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Original article

Post Operative Evaluation of Fallot Tetralogy with Cardiac MRI Compared to Echocardiography

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Abstract:

Background: Tetralogy of Fallot (TOF) is the most common form of congenital cyanotic heart disease, occurring in approximately 4 to 5 per 100 000 live births, and represents 7%-10% of all congenital heart defects. This study aimed to evaluate the role of magnetic resonance imaging in assessment of post Fallot tetralogy surgical repair. **Methods:** This observational study included 30 patients with a repaired Tetralogy of Fallot and referred to diagnostic radiology department, at Benha University Hospitals. All patients were subjected to complete history taking, full clinical examination, 12 lead ECG, Echocardiography, and Cardiac MRI. **Results:** There was no statistically significant difference between ECHO and CMR regarding Main parameters (RVEDV (mL), RVESV (mL), RVEF and LVEF) P>0.05. There was no statistically significant difference between Echo and CMR regarding Postoperative Complications (Residual pulmonary artery stenosis, Pulmonary valve regorge, patch dilatation, right ventricular failure and tricuspid valve regurgitation) P>0.05. **Conclusion:** ECHO and CMR plays a crucial role in the assessment of post-surgical repair cases of Tetralogy of Fallot. By providing detailed anatomical and functional information.

Keywords: Fallot tetralogy, cardiac MRI, Echocardiography.

Introduction

Tetralogy of Fallot (TOF) is the most common form of congenital cyanotic heart disease, occurring in approximately 4 to 5 per 100 000 live births, and represents 7%-10% of all congenital heart defects. Although TOF is often thought of in terms of the tetrad of anomalies—pulmonary stenosis, ventricular septal defect (VSD), aorta overriding the ventricular septum, and right ventricular hypertrophy—it has been proposed that all of these features are the result of anterior malalignment of the infundibular septum with the muscular septum [(1)].

Today, most patients with TOF undergo complete repair in early infancy or early childhood with >90% survival. Children who have undergone palliative procedures often suffer from failure to thrive and erythrocytosis. Left untreated, patients with TOF have a 50%, 5–10-year survival, with mortality related to hypoxemia, endocarditis, brain abscesses, or cerebral vascular accident. Longevity beyond the fourth decade of life in unrepaired or palliated TOF is rare [(2)].

Surgical repair of Tetralogy of Fallot (rToF) has significantly improved long-term survival. However, this repair can result in pulmonary regurgitation (PR) and right ventricular (RV) volume overload, which has been associated with RV dilation, RV dysfunction, symptomatic heart failure, ventricular arrhythmia and sudden death [(3)].

Chronic pulmonary regurgitation (PR) is a common consequence of the surgical repair of Tetralogy of Fallot (rToF) and may result in right ventricular (RV) dilation and dysfunction, decreased exercise tolerance, ventricular arrhythmia, and sudden cardiac death. Pulmonary valve replacement (PVR) can improve functional class, decrease or normalize RV volume, and reduce the risk of arrhythmias [(4)].

However, PVR does not improve RV function once it is already impaired. Hence, the procedure should be performed before the development of overt RV failure. The threshold of RV dilatation linked to irreversible RV dysfunction can vary from patient to patient. Furthermore, the evidence on the impact of PVR on RV remodeling, QRS duration and arrhythmia risk is also conflicting [(5)].

On the other hand, the operative risk of PVR, and more importantly, the limited life expectancy of prosthetic valves (especially in younger patients), needs to be taken into consideration. At present, it is still not clear whether the benefits of PVR outweigh the complications associated with the operation and the limited life expectancy of the prosthetic valves currently used. In addition, there are no specific PVR criteria for the pediatric population (<18 years old) or for gender [(4)].

The radiologist plays an important role, interpreting many different imaging modalities, thus requiring full understanding of TOF anatomical features, surgical approaches and potential postoperative complications [(6)].

Echocardiography remains the main diagnostic tool for the evaluation of pre and postoperative CHD. Because of numerous technical limitations, transthoracic echocardiography can fail to assess adequately hemodynamic or anatomic information. Among noninvasive imaging modalities, computed tomography (CT) angiography allows to evaluate cardiovascular structures with an excellent spatial resolution in a very short examination time [(7)].

Magnetic resonance imaging (MRI) provides a better image quality of intracardiac anatomy, unlimited choice of imaging planes, accurate flow quantification and ventricular function evaluation without the use of ionizing radiation, and can thus be repeated without concerns for radiation toxicity [(7)].

The aim of this study is to evaluate the role of magnetic resonance imaging in assessment of post Fallot tetralogy surgical repair.

Patients and methods:

Patients:

This observational study included Thirty patients with repaired Tetralogy of Fallot who were referred to the Diagnostic Radiology Department at Benha University Hospitals, during the period from January 2022 to December 2022.

An informed written consent was obtained from the patients. Every patient received an explanation of the purpose of the study and had a secret code number. The study was done after being approved by the Research Ethics Committee, Faculty of Medicine, Benha University.

Inclusion criteria were patients of both sex who attended to the diagnostic radiology department at Benha University Hospitals, age range from 1-20 years old, patients diagnosed with Fallot tetralogy and those underwent surgical repair for assessment by cardiac MRI after repair.

The exclusion criteria were patients with significant confounding congenital heart defects as: common atrioventricular canal, heterotaxy syndrome, double outlet RV, major aorto-pulmonary collateral arteries, RV-to-pulmonary artery conduits, regurgitation of the aortic and/or the mitral valve, and those with contraindications to MRI as: patients with cochlear implant, cardiac pacemaker and foreign bodies.

Methods:

All studied cases were subjected to the following: Detailed history taking, including [Personal history; name, age, gender and body mass index (BMI), Present history: course of the disease and duration, past history of any medical condition or previous hospital admission, Surgical data concerning the timing and type of surgery. and Family history of similar condition]. **Full clinical examination: General examination including [**General comment on patient consciousness and mental state, Vital signs: pulse, blood pressure, capillary filling time, respiratory rate and temperature]. **Systemic examination including: [**cardiovascular System, respiratory System, central Nervous System and musculoskeletal System Assessment of Glasgow coma score, pupillary reaction, examination of motor system]. **Routine laboratory investigations [**complete blood count (Hb, WBCs, Platelets), random blood sugar, kidney function tests and liver function tests]. **Radiological investigations [**cardiac MRI, 12 lead ECG, and echocardiography].

All patients underwent cardiac MRI. MRI examinations were performed on a 1.5 T scanner (AERA 1.5 T scanner, Siemens, Erlangen, Germany), in accordance with previously published imaging protocols, to assess anatomy, cine steady-state free precession sequences for volume and function assessment and phase-contrast imaging to measure flow in the pulmonary valve, aortic valve, and in both pulmonary arteries.

All patients underwent 12 lead ECG. Performing a 12-lead electrocardiogram (ECG) was an important part of the cardiac evaluation of patients with repaired Tetralogy of Fallot. The procedure involved placing a series of electrodes on the patient's chest, arms, and legs to record the electrical activity of the heart. In addition, transthoracic echocardiography was performed by an experienced cardiologist, using a GE VIVID S70 ultrasound system. The examination included standard views such as parasternal long-axis, parasternal short-axis, apical four-chamber, and subcostal views.

The following parameters were assessed: cardiac chamber sizes, wall thickness, and function, presence and severity of any valvular stenosis or regurgitation, presence and severity of any residual ventricular septal defect, and assessment of the pulmonary artery pressure. (SPSS Inc., Chicago, Illinois, USA)

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Statistical analysis

Data collected was processed using IBM SPSS Statistics (Version 25.0). Statistical

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analyses were performed based on the nature of the data. The normality of data distribution was assessed using the Shapiro-Wilk test. Descriptive statistics such as mean and standard deviation (± SD) were used for numerical data, while frequency and percentage were used for non-numerical data. Analytical statistics included the student's t-test for comparing means, Mann-Whitney U test for non-parametric variables, and Chi-square test for examining the relationship between qualitative variables. Correlation analysis was conducted to assess the association between quantitative variables. The ROC curve was used to evaluate the sensitivity and specificity of diagnostic measures, with the optimal cut-off point maximizing the AUC value. An AUC value above 0.9 indicates high accuracy, 0.7-0.9 indicates moderate accuracy, 0.5-0.7 indicates low accuracy, and 0.5 suggests a chance result. Statistical significance was considered at a p-value < 0.05 with a 95% confidence interval.

Results:

The current study was carried out on 30 subjects with the history of surgical repair of tetralogy of Fallot. Their age ranged from 6 to 20 years old. Mean age was 13.13 years. Sixty percent of the studied subjects were males and 40% were females **Table 1**.

According to Echo parameters, RVEF mean level was 50.54%. RVEDV was 151.18±54.4 ml and RVESV mean was 70.87±19.36 ml. LVEF mean was 70.35%. Concerning postoperative complications diagnosed by Echo in the studied subjects, Residual pulmonary artery stenosis was in 3 (10%) of cases, Pulmonary valve regurge in 2 (7%) of cases while patch dilatation in one case (3%) also right ventricular failure has been reported in one case (3%) and tricuspid valve regurgitation had reported in one case (3%). Regarding CMR parameters, RVEF mean level was 51.32%. RV cardiac output mean level was 6.06 L/minute, RV stroke volume mean was 99.94%, RVEDV was 164.18 ml and RVESD mean was 75.87 ml. Pulmonary regurgitation fraction mean was 41.44, RV mass was 91.03 and LVEF mean was 69.25%. According to Postoperative complications diagnosed by CMR in the studied subjects, Residual pulmonary artery stenosis was in 5 (17%) of cases, Pulmonary valve regurge in 4 (13%) of cases while patch dilatation in 2 case (7%) also right ventricular failure has been reported in one case (3%) and tricuspid valve regurgitation had reported in one case (3%) **Table 2.**

There was no statistically significant difference between Echo and CMR regarding Main parameters (RVEDV (mL), RVESV (mL), RVEF and LVEF) P>0.05. There was no statistically significant difference between Echo and CMR regarding Postoperative Complications (Residual pulmonary artery stenosis, Pulmonary valve regurge, patch dilatation, right ventricular failure and tricuspid valve regurgitation) P>0.05 **Table 3**.

Table 1: Baseline criteria of the studied group

		Total subjects n=30		
		Age (years)		
	M±SD	13.13	±	4.08
	Range	6	-	20
Gender, n (%)		***n***		***(%)***
	Male	18		(60%)
	Female	12		(40%)

Table 2: Echo and Cardiac MRI parameters in the studied subjects

		Total subjects n=30	
		M±SD	***Range***
	Echo		
Main parameters	RVEDV (mL)	151.18±54.4	48.39-239.01
	RVESV (mL)	70.87±19.36	29.54-107.35
	RVEF	50.54±5.47	29.21-67.40
	LVEF (%)	70.35±7.82	58.54-81.21
		N	***%***
Postoperative complications	Residual pulmonary artery stenosis	3	10%
	Pulmonary valve regurge	2	7%
	patch dilatation	1	3%
	right ventricular failure	1	3%
	tricuspid valve regurgitation	1	3%
CMR			
Main parameters	RV cardiac output (L/min)	6.06±0.85	4.32-8.08
	RV stroke volume (mL)	99.94±33.55	40.69-163.55
	RVEDV (mL)	164.18±50.4	50.19-249.11
	RVESV (mL)	75.87±19.36	31.64-112.83
	Pulmonary regurgitant fraction (%)	41.66±4.44	29.65-49.36
	RV mass (g)	91.03±25.69	38.94-145.54
	RVEF	51.32±6.47	31.90-69.14
	LVEF (%)	69.25±6.82	55.54-84.76
		N	***%***
Postoperative complications	Residual pulmonary artery stenosis	5	17%
	Pulmonary valve regurge	4	13%
	patch dilatation	2	7%
	right ventricular failure	1	3%
	tricuspid valve regurgitation	1	3%

Table 3: Comparison between ECHO and CMR regarding main parameters and Postoperative Complications in the subjects studied

		Total subjects n=30		
		Echo	**CMR**	**P value**
Main parameters	RVEDV (mL)	151.18	164.18	0.91
	RVESV (mL)	70.87	75.87	0.87
	RVEF	50.54	51.32	0.90
	LVEF (%)	70.35	69.25	0.93
Postoperative Complications				
Residual pulmonary artery stenosis		3	5	0.98
Pulmonary valve regurge		2	4	
patch dilatation		1	2	
right ventricular failure		1	1	
tricuspid valve regurgitation		1	1	

Discussion:

This study was conducted on a cohort of 30 patients who had undergone surgical repair for Tetralogy of Fallot and were referred to the Diagnostic Radiology Department at Benha University Hospitals. Every patient underwent a comprehensive process that included obtaining a detailed medical history, conducting a thorough clinical examination, performing a 12-lead

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electrocardiogram (ECG), conducting an echocardiography, and obtaining a cardiac magnetic resonance imaging (MRI) scan.

The current study examined the demographic characteristics, specifically the age range, which spanned from 6 to 20 years old. The average age was 13.13 years. Of the subjects examined, 60% were male and 40% were female. Consistent with the current study, Ibrahim et al. (2022) conducted a study to assess the function and structure of the right ventricle in patients with tetralogy of Fallot (TOF) after surgical treatment using cardiac MRI. The researchers found that the average age of the participants was 21.20 years, with a standard deviation of 13.59 years. The age of the patients in the study varied widely, ranging from 4 to 64 years. In terms of gender distribution, there were 18 (60%) male patients and 12 (40%) female patients, resulting in a male-to-female ratio of 1.5:1 [(8)].

On the other hand, a separate study conducted by Babu-Narayan et al. (2012) sought to assess the lasting effects of cardiovascular magnetic resonance imaging on patients who had undergone surgical repair for Tetralogy of Fallot. The study comprised 93 adult patients, with an average age of 29.8 years, which exceeds the age of our patients [(9)].

The CMR diagnosis revealed postoperative complications in the subjects studied. Specifically, residual pulmonary artery stenosis was observed in 17% of cases, pulmonary valve regurgitation in 13% of cases, and patch dilatation in 7% of cases. Furthermore, there was a single case (3%) of right ventricular failure and another case (3%) of tricuspid valve regurgitation reported [(9)].

There was no statistically significant difference between ECHO and CMR in terms of the main parameters, including RVEDV (mL), RVESV (mL), RVEF, and LVEF ($p>0.05$). There was no statistically significant disparity observed between Echo and CMR in relation to the occurrence of postoperative complications, including residual pulmonary artery stenosis, pulmonary valve regurgitation, patch dilatation, right ventricular failure, and tricuspid valve regurgitation. The value is less than 0.05 [(9)].

The study found that the mean level of right ventricular ejection fraction (RVEF), as determined by ECHO parameters, was 50.54%. The right ventricular end-diastolic volume (RVEDV) was measured to be 151.18±54.4 ml, while the mean right ventricular end-systolic volume (RVESV) was found to be 70.87±19.36 ml. The mean left ventricular ejection fraction (LVEF) was 70.35% [(9)].

The study found that 10% of the cases had residual pulmonary artery stenosis, 7% had pulmonary valve regurgitation, and 3% had patch dilatation, as diagnosed by Echo for postoperative complications. Additionally, there was a reported incidence of right ventricular failure in one case (3%) and tricuspid valve regurgitation in another case (3%) [(9)].

Based on the CMR parameters, the mean level of right ventricular ejection fraction (RVEF) was 51.32%. The mean level of cardiac output in the right ventricle was 6.06 L/minute. The mean stroke volume in the right ventricle was 99.94%. The mean right ventricular end-diastolic volume (RVEDV) was 164.18 ml, and the mean right ventricular end-systolic volume (RVESD) was 75.87 ml. The mean pulmonary regurgitation fraction was 41.44, the right ventricular mass was 91.03, and the mean left ventricular ejection fraction was 69.25% [(9)].

The reported value exceeds the findings of Geva et al. (2004), who observed a mean RVEF of 44% in patients with repaired Tetralogy of Fallot. The mean level of cardiac output in the right ventricle was 6.06 L/minute. The mean stroke volume in the right ventricle was 99.94%. The mean right ventricular end-diastolic volume (RVEDV) was 164.18 ml, and the mean right ventricular end-systolic volume (RVESD) was 75.87 ml [(10)].

In a study conducted by Wald and colleagues (2009), the diagnostic accuracy of cardiac MRI in evaluating post-operative cardiac function in patients with tetralogy of Fallot was assessed. The researchers discovered that cardiac MRI exhibited a high level of sensitivity (96%) and specificity (90%) in identifying right ventricular dysfunction. Furthermore, they determined that cardiac MRI demonstrated superior diagnostic accuracy when compared to echocardiography [(11)].

Cardiac MRI not only has excellent diagnostic accuracy, but it can also offer important insights into cardiac anatomy and blood flow. This information can be particularly helpful in evaluating post-operative complications like pulmonary regurgitation and right ventricular dilation. In a study conducted by Li and colleagues (2020), cardiac MRI was employed to assess the effectiveness of pulmonary valve replacement in individuals who had undergone surgical repair for tetralogy of Fallot. Li X (2020) discovered that replacing the pulmonary valve led to notable enhancements in right ventricular volume, ejection fraction, and pulmonary regurgitation fraction [(12)].

According to a study conducted by Alghamdi et al. (2012), cardiac MRI is an effective tool for evaluating cases of surgical repair after Fallot tetralogy. According to Alghamdi et al. (2012), cardiac MRI is a reliable method for measuring RV volumes and function, as well as evaluating pulmonary regurgitation. This information is important for making decisions about potential interventions and for follow-up care [(13)].

A separate investigation conducted by van der Bom et al. (2013) proposed that cardiac magnetic resonance (CMR) measurements may not consistently provide an accurate representation of the clinical results in individuals who have undergone surgical repair for Tetralogy of Fallot. The study by van der Bom et al. (2013) found that RV mass, RVEDV, and RVESV did not have a significant association with clinical outcomes. However, factors such as age at repair, pulmonary valve regurgitation, and RV function measured by echocardiography were found to be more predictive of long-term outcomes [(14)].

The study has some limitations: It was a single-center study with a relatively small sample size and the results may differ elsewhere. The study only included patients who underwent surgical repair of tetralogy of Fallot, and therefore, the findings may not be applicable to patients with other types of congenital heart disease. The study only assessed cardiac function using CMR and did not include other measures such as exercise capacity or quality of life. The study did not assess the impact of postoperative complications on cardiac function.

Conclusion:

ECHO and CMR play a crucial role in the assessment of post-surgical repair cases of Tetralogy of Fallot. By providing detailed anatomical and functional information, it helps clinicians evaluate the success of the surgical repair, detect residual abnormalities, and guide further interventions. Its non-invasive nature and excellent imaging capabilities make it a valuable tool in the management of TOF patients, ensuring optimal long-term outcomes.

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Author contribution

The authors contributed equally to the study.

Conflicts of interest

No conflicts of interest

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