Can T1 mapping be an alternative of post-contrast magnetic resonance sequences in patients with surgically corrected tetralogy of Fallot?

Hasan Yiğit, Elif Ergün, Pelin Seher Öztekin, Pınar Nercis Koşar

Department of Radiology, University of Health Sciences, Faculty of Medicine, Ankara Health Practice and Research Center; Ankara-*Turkey*

Abstract

Objective: The objective of this study is to investigate the ability of native T1 mapping in the determination of myocardial fibrosis in patients with surgically corrected tetralogy of Fallot (TOF).

Methods: We included 35 patients with surgically corrected TOF who underwent cardiac magnetic resonance imaging in this study. Additionally, we added pre- and post-contrast T1 mapping sequences at the right ventricular outflow tract (RVOT) and short-axis planes to the routine protocol. We visually evaluated the pre-contrast native T1 mapping images to determine the presence of areas with higher T1 times that indicate focal fibrosis. We compared the findings with the findings of post-contrast images.

Results: In 22 of the 35 cases, RVOT enhancement was observed in the delayed enhancement images; however, none of these cases could be distinguished on the native T1 maps. When compared to post-contrast imaging, 28 of the 30 contrast enhancements at right ventricle insertion points and 14 of the 17 contrast enhancements at the remaining left ventricle walls were visually observed on the color-coded native T1 maps. The sensitivity, specificity, positive and negative predictive values of native T1 mapping for the detection of focal fibrosis at the right ventricle insertion points were found to be 93.3%, 100%, 100%, and 71.4%, respectively, whereas these values were found to be 82.4%, 100%, 100%, and 85.8% in the detection of fibrosis in the remaining left ventricle walls.

Conclusion: Native T1 mapping is valuable in the detection of focal fibrosis at the right ventricle insertion points and the remaining left ventricle walls; however, it was not possible to visually detect RVOT fibrosis by native T1 mapping. Hence, T1 mapping may not replace the contrast-enhanced imaging in patients with surgically corrected TOF. *(Anatol J Cardiol 2020; 24: 377-81)*

Keywords: tetralogy of Fallot, T1 mapping, fibrosis, magnetic resonance imaging

Introduction

Cardiac magnetic resonance imaging (MRI) has been playing a crucial role in the follow-up of patients with surgically corrected tetralogy of Fallot (TOF) who may require re-intervention. MRI plays a major role in this patient group by quantitatively evaluating the pulmonary valve insufficiency and right ventricular function (1). Beyond this ability, it accurately defines the cardiac and vascular anatomies, and is the gold standard method in the quantification of volume and function of both ventricles. Moreover, MRI may non-invasively evaluate the myocardial viability and/or fibrosis. Right ventricular outflow tract (RVOT) enhancement compatible with fibrosis is frequently observed by MRI in patients with surgically corrected TOF, especially those who underwent the augmentation of RVOT with patch. In addition, the delayed enhancement of right ventricular insertion points caused by the right ventricle overload and delayed enhancement of other ventricle walls caused by fibrosis are also frequently observed (2, 3). These abnormal contrast enhancements that can be considered as a scar tissue are the negative indicators of ventricular dysfunction and arrhythmia (4).

T1 mapping, one of the newest tissue characterization methods in cardiac MRI, holds the potential to detect myocardial edema, amyloidosis, or fibrosis without the administration of contrast agent and may perform this function at an earlier phase as compared to the contrast-enhanced conventional MRI (5). Gadolinium-based contrast agents, particularly those with a linear structure, have the potential to accumulate in the body, especially in the central nervous system. This fact and the risk of nephrogenic systemic fibrosis are some of the concerns about the safety of these agents (6). The repeated use of gadolinium-based contrast agents increases the risk of their accumulation in the body. The objective of this study is to investigate the ability of

Address for correspondence: Dr. Hasan Yiğit, Sağlık Bilimleri Üniversitesi Tıp Fakültesi, Ankara Sağlık Uygulama ve Araştırma Merkezi, Ankara-*Türkiye*
Phone: +90 312 595 37 85 E-mail: hayigit@hotmail.com

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Table 1. Imaging parameters in delayed enhanced imaging and T1 mapping

Parameters	Delayed enhanced imaging	Native (Pre-contrast) T1 mapping	Post-contrast T1 mapping
Sequence	PSIR	Optimized MOLLI 5(3)3	Optimized MOLLI 4(1)3(1)2
TR (ms)/TE (ms)	533/1.1	265/1.0	345/1.0
Flip angle (°)	40	35	
Slice thickness (mm)/gap (mm)	7/1.4	RVOT: 7/1.4 SAX: 7 (base, mid, apical)	
FOV (cm^2)	27x34	31x36	
Matrix	124x192	145x256	

PSIR - phase-sensitive inversion recovery, MOLLI - modified look–locker inversion recovery, TR - repetition time, TE - echo time, ms - milliseconds, mm - millimeters, cm - centimeters, RVOT - right ventricular outflow tract, SAX - short-axis, FOV - field of view

native T1 mapping in the determination of myocardial fibrosis in patients with surgically corrected TOF who need to be evaluated with repeated cardiac MRIs.

Methods

We included patients with surgically corrected TOF who underwent routine cardiac MRI at our institution between 2016 and 2018 in this study. In the study group, we added the T1 mapping sequences before and after the administration of contrast material to the routine cardiac MRI protocol. Moreover, we excluded patients with a poor image quality caused by the failure of breath-holding or cardiac cycle synchronization problems from this study. The Institutional Review Board approved the protocol, design, and procedures of this prospective study, and all patients provided their written informed consent prior to their participation in the study.

We performed cardiac MRI on a 1.5 Tesla MR system (MAGNETOM Aera, Siemens Healthineers) with 18-channel phased array torso surface coil. Additionally, we used vectorcardiography for synchronization with the cardiac cycle, and obtained images via breath-holding by patients.

We obtained delayed enhancement images at RVOT and short-axis planes, as the stack images traversing RVOT and both ventricles. We performed phase-sensitive inversion recovery sequence ten minutes after the administration of gadolinium-based contrast material at a dose of 0.15 mmol/kg. We used the TI scout software to determine the optimal inversion time. Within the scope of the study, we added native (pre-contrast) and post-contrast T1 mapping sequences (as RVOT images and short-axis images) to the protocol. The RVOT T1 mapping images were obtained at the identical planes with the delayed enhancement images, whereas short-axis T1 mapping images were obtained at the base, mid, and apical segments. We used optimized modified look–locker inversion recovery as the T1 mapping sequence, which was obtained as 5(3)3 before contrast and 4(1)3(1)2 after contrast. Table 1 shows the technique parameters of delayed enhancement imaging and T1 mapping sequences.

A radiologist with ten-year working experience with cardiac MRI performed image analysis on a remote diagnostic workstation (Leonardo Syngo MR E11, Siemens Healthineers). Initially, we evaluated the pre-contrast native T1 mapping images for the presence of areas with higher T1 times that indicate focal fibrosis and are coded as bright areas in the colored maps. Then, we evaluated late enhancement images for the presence of enhanced areas. Thereafter, we evaluated post-contrast T1 mapping images for the presence of dark areas in the color maps, which indicate T1 shortening. We calculated the sensitivity, specificity, positive and negative predictive values of native T1 mapping for the detection of fibrosis by taking the post-contrast imaging as the gold standard. We used medical diagnostic testing methods to evaluate the data.

Results

We included 35 cases in this study. Table 2 shows the demographic data of the patients.

RVOT enhancement was observed in the late enhancement images of 22 cases (63%) (Fig. 1a, 1b). None of these cases could be distinguished on the native T1 maps (Fig. 1c). In 19 of these cases, the decrease in focal T1 time was detected visually on the post-contrast T1 map (Fig. 1d), whereas visual detection was not possible in 3 of the cases.

The delayed enhancement of ventricular junction pattern caused by the right ventricle overload was observed on the de-

Table 2. Demographic data and research period

Gender	Age	Research period
19 (54.3%) Male 16 (45.7%) Female	9 to 46 years (mean age 17.1±8)	2016 to 2018

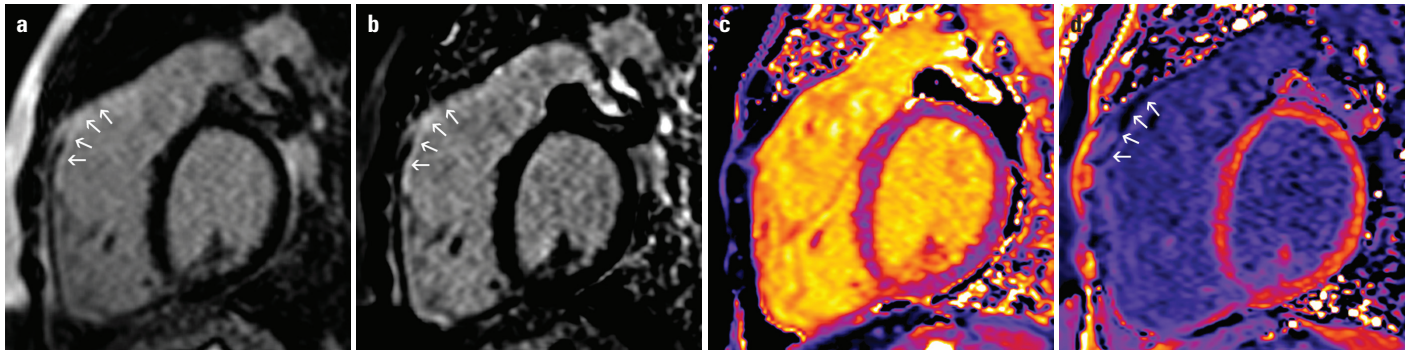

Figure 1. RVOT images of a 25-year-old woman. (a) The delayed enhanced magnitude and (b) phase images show contrast enhancement in RVOT. This area cannot be distinguished on (c) the pre-contrast native T1 map. (d) The post-contrast T1 map shows this contrast enhancement as a linear dark region, which indicate T1 shortening

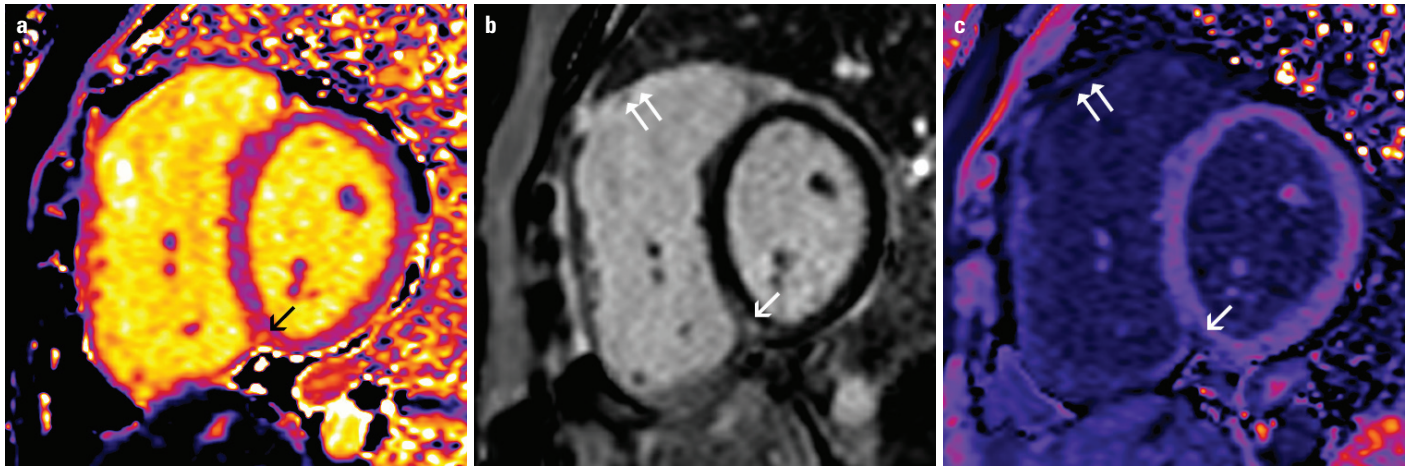

Figure 2. Short-axis images of a 25-year-old woman. (a) The bright region on the native T1 map indicates focal fibrosis at the right ventricular insertion point (black arrow). (b) The delayed enhanced image and (c) post-contrast T1-map show the corresponding contrast enhancement and T1 shortening at this point, respectively (white arrows). Post-contrast images also show enhancement in RVOT (double arrows)

layed enhanced images in 30 cases (85.7%). Among these cases, the decrease in focal T1 time that matches the delayed enhanced areas could be distinguished on the post-contrast T1 map images in 29 cases, whereas the decrease in focal T1 time could not be visually detected in only one case. Due to T1 lengthening corresponding to the late enhanced areas, bright areas on the color-coded native T1 map images were observed in 28 cases (82.9%) (Fig. 2a-2c). When compared to post-contrast imaging, the sensitivity, specificity, positive and negative predictive values of native T1 mapping for the detection of fibrosis due to right ventricular overload were calculated as 93.3%, 100%, 100%, and 71.4%, respectively.

In delayed enhancement images, the sub-epicardial or mid-myocardial focal non-ischemic enhancements on the left ventricle walls and/or the decrease in focal T1 time on the post-contrast T1 map images that indicate focal fibrosis were observed in 17 cases (48.6%). The regions with increased T1 time corresponding to the contrast-enhanced areas were distinguished in 14 cases (40%) on the pre-contrast native T1 map (Fig. 3a-3c). When compared to contrast-enhanced images, the sensitivity, specificity, positive and negative predictive values of native T1 mapping for the visual detection of focal fibrosis were calculated as 82.4%, 100%, 100%, and 85.8%, respectively. In only one case, enhancement, which was detected on delayed enhanced images, could not be detected by post-contrast T1 mapping, whereas enhanced regions detected on the delayed enhancement images could also be distinguished on the post-contrast T1 map images in all the remaining cases. Moreover, delayed enhancement images could not detect the region that had T1 shortening (indicating contrast enhancement) on the post-contrast T1 map images in one case.

Discussion

Myocardial parametric mapping enables quantitative tissue characterization, which makes it possible to non-invasively detect diffuse myocardial disease. The detection of focal myocardial pathologies without using contrast material or earlier than conventional MRI, clarification of suspicious conventional MRI findings, quantitative evaluation of progression of the disease, and follow-up of treatment response are the other advantages of this method (5, 7, 8).

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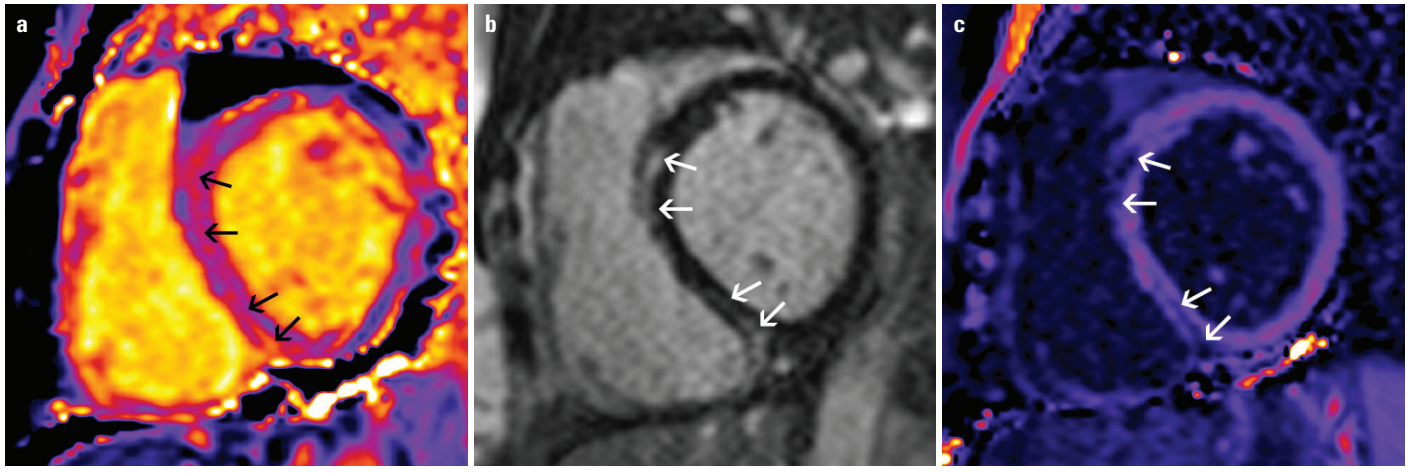

Figure 3. Short-axis images of a 37-year-old woman. (a) The mid-myocardial bright areas extending to the insertion points in the septal wall are compatible with the non-ischemic fibrosis on the native T1 map (black arrows). (b) Delayed enhanced image and (c) post-contrast T1 map show the corresponding contrast enhancements and T1 shortening at these regions, respectively (white arrows)

Studies on T1 mapping in patients with surgically corrected TOF are limited; moreover, some of these studies only evaluated the left ventricle myocardial T1 time and extracellular volume (ECV) (9-11). The ROI analysis of the right ventricle wall is difficult because the thin structure of this wall increases the risk of contamination from the blood pool or adjacent fat tissue; however, some studies have also evaluated the right ventricle walls (12-14). These studies reveal the increase in mean T1 time and ECV, which confirm the presence of diffuse interstitial fibrosis. Because it can quantify diffuse interstitial fibrosis, parametric mapping holds the potential to be the part of the routine protocol in the follow-up of patients with surgically corrected TOF in the near future. The current protocol includes contrast-enhanced studies that show a myocardial scar. To our knowledge, this study is the first one to investigate the visual detectability of scar tissue without using contrast media.

In this study, the sensitivity, specificity, positive and negative predictive values of native T1 mapping in detection of focal fibrosis in the right ventricular insertion points and the remaining left ventricle walls were found to be high; however, it was not possible to visually detect RVOT fibrosis by native T1 mapping. This observation occurs because fibrosis in the thin right ventricular wall cannot be clearly distinguished from the blood pool that naturally has a high T1 time. Hence, we can say that parametric mapping cannot replace contrast-enhanced imaging in patients with surgically corrected TOF.

Although the regions with a focal decrease in T1 time that corresponds to the contrast-enhanced regions in late enhancement images were detected in most of the study population, there are still few cases in which they could not be detected. We believe that this happens because focal enhancements were more limited in these cases. Additionally, the late enhanced images and post-contrast T1 mapping images were not obtained at the identical planes, and T1 mapping images could not capture these small areas. Due to the same reason, in one case, the decrease in T1 time corresponding to late enhancement was detected by mapping images; however, no-enhancement was observed in the late enhanced images. Therefore, the addition of post-contrast mapping images to the routine protocol may increase the sensitivity of MRI in the detection of focal fibrosis in addition to confirming the suspicious findings of late enhanced images. On the contrary, it may be more appropriate to spend the extra time used to obtain the T1 mapping images on increasing the number of slices by decreasing the slice thickness in delayed enhancement imaging or on using a high-resolution protocol. However, delayed enhancement imaging has no role in the detection of diffuse myocardial fibrosis, which is a negative prognostic criterion and can only be detected non-invasively by mapping sequences (15).

This study has some limitations. Although pre-contrast native T1 maps and post-contrast T1 maps were performed on identical short-axis planes, they were taken as fewer and wider-spaced sections than the late enhanced images to reduce the examination time and patients' tolerance. For this reason, the sensitivity of native T1 mapping may be underestimated, especially when fibrosis is limited. The interobserver variability was not calculated because only one observer performed visual evaluation. Our study is based on the visual detection of focal fibrosis on color maps and does not include native T1 measurements and ECV calculations. Therefore, diffuse myocardial fibrosis was not evaluated. However, the addition of T1 mapping to the routine cardiac MRI protocol will allow the evaluation of diffuse myocardial fibrosis, which otherwise cannot be detected non-invasively at the expense of prolonged imaging time.

Conclusion

Native T1 maps do not visually show fibrosis in the thin-walled RVOT. Therefore, native T1 mapping may not be an alternative to the delayed enhanced imaging in the detection of fibrosis in RVOT. However, focal fibrosis in the left ventricle wall can be shown by native T1 images without using contrast material

in the majority of patients. Adding T1 mapping sequences to the protocol will enable the non-invasive detection of diffuse myocardial fibrosis in addition to confirming the suspicious findings of delayed enhanced images. However, it will prolong the examination time, which is already long and may not be well tolerated by some patients.

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