53.6%)	32 (57.2%)		p<0.001 *
Moderate	15 (26.7%)	12 (21.4%)		
Severe	5 (9%)	4 (7%)		

FET: Fischer exact test. p: Probability. *Statistically significant (p<0.05).

Table (3): MRI values of LV volumes and EF.

Valve affected	EDV (ml)	ESV (ml)	SV (ml)	EF %
Overall tricuspid valve disease N=56:				
Mean ± SD	158.71±31.2	76.7± 15.84	82±16.5	51.5±2.68
Median	147	69	80	52.3
Min/Max	121-200	61-95	59-105	41-55.2
Isolated TR N=36:				
Mean ± SD	169±11.33	82±4.22	87± 1.26	50.1±6
Median	180	90	85	52.3
Min/Max	128-200	61-95	67-105	41-52.6

EDV: End diastolic volume. EF: Ejection fraction. SD: Standard deviation.
ESV : End systolic volume. SV: Stroke volume.

Table (4): MRI values of RV volumes and EF.

Valve affected	EDV (ml)	ESV (ml)	SV (ml)	EF %
Overall tricuspid valve disease N=56:				
Mean ± SD	188.7±72.13	100±52.64	88.7±27.8	48.24±8.25
Median	178	86	90	51.3
Min/Max	95-320	52-210	43-128	34-56.2
Isolated TR N=36:				
Mean ± SD	218.8± 19.48	117.2±46.58	101.6±5.72	47.84±4.03
Median	190	102	100	51.3
Min/Max	176-320	78-210	80-128	34-56.2

EDV: End diastolic volume. EF: Ejection fraction. SD: Standard deviation.
ESV : End systolic volume. SV: Stroke volume.

Table (5): Correlation between MRI and echo as regard LV and RV EF.

	MRI LV EF		MRI RV EF	
Echo LV & RV EF	*r*	0.873	*r*	0.927**
	p	0.01*	*p*	0.003

p : Probability. *Statistically significant (p<0.05).
EF: Ejection fraction.

Discussion

Tricuspid valve disease in this study was categorized as isolated TR, isolated TS and mixed tricuspid valve disease by 64.3%, 17.8% & 17.8% respectively. This is explained by Gulsin et al., report that tricuspid stenosis is a rare entity and not ordinarily assessed by CMR [10].

The main findings in this study is strong and significant correlation between MRI and echocardiography in tricuspid valve evaluation as regard tricuspid valve area with high interclass correlation coefficient (r=0.991, p<0.001). Also, strong correlation between MRI and echo in calculation of mean pressure gradient with significant interclass correlation coefficient (r=0.996, p<0.001). Similar previous studies stated that in comparison to echocardiography, MRI is accurate in evaluation of tricuspid valve area and its changes in disease process with good agreement and low interobserver variability [20].

Morphological assessment of tricuspid valve, as regards cusp thickness, cusp calcification and leaflet mobility, was carried out by both 2D echo and MRI. Both modalities show moderate agreement in evaluation of cusp thickness (k=0.78, p=0.003). Cusp thickness evaluation is hampered by the thin nature of TV (1-2mm) rendering valve leaflets susceptible to partial volume effects due to the slice thickness of CMR images (typically 5-8mm), thus details of delicate valve structure are difficult to assess clearly with CMR [1,11,21,22]. There was no agreement in detection of cusp calcification, this explained by multiple factors ; first TV calcification is rare, second MRI ability to detect calcification is limited [19,23,24]. There is weak agreement in evaluation of leaflet mobility (k=0.58, p=0.001), this also explained by the subjective method of evaluation in both modalities [25,26].

Regurgitant jet area showed strong agreement (k=0.8, p<0.001) which is comparable to previous study by Medovesky et al., 2017 who found moderate agreement between 2D echocardiography and CMR in calculation of regurgitant jet area [12]. While, regurgitant jet location shows moderate significant agreement (k=0.61, p=0.003) between MRI and echo.

Quantitative data as regard regurgitant fraction and regurgitant volume have strong and moderate agreement. Regurgitant volume which was evaluated indirectly by subtraction of pulmonary artery stroke volume from RV stroke volume then graded as mild, moderate and severe to be compared to results of transthoracic echo. Similar studies stated that MRI measurements of regurgitation fraction and regurgitant volume are more accurate and in good concordance with angiographic and echocardiographic data [27]. Medvedofsky et al., reported moderate agreement between MRI and echo as regard regurgitant jet area, regurgitation fraction and regurgitant volume. They acknowledged that to indirect evaluation of regurgitant volume through RV volumes including stroke volume and pulmonary artery flow then subtraction rather than direct evaluation through tricuspid valve due to its non-planar orientation and extensive excursion [12]. However, Sawhney et al., reported moderate agreement between MRI and echo as regard qualitative and quantitative evaluation of tricuspid regurgitation. They attributed that to MRI underestimation of trace or minimal regurgitation [28].

In our study there was strong agreement between MRI and echo in evaluation of right and left ventricles ejection fraction in tricuspid valve disease (r=0.93 & r=0.87 respectively). The coincides with Greupner et al., who stated that there is good correlation between multi-detector CT, MRI, 2D and 3D echo in evaluation of global ventricular function with the highest correlation between MRI and CT, which may be due to similarity between the two diagnostic modalities. This study considered MRI is the gold standard in evaluation of RV and LV volumes and function [15,29].

Limitations of our study were small sample size, problems in the presence of arrhythmias or claustrophobia, relative inability to perform CMR for patients with metallic implants e.g pacemakers and internal cardioverters defibrillators. Included patients were based upon treating cardiologist need for cardiac MRI. Future recommendations; Additional clinical experience with both techniques in all patients with TV dysfunction is critical to facilitate appropriate comparison and to determine comparable reporting techniques, potential diagnostic pitfalls, and areas for improvement. Also, to study tricuspid valve dysfunction with 4D-flow MRI in large multicenteric study.

Conclusion:

Cardiac MRI can be used routinely to compliment echocardiographic evaluation of tricuspid valve. It is a reliable versatile accurate imaging modality to evaluate Tricuspid valve dysfunction. It was superior to echo in evaluation of regurgitation fraction, regurgitant volume and ventricular volumes & function as well.

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دور الرنين المغناطيسى على القلب
فى تقييم الاختلال الوظيفى للصمام الثلاثى الشرفات

إن الاختلال الوظيفى للصمام ثلاثى الشرفات وخاصة الارتجاع هو مرض كثير الحدوث بين مرضى القلب وله تفاصيل باثوفسيولوجية معقدة كما أن له أثار سلبية بعيدة الأمد

أن الهدف من هذه الدراسة هو اختبار دقة الرنين المغناطيسى على القلب فى تقييم الاختلال الوظيفى للصمام الثلاثى الشرفات مقارنة بالايكو ثنائى الأبعاد.

المرضى وطريقة البحث: نوع الدراسة ومدتها: هذه دراسة مرتقبة تمت فى الفترة ما بين يناير ٢٠١٥ إلى يناير ٢٠١٨.

المرضى: اشتملت هذه الدراسة على ٥٦ مريض تم تشخيصهم بالاختلال الوظيفى للصمام الثلاثى الشرفات بواسطة الايكو ثنائى الأبعاد

طريقة الدراسة: تم فحص جميع المرضى بواسطة الرنين المغناطيسى على القلب ومقارنة نتائج الوصف المرفولوجى والوظيفى للصمام الثلاثى الشرفات مع نتائج الايكو.

النتائج: قسمت الاختلالات الوظيفية للصمام الثلاثى الشرفات إلى مجموعات (ارتجاع فقط، ضيق فقط ارتجاع مع ضيق).

توصلت هذه الدراسة إلى نسبة ارتباط عالية بين نتائج الرنين المغناطيسى ونتائج الايكو من حيث تحديد مساحة فتحة الصمام وفرق الضغط فى حالات ضيق الصمام

كما توصلت إلى نسبة توافق عالية فى تقييم وظائف الصمام من حيث موضع التدفق المرتجع وحجم الارتجاع.

الاستنتاج: نستنتج من هذه الدراسة أن الرنين المغناطيسى على القلب هو وسيلة تشخيصية دقيقة لتقييم الاختلال الوظيفى للصمام الثلاثى الشرفات.