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The Role of Cardiac MRI in Functional and Structural Assessment of The Right Ventricle in Patients with Repaired Fallot Tetralogy

Ayman Mohamed Ibrahim*, Ali Haggag Ali, Naiad Medhat Elsaied
Department of Radiodiagnosis, Faculty of Medicine, Ain Shams University
***Corresponding author**: Ayman Mohamed Ibrahim, **Mobile**: (+20)01000150157, **Email**: aymanibrahim_9@hotmail.com

ABSTRACT

Background: Tetralogy of Fallot (TOF), the second most prevalent kind of complicated congenital heart disease (CHD), accounts for 7-10% of CHD and affects 0.5/1000 live births. After surgical care, cardiac magnetic resonance imaging (MRI) may be used to assess the right ventricle in TOF. The aim of the current study is to evaluate the role of cardiac MRI in functional and structural assessment of the right ventricle in TOF patients after surgical management.

Patients and methods: The study was conducted on 30 patients of variable age groups that were collected from our institute, who were referred to the radio diagnosis department after TOF operations and underwent cardiac MRI. Full structural and functional assessment of the right ventricle could be done using various MRI pulse sequences as well as the late gadolinium enhancement protocol.

Results: Of the included 30 patients, 26 (86.6%) showed right ventricular dilatation. Right ventricular end diastolic volume index: Left ventricular end diastolic volume index (RVEDVI: LVEDVI) ratio was 1.84:1. Four patients had right atrium dilatation. Of the 30 participants, 8 (26.6%) had RV systolic dysfunction with mean ejection fraction (EF) was 51.83% (SD 9.39). Out of 30 TOF cases, 29 (96.6%) had main pulmonary artery (MPA) regurgitation, and 18 (60%) had right ventricular outflow tract obstruction (RVOTO).

Conclusions: MRI is an extremely useful imaging method for the functional and structural assessment of the right ventricle after surgical repair of TOF.

Keywords: Cardiac MRI, Right ventricle, Repaired fallot tetralogy.

INTRODUCTION

Tetralogy of Fallot (TOF), the second most prevalent kind of complicated congenital heart disease (CHD), accounts for 7-10% of CHD, occurring in 0.5/1000 live births. The four components of TOF are (a) sub-pulmonary obstruction leading to (b) right ventricle (RV) hypertrophy, (c) malaligned ventricular septal defect (VSD) leading to (d) apparent overriding of the aorta over both ventricles. TOF is caused by anterior deviation of the infundibular septum during embryogenesis which separates the outflows of the two ventricles [(1)].

Primary repair, or a palliative temporary procedure during the neonatal period that uses a shunt (3.5 to 5mm prosthetic tube) between a large artery that branches off from the aorta (brachiocephalic or subclavian) and the ipsilateral pulmonary artery usually via thoracotomy, typically a modified Blalock-Taussig (mBT) shunt—has been used to increase pulmonary flow, reduce hypoxemia [(2)].

Primary intracardiac repair entails widening of the RVOTO. If the pulmonary annulus is hypoplastic, a longitudinal incision is made across the major pulmonary artery (PA), the pulmonary annulus, and the RV infundibulum, and a transannular patch is used to rebuild it. A sub-valvular muscle excision is performed in patients with a large enough pulmonary annulus. In situations of pulmonary atresia, a valved RV-PA conduit is implanted in addition to RV muscle repair and VSD closure [(3)].

The majority of patients who undergo transannular patch repair of RVOTO experience the postoperative complication known as pulmonary regurge (PR), which compromises the integrity of the pulmonary valve. Tricuspid regurgitation (TR) and RV dysfunction may develop as a result of the volume overload caused by PR, which also causes increasing RV dilatation [(4)].

Following TOF repair, residual or recurrent pulmonary stenosis is frequently observed. It ranges from distal branch pulmonary artery stenosis to proximal RV outflow tract occlusion. The development of pulmonary stenosis is either a complication of the surgical procedure brought on by excessive internal endothelial proliferation or a kink resulting from patient growth [(5)].

Trans-annular patch repair that relieves RVOTO is frequently followed by RVOT fibrosis and aneurysmal dilatation. RV-PA conduit obstruction and palliative shunt complications such leakage and thrombosis are additional post-operative side effects [(5)].

In addition to assessing ventricular size and function quantitatively, cardiac magnetic resonance imaging (MRI) also assesses pulmonary and aortic size and flow. It can be used to evaluate the volume and proportion of pulmonary regurgitation as well as pulmonary outflow blockage [(6)].

With the late gadolinium enhancement (LGE) technique, pictures are taken 10 minutes after gadolinium contrast material has been administered and has accumulated in a tissue with increased extracellular space, such as a fibrotic ventricular segment. The seven segments RV LGE grading protocol is a scoring system, where the right ventricle is divided into 7 segments, including 2 surgically manipulated segments (VSD patch region and the anterior wall of RVOT), and 5 remote LGE segments: anterior wall of RV, inferior

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wall of RV, RV surface of septum, trabecular bands and RV insertion points [7].

The aim of the current study is to evaluate the role of cardiac MRI in functional and structural assessment of the right ventricle in TOF patients after surgical management.

PATIENTS AND METHODS

This study was conducted on 30 patients of variable age groups that were collected from Ain Shams University Hospitals, who were referred to the radio-diagnosis department for follow up by protocol-based MRI after TOF operations as VSD closure and pulmonary out-flow tract widening interventions. Such interventions include trans-annular patch (in hypoplastic pulmonary annulus), pulmonary balloon vulvoplasty (in adequate size pulmonary annulus) and valved PA-RV conduit (in pulmonary atresia).

Inclusion Criteria: Any patient with repaired TOF, with no age or sex predilection, who were presented for MRI examination in the last year.

Exclusion Criteria: Patients suffering from claustrophobia, those with known contraindication for MRI examination, e.g., pacemakers and aneurysmal clips. Patients with elevated kidney functions or those who have contrast allergy are also excluded.

Study Tools: Full clinical history was fulfilled for all patients. All patients will undergo MRI examination with the possibility of intravenous (IV) injection of contrast.

Study Procedure and Methods:

Machine used: MRI examination is done using a 1.5-T unit machine (Philips HealthCare, Best, the Netherlands), a sensitive cardiac coil will be used.Contrast used: MRI contrast agent Gadolinium "gadolinium diethylene triamine penta-acetic acid (D.T.P.A)" IV injection. MRI contrast was not recommended for patients with previous allergic reaction, or severe kidney disease.

Initially a localizer scan, electrocardiogram (ECG)-gated steady-state free precession (SSFP) has been performed in transaxial, sagittal and coronal orientation. Different views are taken, including left 2-chamber (long axis) view, short axis view, 4-chamber (horizontal) view, short axis stack views, left 3-chamber vertical view, right 2-chamber view, right and left ventricular outflow tract views, main, right and left pulmonary artery views.

Bright-blood gradient echo-cine images: ECG-triggered breath-hold SSFP images were performed in short axis cine and axial cine planes. Images are taken through the whole heart, in addition to Cine 3-chamber, Cine 2-chamber for right and left sides, Cine pulmonary sagittal, Cine pulmonary coronal, Cine RVOT and left ventricular outflow tract (LVOT) cross, Cine right postro-anterior (RPA) sagittal, Cine left postro-anterior (LPA) sagittal.

Imaging parameters: echo time 1.7ms, repetition time 3.3ms, flip angle 60°, field of view 260mm; matrix 160 × 160 reconstructed to 256 × 256, voxel size 1.6 × 1.8 × 6-8mm reconstructed to 1.0 × 1.0 × 6-8mm, 30 reconstructed images per cardiac cycle.

Volumetric measurements are conducted: Using short-axis plane pictures, end diastolic volume (EDV) and end systolic volumes (ESV) are computed for both ventricles by manually drawing the endocardial contours of the right and left ventricles on the end-diastolic and end-systolic frames **(Figure 1)**. After determining the patient's body height and weight, end diastolic volume index (EDVI) and end systolic volume index (ESVI) can be calculated. The volumes of blood in the RV and LV at end systole and end diastole filling are indexed for body surface area (ml/m2). The evaluation of Phillips workstations could be used for this.

The stroke volume, cardiac output, and ejection fraction can be calculated as follows: end-diastolic volume − end-systolic volume = stroke volume, stroke volume × heart rate = cardiac output, and stroke volume ÷ end-diastolic volume = ejection fraction.

Right ventricular dilatation: is considered when the Right Ventricular End Diastolic Volume Index (RVEDVI) is more than 150 ml/m2 or End Systolic Volume Index (ESVI) more than 80 ml/m2 and in comparison with LVEDVI if the ratio RVEDVI: LVEDVI is more than 1.

Ventricular function: is assessed via calculation of ejection fraction for both left ventricle (LV) (N=>55%) and RV (N=>47%).

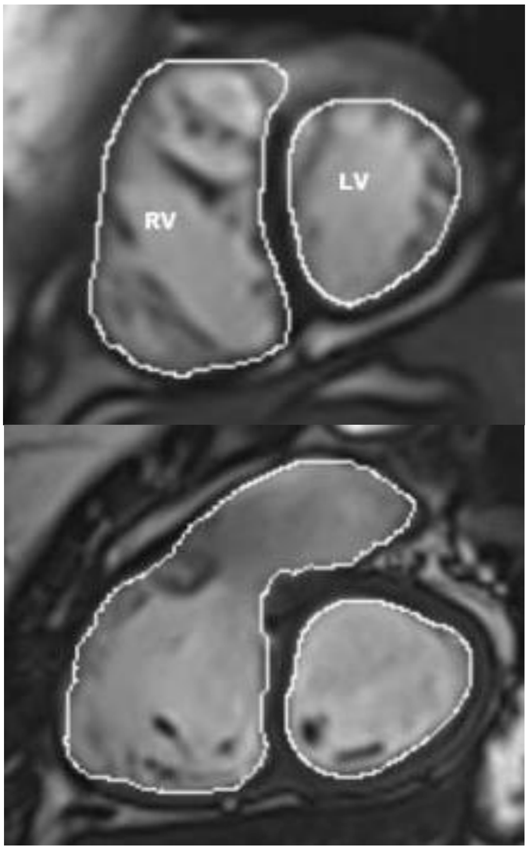

Figure (1): Cardiac MRI endocardial tracing for ventricular volumetric measurements.

Ventricular septal flattening could be detected with cine short-axis images where the interventricular septum (IVS) should be curved with concavity towards the RV. If the IVS is flattened or with D-shaped LV in systole, this refers to RV pressure overload. If the IVS is flattened during diastole, this refers to RV volume overload.

Ventricular septal flattening could be detected with cine short-axis images where septum should be curved with concavity towards RV, if flattening of IVS with D-shaped LV in systole means RV pressure overload, if flattening of IVS during diastole means RV volume overload **(Figure 2).**

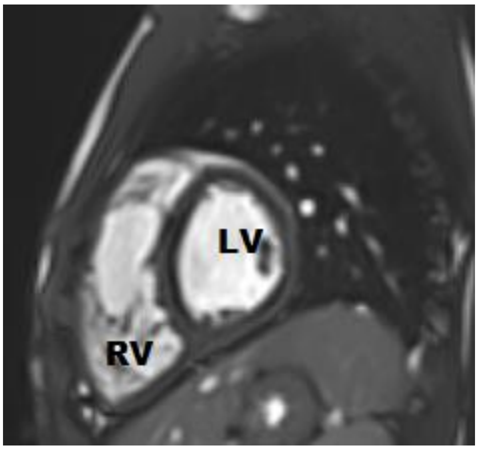

Figure (2): Cardiac MRI short axis view for evaluation of the interventricular septal flattening.

- **Phase contrast/velocity studies:** obtained with ECG-triggered free-breathing for quantification of flow, regurgitation and stenosis of aorta and pulmonary arteries by using a through-plane (TP) and in-plane (IP) phase contrast measurement.
- Imaging parameters: echo time 3.7 msec , repetition time 5.9 msec, flip angle 15°, field of view 300 mm, matrix 192 × 192, voxel size 1.56 × 1.56 × 6.0 mm reconstructed to 1.17 × 1.17 × 6.0 mm, 40 reconstructed images per cardiac cycle.
- **Phase contrast study for main pulmonary artery (MPA)** is prescribed from RVOT where the plane is aligned perpendicular to the pulmonary artery (PA) 1 cm above the valve **(Figure 3).**

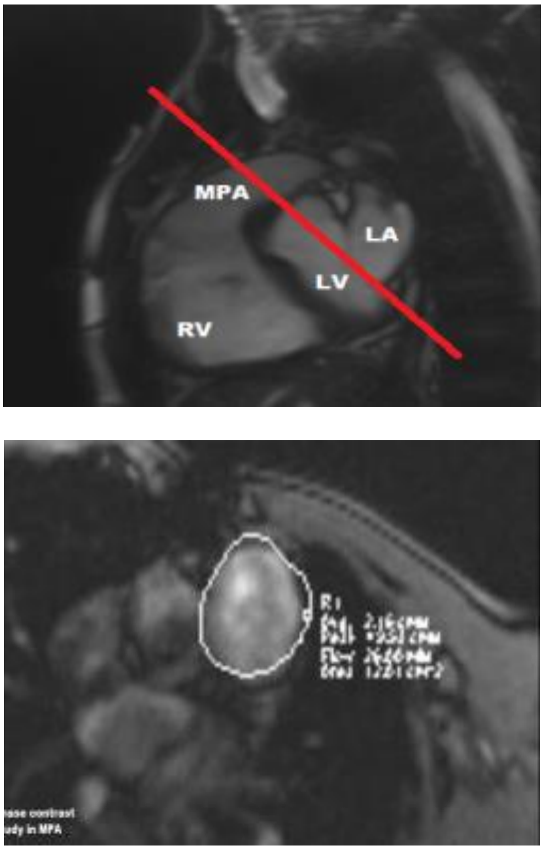

Figure (3): Cardiac MRI RVOT view shows pulmonary phase contrast study.

- **Phase contrast/flow study** is done by manually outlining a region of interest around the main pulmonary artery on the phase and magnitude images **(Fig. 4).**The images were analyzed with the Phillips workstation, where forward blood flow is depicted by high signal and backward blood flow by low signal. Backward flow is considered the regurgitation fraction of blood through pulmonary valve. The net pulmonary blood flow through the main pulmonary artery is calculated by subtracting backward amount from forward amount. a Flow-versus-time curve can be obtained for an average cardiac cycle to estimate possible regurge fraction **(Fig 5).** Similar phase contrast-studies are done for the right and left pulmonary arteries.

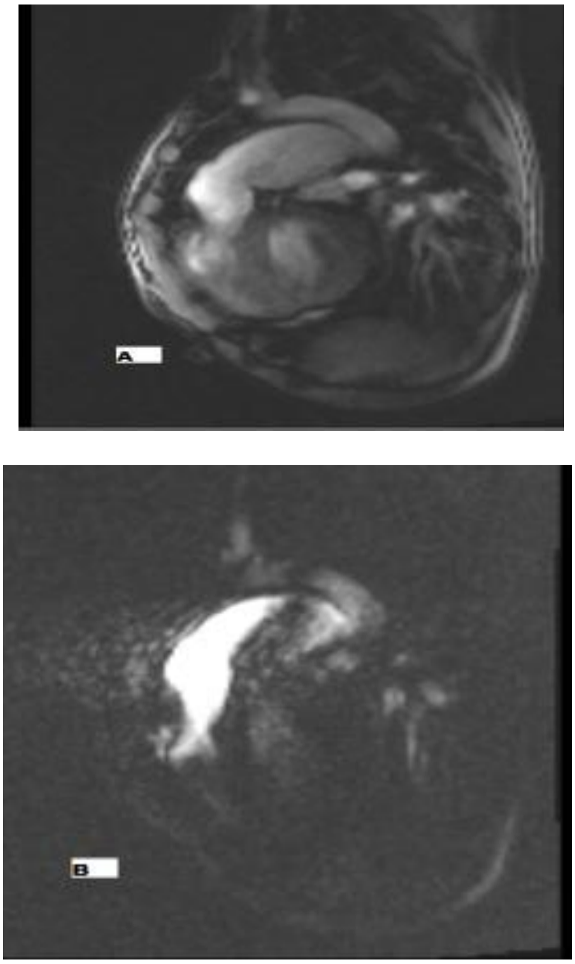

Figure (4): Cardiac MRI phase contrast tracing for MPA (A) MPA phase image, (B) MPA magnitude image.

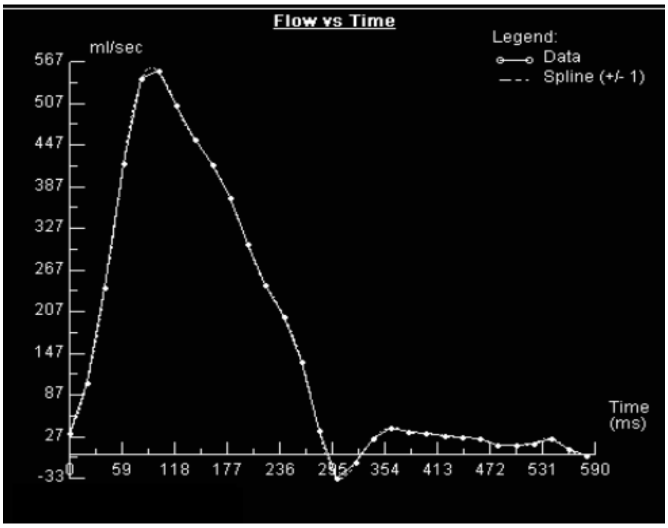

Figure (5): Flow versus time curve for estimation of MPA regurgitation fraction.

- **Estimation of tricuspid regurge (TR):** the regurge fraction is calculated from the Phillips workstation by subtracting the amount of forward blood flow (FF) to the MPA from the right ventricular stroke volume (SV), divided by the right ventricular stroke volume as the following equation (SV-FF/SV) then we detect the degree of tricuspid regurge as (mild=<20%), (moderate= 20-40%)&(severe=>40%).
- **Calculation of possible post-operative residual shunting:** by comparing quantitative pulmonary (QP) net blood flow to quantitative systemic (QS) aortic net blood flow (QP: QS), if pulmonary net blood flow is higher this means residual left to right side shunt.
- **Phase contrast/velocity study for MPA:** is done by performing images in a plane parallel to the direction of blood flow (IP) and through plane perpendicular to the direction of blood flow (TP) in the RVOT **(Figure 6).** If aliasing of the blood signal occurs, this means there is a stenotic area with higher velocity than the encoding velocity setting. If detected, the velocity setting is increased, until aliasing disappears. This represents the maximum-velocity jet (V) distal to the stenosis. The pressure gradient (pr) is then estimated through the stenosis using such equation. ($pr = 4(v^2)$).The velocity encoding setting used for Pulmonary IP is 150cm/sec, pulmonary TP is 150cm/sec, RPA TP is 150 cm/sec, LPA TP is 150cm/sec and aortic flow TP 200 cm/sec.

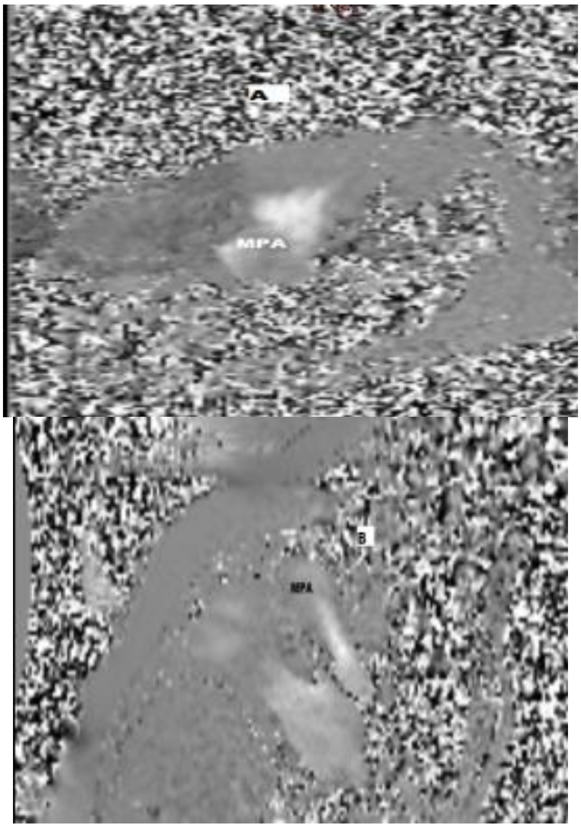

Figure (6): Cardiac MRI phase velocity study through MPA, (A) TP study for MPA, (B) IP study for MPA.

- **Late gadolinium enhancement (LGE) sequences**: ECG-triggered, breath-hold inversion-recovery (TI 175-275) LGE images were performed 10-20min after IV contrast administration in multiple planes (4-chamber, LV 2-chamber, RV 2-chamber, 3-chamber, LVOT and RVOT views).The injection protocol is a total dose of 0.1–0.2 mmol/kg that is administered with injection rate of 3–7 ml/s, followed by at least 30 ml saline flush (5–7 ml/s).

- **RV LGE grading protocol is used with seven RV segments (Fig. 7):** Surgically manipulated area at ventricular septal defect (VSD) patch region, surgically manipulated area at the anterior wall of RV outflow tract, anterior wall of RV apart from the RVOT surgically manipulated area, RV surface of septum apart from the VSD patch region, inferior wall of the RV, Trabecular bands and RV insertion points. Late enhancement images are visually assessed and each segment is graded according to the linear extent of enhanced myocardium. Total scoring is done from 0 to 20 points. The first 5 areas scoring were done as follows: No enhancement: 0 point. Enhancement less than 2 cm: 1 point. Enhancement between 2 & 3 cm: 2 points and enhancement more than 3 cm: 3 points. RV trabeculations were scored as: No enhancement: 0 point. Enhancement of one trabeculation: 1 point. Enhancement of 2-4 trabeculations: 2 points and enhancement of more than 4 trabeculations: 3 points. RV ventricular insertion region scored as: No enhancement: 0 point. Enhancement: 1 point.

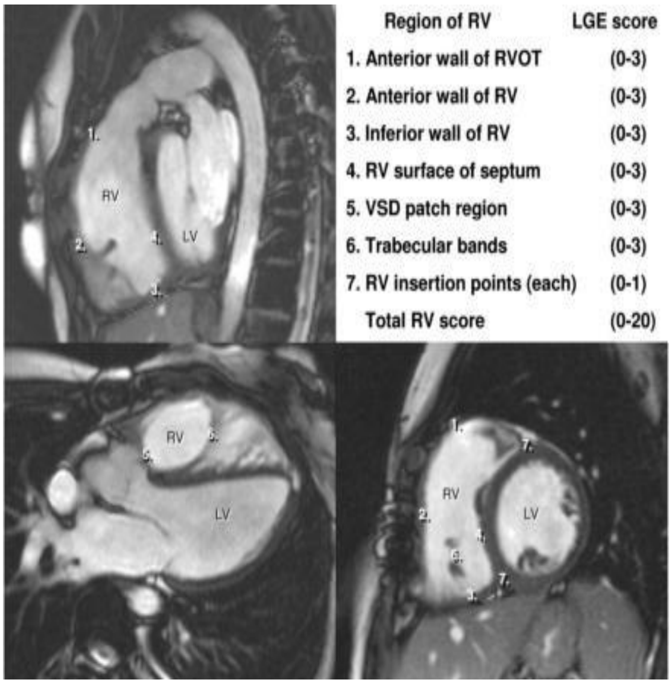

Figure (7): Seven segments late gadolinium enhancement grading.

- The findings were described commenting on: ventricular size and function, right atrial size, phase contrast flow assessment findings, phase velocity study findings, evidence of ventricular septal flattening, evidence of residual post-operative shunting, late gadolinium enhancement sequence and grading data, associated cardiac anomalies, associated extra-cardiac anomalies as well as findings related to the previous surgeries. The findings on MRI were correlated together.

Ethical consent:

An approval of the study was obtained from Ain Shams University Academic and Ethical Committee (FMASU MS 414/2021). Guardians of the patients signed an informed written consent for acceptance of participation in the study. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Statistical analysis

Data collected throughout history, basic clinical examination, laboratory investigations and outcome measures coded, entered and analyzed using Microsoft Excel software. Data were then imported into Statistical Package for Social Sciences (SPSS version 20.0) software for analysis. Qualitative variables were presented in the form of frequencies and percentages, quantitative variables were presented in the form of Means, standard deviations, medians, ranges and percentages were calculated.

RESULTS

This diagnostic study was carried out on 30 patients with repaired TOF that are admitted to the radiodiagnosis Department at Ain Shams University Hospitals.

The age of patients ranged from 4 to 64 years with mean age was 21.20 (SD 13.59) years. Regarding gender, 18 (60%) patients were males while 12 (40%) patients were female with male to female ratio was 1.5: 1 (Table 1).

Table (1): Distribution of socio-demographic characteristics among the studied patients.

Parameters		Studied patients (n=30)	
		N	%
Age (years)	Mean ± SD	21.20 ± 13.59	
	Median	19.0	
	Range	4.0- 64.0	
Gender	Male	18	60.0%
	Female	12	40.0%

SD: standard deviation.

Table 2 shows nearly half patients (46.7%) had mild dilatation of the right ventricle, four patients had marked dilatation of the RV, eight patients had moderate RV dilatation, four patients did not have any RV dilatation with the mean of RVEDVI was 168.70 (SD 41.24) ml/m2. The mean RVEDVI: LVEDVI ratio was 1.84 (SD0.45). Four patients had right atrium dilatation with the remaining patients did not have RA dilatation.

Table (2): Distribution of right atrial & ventricular parametric findings.

Parameters		Studied patients (n=30)	
		N	%
Right ventricle			
RT ventricle volume	**Not dilated**	4	13.3%
	Mild dilated	14	46.7%
	Moderate dilated	8	26.7%
	Marked dilated	4	13.3%
RVEDVI (ml/m^2)	**Mean± SD**	168.70± 41.24	
	Median	171.0	
	Range	89.0- 353.0	
RVEDVI: LVEDVI	**Mean ± SD**	1.84 ± 0.45	
	Median	1.85	
	Range	0.60- 2.80	
Right atrium			
Associated Right atriumdilatation	**Not dilated**	26	86.7%
	Dilated	4	13.3%

Table 3 shows that most patients (73.3%) had good RV systolic function, and 8 patients (26.7%) had poor RV systolic function with the mean EF was 51.83% (SD 9.39).

Table 3: Distribution of right ventricle systolic function in the studied patients.

Parameters		Studied patients (n=30)	
		N	%
RV systolic function			
RV systolic function	**Good**	22	73.3%
	Poor	8	26.7%
EF (%)	**Mean ± SD**	51.83 ± 9.39	
	Median	53	
	Range	27 - 66	

Table (4) shows that 4 patients had mild MPA regurge, 9 patients had severe MPA regurge, 16 patients (53.3%) had moderate MPA regurgitation, and 1 patient had no MPA regurge with mean ± SD was 35.0± 7.62. 8 patients (26.7%) had mild LPA regurgitation, 7 patients had moderate LPA regurge, 3 patients had severe LPA regurge and 12 patients had no LPA regurge with mean ± SD was 24.56± 5.82. Nine patients (30%) had mild RPA regurgitation, 7 patients had moderate RPA regurge, 14 patients had no RPA regurge with mean ± SD was 19.44± 4.71.

12 patients (40%) had mild tricuspid regurgitation, 11 patients had moderate tricuspid regurge and 4 patients had severe tricuspid regurge with mean ± SD was 24.70± 5.73.

Table (4): Distribution of pulmonary & tricuspid regurgitation status in the studied patients:

Parameters		Studied patients (n=30)	
		N	%
MPA regurgitation	**No**	1	3.3%
	Mild	4	13.3%
	Moderate	16	53.3%
	Severe	9	30.0%
	Mean± SD	35.0 ± 7.62	
	Median	36.0	
	Range	5.0- 62.0	
LPA regurgitation	**No**	12	40.0%
	Mild	8	26.7%
	Moderate	7	23.3%
	Severe	3	10.0%
	Mean± SD	24.56 ± 5.82	
	Median	22.50	
	Range	1.0- 50.0	
RPA regurgitation	**No**	14	46.7%
	Mild	9	30.0%
	Moderate	7	23.3%
	Severe	0	0.0%
	Mean± SD	19.44 ± 4.71	
	Median	17.50	
	Range	4.0- 37.0	
Tricuspid regurgitation	**No**	3	10.0%
	Mild	12	40.0%
	Moderate	11	36.7%
	Severe	4	13.3%
	Mean± SD	24.70 ± 5.73	
	Median	23.0	
	Range	6.0- 79.0	

Table 5 shows that 12 patients (40%) had moderate MPA stenosis, 4 patients (13.3%) had severe MPA stenosis and 2 patients (6.7%) had mild MPA stenosis with mean pressure gradient was 33.06 (SD 8.12) mm/Hg. Five patients (16.7%) had moderate LPA stenosis, 2 patients (6.7%) had severe LPA stenosis and 2 patients (6.7%) had mild LPA stenosis with mean pressure gradient was 29.56 (SD 7.11) mm/Hg.

Six patients (20%) had moderate RPA stenosis, 2 patients (6.7%) had severe RPA stenosis and 2 patients (6.7%) had mild RPA stenosis with mean pressure gradient was 29.33 (SD 7.01) mm/Hg.

Table (5): Distribution of pulmonary stenosis in the studied patients:

Parameters		Studied patients (n=30)	
		N	%
MPA stenosis	No	12	40.0%
	Mild stenosis	2	6.7%
	Moderate stenosis	12	40.0%
	Severe stenosis	4	13.3%
Pressure gradient (mm/Hg)	Mean± SD	33.06 ± 8.12	
	Median	25.0	
	Range	16.0- 64.0	
LPA stenosis	No	21	70.0%
	Mild stenosis	2	6.7%
	Moderate stenosis	5	16.7%
	Severe stenosis	2	6.7%
Pressure gradient (mm/Hg)	Mean± SD	29.56 ± 7.11	
	Median	25.0	
	Range	16.0- 49.0	
RPA stenosis	No	20	66.7%
	Mild stenosis	2	6.7%
	Moderate stenosis	6	20.0%
	Severe stenosis	2	6.7%
Pressure gradient (mm/Hg)	Mean± SD	29.33 ± 7.01	
	Median	25.0	
	Range	16.0- 49.0	

Table 6 shows that 11 (36.7%) patients had residual shunting, with mean QP: QS was 1.15 (SD 0.26).

Table (6): Distribution of residual shunting in the studied patients.

Parameters		Studied patients (n=30)	
		N	%
Residual shunting	No	19	63.3%
	Yes	11	36.7%
QP:QS	Mean ± SD	1.15 ± 0.26	
	Median	1.20	
	Range	0.80- 1.90	

Table 7 shows that 25 patients (83.3%) had RVOT enhancement and 18 patients (60%) had VSD patch enhancement, 6 patients (20%) had upper RV insertion area, 3 patients (10%) had RV surface of the septum. The mean LGE RV grading score was 4.53 (SD 1.11).

Table (7): Distribution of Late gadolinium enhancement (LGE) grading protocol of right ventricle in the studied patients.

Parameters		Studied patients (n=30)	
		N	%
LGE	VSD patch region	18	60.0%
	RVOT enhancement	25	83.3%
	RV surface of the septum except for VSD patch region	3	10.0%
	Anterior wall of RV except for RVOT patch region		
	upper RV insertion area	6	20.0%
	RV trabecular bands		0
	RV inferior wall		0
LGE RV grading score	Mean ± SD	4.53 ± 1.11	
	Median	4.0	
	Range	2.0- 9.0	

ILLUSTRATIVE CASE

Female patient 34 years old, with history of surgically repaired TOF, complaining of fatigue and lack of exercise tolerance, presented to MRI scan for follow-up.

MRI findings: revealed mildly dilated right ventricle **(Fig 8, A)**, with RVEDVI measuring 178 ml/m2, RVESVI measuring 87ml/m2 and in comparison with the left ventricle using (RVEDV: LVEDV ratio = 1.5:1).Good right ventricular systolic function is detected, with ejection fraction 51% as calculated from the volumetric measurements. Pulmonary bifurcation moderate stenosis dephasing jet **(Fig. 8, B)**: aliasing is noted at 1.5 m/s. maximum velocity detected is 2.5m/s, estimated pressure gradient is 25 mmHg. Pulmonary regurge fraction: as calculated from the flow versus time curve **(Fig. 9, A)**.

Moderate regurge is noted at the main pulmonary artery as well as left pulmonary arteries **(Fig. 9, B)**, with regurge fraction 37%.Tricuspid regurge fraction: It is also calculated and revealed moderate regurge, with regurge fraction 31%.Septal flattening **(Fig. 10,A)**: is noted during diastole denoting volume overload. RVOT aneurysm: is noted **(Fig. 10,B).**RVOT enhancement **(Fig. 11)**: is noted at the site of the patch, as well as RV upper insertion point. Right ventricular LGE grading score: RVOT enhancement >3cm in length = 3 points, upper RV insertion point = 1 point, total scoring is 4/20.

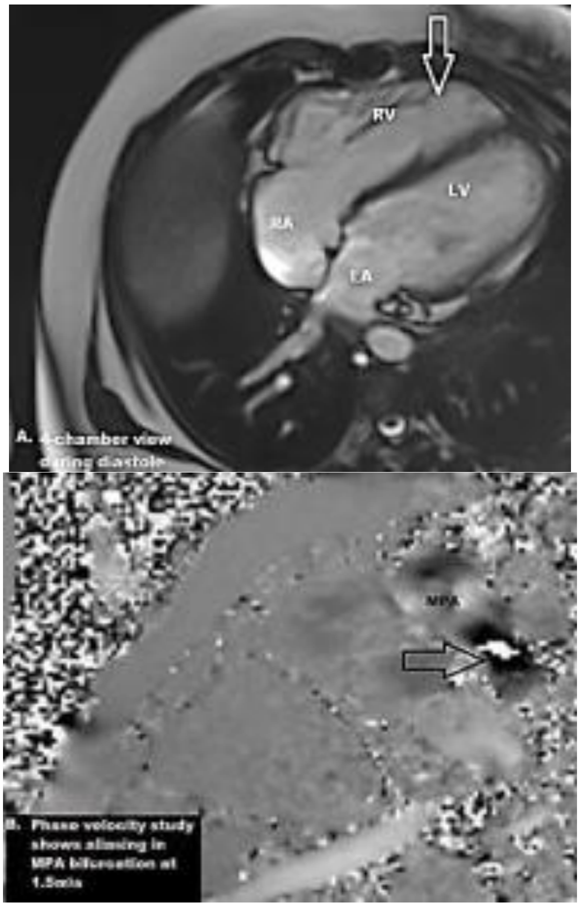

Figure (8): MRI study, (A) axial 4-chamber view shows RV dilatation (arrow), (B) phase velocity sequence for MPA IP shows aliasing at 1.5m/s (arrow) denoting MPA stenosis.

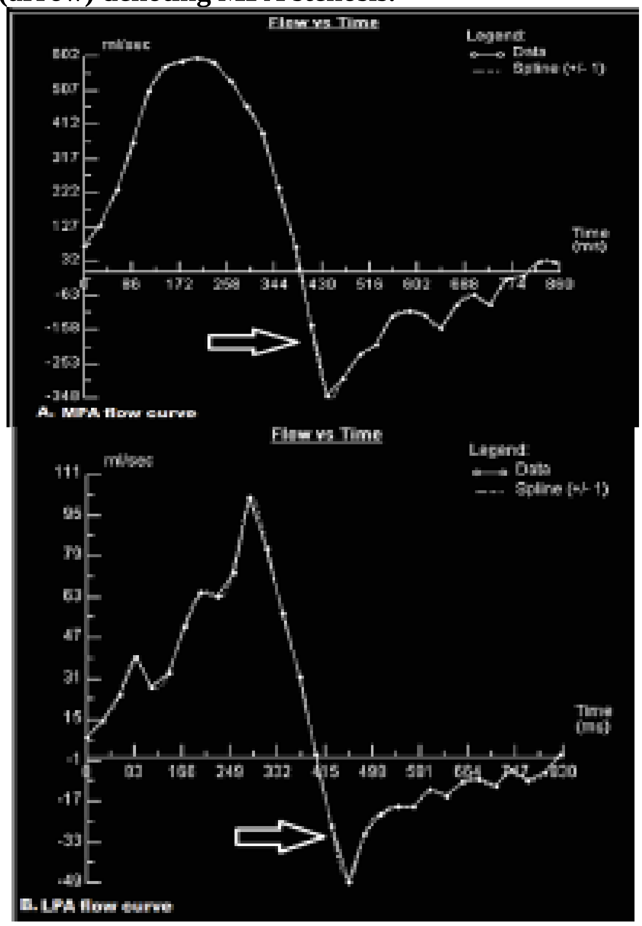

Figure (9): Flow vs. time curve obtained from MRI phase contrast study, (A) shows MPA regurge (arrow), (B) shows LPA regurge (arrow).

Figure (10): MRI study (A) short axis view of both ventricles shows septal flattening during diastole (arrow), (B) right ventricular 3-chamber view shows RVOT aneurysm (arrow).

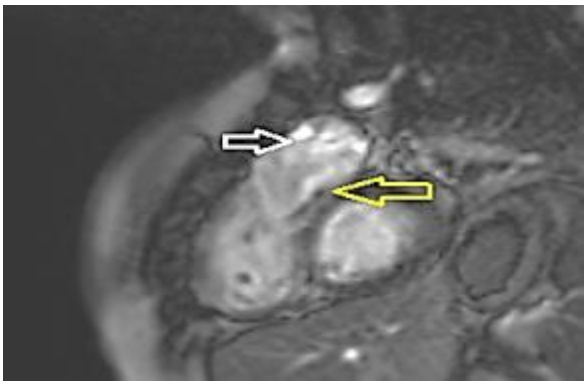

Figure (11): MRI RVOT view LGE sequence shows RVOT enhancement (white arrow) and RV upper insertion point enhancement (yellow arrow).

DISCUSSION

One percent of the population is thought to be affected by CHD, which almost always necessitates cardiovascular surgery in the first few months of life. The most prevalent cyanotic congenital cardiac abnormality is TOF, which affects around 1 in 3,500 newborns [8]. The four components of TOF are caused by the following: (a) sub-pulmonic blockage, which results in (b) RV hypertrophy; (c) misaligned ventricular septal defect, which results in (d), apparent aortic override over both ventricles [9].

The most often utilised TOF imaging modalities are computed tomography, angiocardiography, echocardiography, and cardiovascular magnetic resonance. These modalities provide the imaging data necessary for TOF diagnosis, therapy, and follow-up. It is crucial to understand the function and procedures of imaging to improve patient care and long-term prognosis [1]. Particularly for young newborns, the imaging modality of echocardiography is frequently used. The inadequate acoustic window and technological constraints in the measurement of the three-dimensional (3D) right ventricular shape are two drawbacks of this technology. Consequently, it is necessary to use additional imaging modalities. Nowadays, only to measure right ventricular pressure and carry out interventional treatments is cardiac catheterization performed [10].

Following that, MRI is now advised as the best method for monitoring patients with TOF for measuring the right and left ventricular volumes, mass, stroke volumes, and ejection fraction, evaluating the regional wall motion abnormalities, imaging the anatomy of the right ventricular outflow tract, pulmonary arteries, and aorta, measuring the atrioventricular and semilunar valve regurgitation, measuring the cardiac output and pulmonary-to-systemic flow ratio, and assessing regional wall motion abnormalities [3].

The aim of this study is to emphasize the role of cardiac MRI in functional and structural assessment of the right ventricle in patients with repaired TOF. This present diagnostic study was carried out on 30 patients with repaired TOF that are admitted at Radiology Department "Ain Shams University Hospitals". The age of patients ranged from 4 to 64 years with mean age was 21.20 (SD 13.59) years. Regarding gender, 18 (60%) patients were males while 12 (40%) patients were female with male to female ratio 1.5: 1.

The study of **Attalla *et al.*** [11] was conducted on fifty-six patients, in which all of them underwent surgical repair for TOF. In such study, the majority of the patients 54 had RV dilatation (representing 96.4%), with p value ≤ 0.05. **Similar to the present study** results that showed the majority of the patients 26 out of 30 representing (86.6%) showed right ventricular dilatation.

Regarding ventricular function, the study of **Attalla *et al.*** [11] showed more than one-third of the patients 20 out of 56 had RV dysfunction (representing 35.7%). **Regarding the present study** less than one-third of the patients 8 out of 30 representing (26.6%) had RV systolic dysfunction.

Regarding valvular regurgitation, the study of **Attalla *et al.*** [11] showed the majority of patients 54 out of 56 patients showed pulmonary regurgitation (representing 96.4%). **Similar to the present study**, where the majority of patients 29 out of 30 (96.6%) had MPA regurgitation.

As regards pulmonary stenosis, the study of **Attalla *et al.*** [11] showed more than half of the patients 36 out of 56 had pulmonary stenosis (representing 64.3%). **Similar to present study** results that showed 18 out of 30 (60%) had MPA stenosis, with mean pressure gradient 33.06 (SD 8.12) mm/Hg.

The study of **Attalla *et al.*** [11] showed less than one-third of patients 16 out of 56 are associated with branch stenosis LPA and/or RPA (representing 28.5% from total patients), in which 12 patients had LPA branch stenosis and 12 had RPA branch stenosis and 8 of them had both branch stenosis. **Unlike the present study** results that showed more than half of the patients 19 out of 30 are associated with branch pulmonary stenosis (representing 63.3% from total patients) as 9 patients had LPA stenosis (30%), and 10 patients (33.3%) had RPA stenosis.

Regarding residual VSD shunting, the study of **Attalla *et al.*** [11] results showed less than one-third of the patients had residual VSD (11 out of 56 patients representing 19.6%), **Regarding the present study results**, more than one-third of patients had residual VSD (11 out of 30 patients representing 36.7%) had residual shunting, with mean QP: QS was 1.15 (SD 0.26).

The study of **Saraya *et al.*** [12] which was conducted on 11 repaired tetralogy of TOF, showed more than one-third of patients with right ventricular failure, 4 out of 11 patients with EF less than 40% (representing 36.3% from total patients). **Regarding the present study** results 8 patients out of 30 representing (26.6%) had RV systolic dysfunction.

The study of **Saraya *et al.*** [12] showed less than one-third of patients with marked right ventricular dilatation (3 out of 11 patients representing 27.2%). **Unlike the present study** results that showed the majority of patients 26 out of 30 representing (86.6%) with right ventricular dilatation.

Regarding aneurysmal dilatation of the previously inserted RVOT patch, the study of **Saraya *et al.*** [12] showed more than half of the patients (7 out of 11 patients representing 63.6%) had aneurysmal dilatation with pulmonary regurgitation fraction more than 40%, an indication for re-intervention. **Unlike the present study results** that showed one-third of the patients (10 out of 30 patients representing 33.3%) had RVOT aneurysm. Mean MPA regurgitation was 35.0 (SD 7.62).

Along with our results, the cohort study of **Mercer-Rosa *et al.*** [13] showed the majority of the patients (85%) had moderate pulmonary regurgitation assessed qualitatively both by echocardiogram and cardiac MRI, the mean pulmonary regurgitation fraction by cardiac MRI was 34.2 (SD 16.6), In addition, most of the patients had qualitatively normal RV systolic shortening by echocardiogram and cardiac MRI (75%

and 90%, respectively), and the mean RVEF was 60.6 (SD 8.2%), suggesting that the majority had at least moderate PR with preserved RV shortening. **Similar to the present study** results that showed the majority of the patients 29 out of 30 (96.6%) had MPA regurgitation, and most of the patients (73.3%) had good RV systolic function, with the mean EF was 51.83 (SD 9.39).

Regarding the study of **Latus *et al.*** [(14)] who studied 54 patients with repaired TOF, half of the patients 27 out of 54 had RVOT obstruction and the same number were not having RVOT obstruction (50% for each). **Regarding the present study results**, more than half of the patients 18 out of 30 (representing 60%) had RVOT obstruction as the following: 12 patients (40%) had moderate MPA stenosis, 4 patients (13.3%) had severe MPA stenosis and 2 patients (6.7%) had mild MPA stenosis with mean pressure gradient was 33.06 (SD 8.12) mm/Hg.

The study of **Ylitalo *et al.*** [(15)] showed that all patients had RV LGE and in the majority of patients (39 of 40), it was seen outside the surgically affected areas. The amount of LGE correlated positively with the RV end-diastolic volume and rate of pulmonary regurgitation. The presence of LGE also depended on the post-operative follow-up time. **Similar to the present study results** that showed all patients had RV LG enhancement as the following: the majority of the patients 25 out of 30 patients (83.3%) had RVOT enhancement and 18 patients (60%) had basal IVS enhancement, 6 patients (20%) had upper RV insertion area enhancement, 3 patients (10%) had RV surface of the septum enhancement. The mean LGE RV grading score was 4.53 (SD 1.11).

In conclusion, MRI is an extremely useful imaging method for functional and structural assessment of the right ventricle after surgical repair of TOF patients with absence of ionizing radiation. We have been able to effectively identify post-procedural anatomical and functional features of the right ventricle, with accurate diagnosis of postoperative complications, with an impact on further management.

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