CARDIOLOGIE TUNISIENNE

ARTICLE ORIGINAL

Interest of echocardiography in the study of right ventricular function and quantification of pulmonary regurgitation in repaired Tetralogy of Fallot

Intérêt de l'échocardiographie dans l'étude de la fonction ventriculaire droite et la quantification de l'insuffisance pulmonaire dans la tétralogie de Fallot réparée

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Résumé

Introduction : Patients post-Tetralogy of Fallot (TOF) repair face increased risks of pulmonary regurgitation (PR) and right ventricular (RV) dysfunction, leading to long-term complications. Monitoring RV function and PR is crucial. While cardiac magnetic resonance imaging (MRI) is the gold standard for these assessments, echocardiography remains the accessible initial routine examination.

Aim: Our study aimed to compare RV function and PR as estimated by transthoracic echocardiography with those obtained by MRI to simplify post-TOF repair follow-up.

Methods: This was a comparative cross-sectional study conducted at the Military Hospital of Tunis. It was including 25 patients who had undergone TOF repair and had undergone cardiac MRI following an echocardiogram. RV function and PR parameters in echocardiography were compared to quantitative parameters obtained by MRI.

Results: We observed good overall concordance between echocardiographic measurements of RV function and quantitative MRI parameters, with high intraclass correlation coefficients (>0.9) and p<0.001. Only one echocardiographic parameter had a weak correlation with MRI (p=0.056). For the assessment of pulmonary valve regurgitation, alternative echocardiographic measurements were well correlated with PR fraction obtained by MRI with p values ≤0.01. Echocardiography had acceptable sensitivity and specificity in identifying significant PR when these measurements were performed separately. Combining echocardiographic parameters resulted in higher precision with a sensitivity of 100%.

Conclusions: Echocardiography effectively identified right ventricular dysfunction and/or pulmonary insufficiency compared to MRI. However, it did not provide the precise quantitative assessment observed with MRI

Mots-clés

Echocardiography, Magnetic resonance imaging, tetralogy of Fallot, pulmonary regurgitation, right ventricular function

Summary

Introduction: Les patients après réparation de la Tétralogie de Fallot (TOF) sont confrontés à des risques accrus d'insuffisance pulmonaire (IP) et de dysfonction ventriculaire droit (VD), entraînant des complications à long terme. La surveillance de la fonction VD et de l'IP est cruciale. Bien que l'IRM cardiaque soit la référence pour ces évaluations, l'échocardiographie reste l'examen de routine initial accessible.

Objectif : Notre étude visait à comparer les paramètres de la fonction VD et l'IP estimées par échocardiographie avec celles obtenues par IRM afin de simplifier le suivi post-réparation de la TOF.

Méthodes : Il s'agit d'une étude comparative transversale menée à l'Hôpital Militaire de Tunis. Elle a inclus 25 patients ayant subi une réparation de la TOF et ayant bénéficié d'une IRM cardiaque après l'échocardiographie. La fonction VD et les paramètres de l'IP à l'échocardiographie ont été comparés aux paramètres quantitatifs obtenus par IRM.

Résultats : Nous avons observé une bonne concordance globale entre les mesures échocardiographiques alternatives de la fonction VD et les paramètres quantitatifs de l'IRM, avec des coefficients de corrélation intraclasse élevés (>0,9) et p<0,001. Un seul paramètre échocardiographique présentait une faible corrélation avec l'IRM (p=0,056). Pour l'évaluation de la régurgitation de la valve pulmonaire, les mesures échocardiographiques étaient bien corrélées avec la fraction d'IP obtenue par IRM, avec des valeurs de p ≤ 0,01. L'échocardiographie avait une sensibilité et une spécificité acceptables pour l'identification de l'IP significative lorsque ces mesures étaient effectuées séparément. La combinaison des paramètres échocardiographiques a permis une plus grande précision avec une sensibilité de 100%.

Conclusions: L'échocardiographie a permis d'identifier efficacement la dysfonction ventriculaire droite et/ou l'insuffisance pulmonaire par rapport à l'IRM. Cependant, elle n'a pas fourni l'évaluation quantitative précise observée avec l'IRM.

Keywords

Échocardiographie, imagerie par résonance magnétique, Tétralogie de Fallot, insuffisance pulmonaire, fonction ventriculaire droite

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INTRODUCTION

Tetralogy of Fallot (TOF) is the most common cyanotic congenital heart disease (CHD), with an average incidence of 32.6 per 100,000 live births [1]. Advances in diagnostic and therapeutic means have improved the prognosis of TOF patients, with an immediate postoperative survival rate exceeding 98% [2], and approximately 90% at 30 years of age [3]. Patients who have undergone repair for Tetralogy of Fallot (TOF) are at an increased risk of developing pulmonary regurgitation (PR) and subsequent right ventricular (RV) dysfunction [4], leading to long-term complications [5,6]. Therefore, monitoring RV function and the fraction of pulmonary regurgitation (PR) is of great importance [7,8].

Echocardiography is commonly used for monitoring TOF patients due to its simplicity [9,10], although its assessment is limited by the complexity of cardiac geometry. Therefore, cardiac magnetic resonance imaging (MRI) has become the gold standard for accurately evaluating cardiac function and pulmonary regurgitation.

This study aims to compare the results of echocardiography and cardiac MRI in patients who have undergone TOF repair, with the goal of simplifying postoperative follow-up by determining the extent of concordance between these two imaging modalities.

METHODS

This was a comparative cross-sectional study that included patients who had undergone TOF repair. The study was conducted at the main military teaching hospital in Tunis over a 5-year period, from November 2016 to November 2021. It involved systematic echocardiography and cardiac MRI. Inclusion criteria comprised patients who had undergone curative surgery for TOF, with no prior pulmonary valve replacement, no absolute contraindications for MRI, and transthoracic echocardiography (TTE) preceding the MRI. Patients with poor-quality MRIs or TTEs due to cardiac arrhythmias, uninterpretable respiratory movements, or complex cyanotic heart diseases other than TOF were excluded. Epidemiological data, including gender, age, and the time interval between cardiac MRI and echocardiography, were collected from patient records.

Echocardiograms were performed using a VIVID E9W device (GENERAL ELECTRIC) in two-dimensional and Doppler modes. Images were obtained in the left lateral decubitus position, and various measurements and evaluations were performed to assess RV function and PR.

For RV systolic function, the Tricuspid Annular Plane Systolic Excursion (TAPSE) was used, with a TAPSE of less than 18 mm indicating functional impairment. Surface Fractional Shortening (FS) was calculated, with a normal value of 46 ± 7% [11]. Myocardial Tissue Doppler Imaging (TDI) was used to measure myocardial displacement velocities, with an S wave velocity in the RV (SRV) less than 10 cm/s being associated with right ventricular dysfunction [11].

A study of longitudinal myocardial deformation using Speckle tracking (2D strain) was conducted to measure longitudinal strain in the RV free wall from an apical 4C view. The normal value for RV free wall strain (RVFWS) was > 24% in absolute value. RV dysfunction was considered if this value was > -20% (or < 20% in absolute value).

PR was qualitatively assessed through visual Doppler mapping of the regurgitant jet in the short-axis view and classified as mild, moderate, or severe. This categorization allowed patients to be divided into three groups based on the severity of PR:

- Group 1 had mild PR (reflecting PRF<20% on MRI).
- Group 2 had moderate PR (reflecting PRF of 20-40% on MRI).
- Group 3 had severe PR (reflecting PRF>40% on MRI).

A semi-quantitative evaluation of PR was performed by measuring the jet/annulus ratio. The jet diameter was measured at the beginning of diastole using color Doppler while avoiding aliasing. The annulus diameter was measured on the same image using colorless 2D images. Subsequently, both diameters were used to calculate the jet/annulus ratio. A ratio > 1/3 indicated significant PR [14].

Pressure half-time (PHT) was also measured, with a PHT > 150 ms considered normal and a PHT < 100 ms suggesting significant regurgitation [9]. In cardiac MRI, indexed end-diastolic and end-systolic volumes to body surface area, and right ventricular ejection fraction (RVEF) were calculated from cine MRI sequences. RVEF < 45% was considered impaired. Pulmonary regurgitation fraction (PRF) was calculated from the phase-contrast sequence and a formula incorporating regurgitant and systolic ejection volumes. PRF > 20% was considered significant and classified as mild (<20%), moderate (20-40%), and severe (>40%).

Data was collected and analyzed using IBM SPSS Statistics version 26.0. Statistical tests were used to compare the values measured in echocardiography and MRI. A literature review was also conducted to support the study.

No ethical issues were encountered, and there were no conflicts of interest related to the study.

RESULTS

The epidemiological data of our study included a group of 25 patients, comprising 14 males and 11 females, with an average age of 23.8 ± 2.4 years, ranging from 4 to 45 years. The average time interval between the two imaging methods was 9 ± 1 days.

In the analysis of the correlation between echocardiographic measurements and cardiac MRI, we focused on the RV. The RV volumes measured in echocardiography and MRI were as follows: Indexed End-Diastolic Volume of the RV (RV-EDVi) in MRI = 129.8 ml/m², Indexed End-Systolic Volume of the RV (RV-ESVi) in MRI = 74.5 ml/m², End-Diastolic Volume of the RV (RV-EDVi) in echocardiography = 124 ml/m², End-Systolic Volume of the RV (RV-ESVi) in echocardiography = 69.2 ml/m². We observed a strong correlation between the indexed RV volumes in echocardiography and MRI, with intraclass correlation coefficients (ICC) of 0.96 for RV-EDVi and 0.99 for RV-ESVi (figure1).

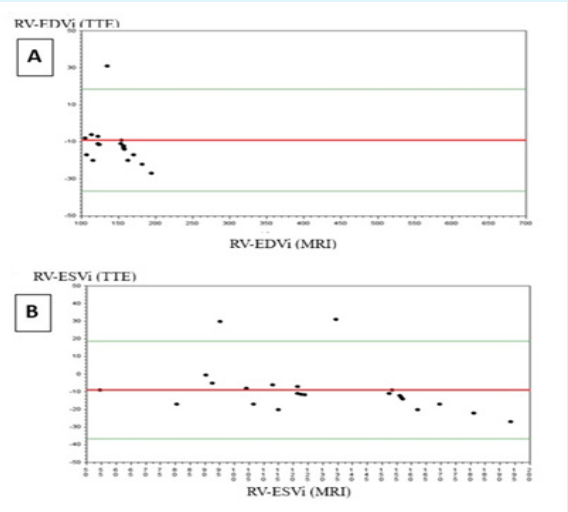

Figure 1. Bland-Altman plot of the correlation between echocardiographic RV-EDVi (A) and RV-ESVi (B) and those obtained in MRIires

However, we noted a slight underestimation of volumes in echocardiography compared to MRI, which amounted to 5 ml/m² for RV-EDVi and 5.3 ml/m² for RV-ESVi. The RVEF measured by MRI was 46.6%.

Regarding TAPSE, we found an average value of 18.2 ± 3.3 mm in MRI and 16.9 ± 3.3 mm in echocardiography, with a significant correlation (ICC = 0.75).

The average FS in echocardiography was 40.2%, with a significant correlation with RVEF measured by MRI (r = 0.66) (figure2).

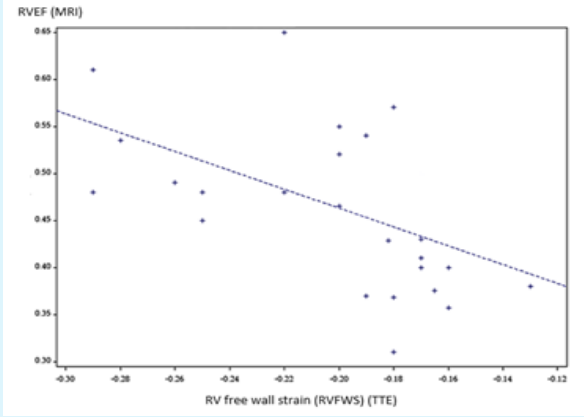

Figure 2. Bland-Altman graphic of the correlation between echocardiographic RVFWS and RVEF obtained in MRI.

In the analysis of TDI, the average value of SRV was 9.7 cm/s, showing good agreement with RVEF, with a significant correlation (r = 0.41). The sensitivity of TDI for an RVEF less than 45% was 70%, and the specificity was 80%.

As for the study of longitudinal myocardial deformation, the average value of RVFWS was -20.4%. An excellent correlation was observed between 2D strain in echocardiography and RVEF in MRI (CC r = -0.94). The sensitivity of 2D strain for an RVEF less than 45% was 100%, with a specificity of 73.3%.

The Table I summarizes the correlation between echocardiographic parameters and RVEF quantified by MRI.

Table 1. Summary table of the correlation between echocardiographic parameters and RVEF quantified by MRI

Echocardiography	p value	Sensibility (%)	Specificity (%)	PPV (%)	NPV (%)
TAPSE	0.056	50	64	40	73
SFS	<0.001	61	83	80	66
SRV	0.039	70	80	70	80
RVFWS	<0.0001	100	73	100	69

TAPSE: Tricuspid Annular Plane Systolic Excursion, SFS: Surface Fractional Shortening , SRV: S wave velocity in the RV, RVFWS: RV free wall strain, PPV: positive predictive value, NPV: negative predictive value
MRI: cardiac magnetic resonance imaging, RVEF: right ventricular ejection function

The evaluation of the pulmonary valve revealed a PRF measured by MRI of 32% ± 17. Echocardiography showed a sensitivity of 80% and a specificity of 94% in identifying cases of severe PR, as well as a sensitivity of 75% and a specificity of 86% for cases of mild PR. The jet/annulus ratio of the pulmonary valve exhibited a significant correlation with PRF measured by MRI (r = 0.69), with a sensitivity of 61.1% and a specificity of 83.3% (figure 3, table 2).

Pressure half-time (PHT) also correlated with PRF measured by MRI (r = -0.73), demonstrating a sensitivity of 89.5% and a specificity of 83.3%. By combining the jet/annulus ratio and PHT to identify significant PR, a sensitivity of 100% and a specificity of 85% were observed (figure 4, table 2).

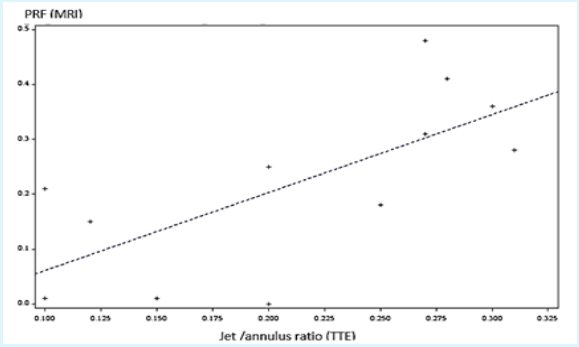

Figure 3. Bland-Altman graphic of the correlation between jet/anneau ratio and PRF obtained in MRI.

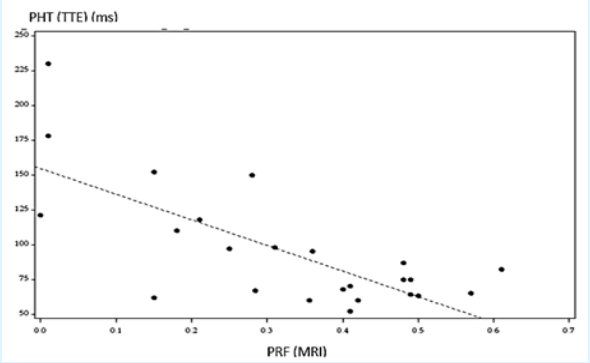

Figure 4. Bland-Altman graphic of the correlation between PHT in echocardiographic and PRF obtained in MRI.

Table 2. Sensitivity, specificity, PPV and NPV of echocardiographic parameters to identify RP severity on MRI

	PRF on MRI (%)		
	(>20	(<20)	Total
jet/ annulus ratio			
Sensibility: 61.1% , specificity: 83.3%			
PPV :91.7% , NPV :41.7%			
Severe (>1/3)	11	1	12
Mild at moderate (<1/)	8	5	13
Total	19	6	25
PHT			
Sensibility: 89.5% , specificity: 83.3%			
PPV :94.4% , NPV :71%			
Severe (<100ms)	17	1	18
Mild at moderate (>100 ms)	2	5	7
Tota	19	6	25

PR: pulmonary regurgitation; PRF: pulmonary regurgitation fraction; MRI: cardiac magnetic resonance imaging, PPV: positive predictive value, NPV: negative predictive value, PHT: pressure half time

These findings suggest that echocardiography is a valuable tool for assessing cardiac parameters in patients with TOF, particularly for PR when combined with multiple measurements.

DISCUSSION

Our study has revealed that echocardiography is a reliable method for measuring RV volumes in these patients. However, there is a slight underestimation of volumes in echocardiography compared to MRI. Tricuspid Annular Plane Systolic Excursion (TAPSE) measured in echocardiography demonstrated limited correlation with MRI. Surface Fractional Shortening (SFS) proved to be a better measure of right ventricular function than TAPSE. Furthermore, longitudinal myocardial deformation using Speckle tracking (2D strain) is a precise measure of right ventricular function. These results suggest that echocardiography is useful for assessing cardiac function in TOF patients, with some limitations to consider.

Regarding pulmonary regurgitation, echocardiography is effective in detecting severe pulmonary regurgitation but less precise for mild regurgitation. Our study has shown that the jet/ring diameter ratio of the pulmonary valve and pressure half-time (PHT) correlated with pulmonary regurgitation fraction (PRF) measured by MRI. When combined, these two parameters exhibited the best correlation in detecting significant PRF, with a sensitivity of 100% and specificity of 85%.

Several previous studies have compared measurements obtained through echocardiography and MRI. Crean et al. examined 25 patients, including 14 with TOF. Their results demonstrated an average underestimation of right ventricular volumes in echocardiography compared to MRI, with an average underestimation of 80 ml (-36%). A mean overestimation of 25% was observed for the RVEF in echocardiography in this population [15].

Another study by Grewal et al. followed 25 TOF patients using both echocardiography and MRI. Although this study showed better correlation between echocardiography and MRI for volumes and RVEF compared to the previous study, a mean underestimation of 9% was observed for the right ventricular end-diastolic volume indexed to body surface area (RVEDVi) in echocardiography compared to MRI [16].

In our study, a good correlation was observed between echocardiographic measurements of RVEDVi and RVESVi

compared to MRI, with an intraclass correlation coefficient (ICC) of 0.96. Volume underestimation was also noted in echocardiography, although it was not significant. The mean underestimation was 5 ml/m² for RVEDVi and 5.3 ml/m² for RVESVi.

Regarding the evaluation of right ventricular function using TAPSE, our study used a threshold of 18 mm to predict right ventricular dysfunction [17]. However, the correlation between TAPSE measured in echocardiography and RVEF obtained by MRI was not significant (r=0.38, p=0.056). This weak correlation in TOF patients could be attributed to the complex anatomy of the RV in this population.

The study also explored right ventricular function using Right Ventricular Surface Fractional Shortening (FRS), which exhibited a better correlation with RVEF than TAPSE in other studies [18, 19]. FRS takes into account the longitudinal and transverse shortening of the right ventricular wall. In our study, right ventricular FRS measured in echocardiography showed a good and significant correlation with RVEF obtained by MRI (ICC of 0.66, p<0.001) and was more reliable than TAPSE in predicting right ventricular function.

Myocardial Tissue Doppler Imaging (TDI) was also used to assess right ventricular function. D'Anna et al.'s study showed a low but significant correlation between echocardiographic TDI and RVEF obtained by MRI, as well as a better correlation of TDI compared to TAPSE with RVEF. The respective correlation coefficients were r=0.4; p<0.001 versus r=0.36; p<0.005 [20].

Our study demonstrated good concordance between echocardiographic TDI and RVEF in MRI, with a significant correlation (r=0.41, p=0.039). TDI had a sensitivity of 70% and specificity of 80% in detecting right ventricular dysfunction in MRI.

Regarding pulmonary valve assessment, a visual qualitative evaluation with color Doppler was used to categorize PR into three severity groups. A semi-quantitative evaluation based on the jet-to-pulmonary annulus diameter ratio was also performed, with a threshold of >1/3 to identify significant regurgitation. Our study results showed a good correlation between visual qualitative assessment and PRF obtained by MRI for mild and severe regurgitation groups. However, the correlation was poor for the moderate regurgitation group.

The jet/annulus diameter ratio >1/3 was evaluated as a potentially reliable threshold for detecting significant pulmonary regurgitation, with a sensitivity of 61.1%, specificity of 83%, positive predictive value (PPV) of 97.1%, and negative predictive value (NPV) of 41.7%.

Our study highlights the importance of carefully selecting methods for evaluating right ventricular function in operated TOF patients. The results suggest that FRS and 2D strain can be accurate alternative measures of RV function, while echocardiography can be particularly useful in detecting severe pulmonary regurgitation. The combination of the pulmonary valve jet/annulus diameter ratio and PHT can also be a valuable tool for assessing pulmonary regurgitation.

CONCLUSION

Surgical repair of TOF can lead to PR, which can be problematic, affecting right ventricular function and potentially causing serious complications. Our work highlighted the utility of echocardiography as a follow-up tool for patients who have undergone TOF repair, especially in detecting severe PR. The 2D strain, a novel method for evaluating ventricular function, showed excellent correlation with RVEF measured by MRI, suggesting it could be a valuable alternative. However, cardiac MRI remains essential for a more precise evaluation of right ventricular morphology and function. The study has limitations, including its small sample size, and the results should be confirmed by further multicenter studies.

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