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ORIGINAL STUDY

Efficacy of native T1 mapping in differentiating viable and nonviable myocardium in chronic ischemia

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Abstract

Background: Myocardial ischemia may lead to reversible or irreversible myocardial insult. A precise assessment of myocardial viability (MV) is of clinical relevance to determine the recovery potential of the affected segments. Contrast-enhanced cardiac magnetic resonance with late gadolinium (Gd) sequence is the gold standard method for MV assessment. Our study tested the accuracy of segmental native T1 mapping (NT1M) imaging as a noncontrast technique for assessing MV.

Patients and methods: Forty-three patients with chronic myocardial ischemia underwent 1.5 T cardiac magnetic resonance. Imaging protocol includes cine images to assess left ventricular function, and late gadolinium enhancement (LGE) images to detect and estimate the extension of myocardial enhancement. Segments with more than or equal to 75% enhancement were considered ischemic nonviable. Segmental NT1M (modified Look-Locker inversion recovery MOLLI sequence 5(3)3) was obtained at basal, mid-ventricular, and apical levels. Segmental native T1 mapping values (NT1MV) were analyzed and referred to the LGE results.

Results: This study included 688 myocardial segments, divided into healthy myocardium (HM) with no LGE comprising 422 segments; ischemic viable myocardium (IVM) with LGE <75% consisting 182 segments; and ischemic nonviable myocardium with LGE more than or equal to 75% with 84 segments. A statistically significant difference between segmental NT1MV and MV ($P < 0.001$) was found. The mean segmental NT1MV difference of ischemic myocardium from HM was ~8% for IVM and about 25% for ischemic nonviable myocardium. Receiver-operating characteristics curve analysis showed a high diagnostic accuracy of segmental NT1MV for distinguishing between HM and ischemic myocardium (90.7%).

Conclusions: Segmental NT1MV correlates well with the transmural extent of the myocardial scar, and distinguishes between HM, IVM, and ischemic nonviable myocardium.

Keywords: Cardiac magnetic resonance, Late gadolinium enhancement, Native T1 mapping

1. Background

Myocardial ischemia can lead to reversible or irreversible myocardial injury, leaving the injured myocardium viable/stunned, or irreversibly nonviable (NV). Therefore, an accurate assessment of the site, size, and transmural (TM) extent of myocardial infarction (MI) have a crucial role in choosing the suitable management of these patients.

This may reduce mortality and the risk of heart failure as a complication of ischemic heart disease [1,2].

Cardiac magnetic resonance (CMR) with late gadolinium enhancement (LGE) sequence is the modality of choice for the evaluation of MI, as it allows detection and accurate assessment of myocardial scar [3]. Viability assessment is performed by assessing the extent of the scar thickness

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in the LGE sequence, considering the myocardial segment NV if the scarring involves more than or equal to 75% of myocardial thickness [4].

Yet, the LGE sequence requires the administration of gadolinium (Gd)-based contrast media, which may be risky in patients with advanced renal pathologies due to the risk of systemic fibrosis [5], in addition to the risk of deposition of Gd in the central nervous system structures with uncertain clinical significance [6].

Native T1 mapping (NT1M) is a novel CMR imaging tool that quantifies important biological changes in both regional and global myocardium independent of function without the need for Gd [7].

In this study, we tested the hypothesis that NT1M can effectively differentiate between normal healthy, ischemic viable myocardium (IVM), and ischemic nonviable myocardium (INVM).

2. Patients and methods

The institutional committee's ethical criteria were followed during all proceedings. The ethical committee approved the study (no. 4714) at 4.11.2021.

This prospective study was conducted on 43 patients with chronic myocardial ischemia, who were referred for myocardial viability (MV) assessment at the Radiology Department between December 2021 and June 2022.

All participants were assessed as follows.

2.1. Basic clinical and demographic data

The data include age, sex, height, weight, body surface area, hypertension, hyperlipidemia, and results from echocardiography.

2.2. Cardiac magnetic resonance image acquisition

All images were acquired on a 1.5 T magnetic resonance system (Achieva dStream 1.5T, Phillips Medical Systems, The Netherlands) using specially designed software. A digital body coil and a four-lead vector cardiogram were used.

The imaging protocol consisted of the following: localizers (axial, coronal, and sagittal), pseudo short-axis (SA) and 2-chamber (ch.) views, steady-state free precession (SSFP) cine images of 2-, 3- and 4-ch views. SAX volume data acquisition for the evaluation of left ventricular (LV) and right ventricular (RV) functions and volumes. Flow images at the level of aortic and pulmonary valves were obtained. Native MOLLI T1 mapping, EGE with high TI (500–600 s), and LGE imaging 8–10 min after intravenous administration of contrast media.

Table 1. Baseline clinical data of the study population.

Variables	N = 43
Age (mean ± SD)	61.3 ± 7.59
Sex [n (%)]	
Male	30 (69.8)
Female	13 (30.2)
Hypertension [n (%)]	
Present	22 (51.2)
Absent	21 (48.8)
Hyperlipidemia [n (%)]	
Present	17 (39.5)
Absent	26 (60.5)
Height (cm) (mean ± SD)	166 ± 3.89
Weight (kg) (mean ± SD)	83.37 ± 7.18
Body surface area (cm/kg) (mean ± SD)	1.96 ± 0.09

2.3. LGE images

Taken 8–10 min after administering 0.2 mmol/kg intravenous Gd (Omniscan Co., Cork, Ireland) using typical parameters with 6.1 ms time of repetition, 6 ms echo time; matrix 188 × 146; 25° flip angle; 10 mm thickness, no gap; and 1.6 × 1.9 × 10 mm voxel size. The inversion time was continuously optimized to a null normal myocardium. Images were obtained on both short-axis and long-axis planes. Each slice was obtained during a breath-hold of 7–12 s, depending on the heart rate.

2.4. T1 mapping sequence

NT1M images were acquired before Gd injection using the MOLLI 5(3)3 acquisition protocol, with T1 mapping data in three SAX sections across the LV using an ECG-triggered and breath-hold method with 300 × 300 field of view, 1.97 × 1.99 × 10 mm³ spatial resolution, 10 mm section thickness, and 13 mm gap.

2.5. Cardiac magnetic resonance imaging analysis

All image analyses were performed on cvi⁴² (Circle Cardiovascular Imaging Inc., Calgary, Canada) and all CMR data were analyzed and reviewed by two experienced radiologists (>5 years' experience).

LV volumes, ejection fraction (EF), segmental wall thickening, and wall motion abnormalities were assessed. Myocardial segments were assigned to coronary arteries as described in the American

Table 2. Interobserver and intraobserver variability for segmental T1 value.

Interclass correlation coefficient (ICC)	Interobserver	Intraobserver
ICC (95% confidence interval)	0.972 (0.968–0.986)	0.990 (0.979–0.997)

Heart Association's 16-segment model (excluding the apical cap) [8].

The transmural extent of infarction was quantitatively calculated by dividing the thickness of the enhanced region of each segment by the total segment thickness and graded on a four-point scale: 'a score of (1) indicates 0–25% LGE, (2) 26–50% LGE, (3) 51–75% LGE, and (4) more than 75% LGE'

[9]. A scar TM grade of 3 or less (<75% TEI) was deemed IVM [10]. For assessing the regional wall motion abnormality, segments were scored into 1 indicates normo-kinetic, 2 hypokinetic, 3 akinetic, and 4 indicates dyskinetic.

NT1M images of varying inversion times were analyzed to generate parametric T1 relaxation maps. Grayscale and color mappings were

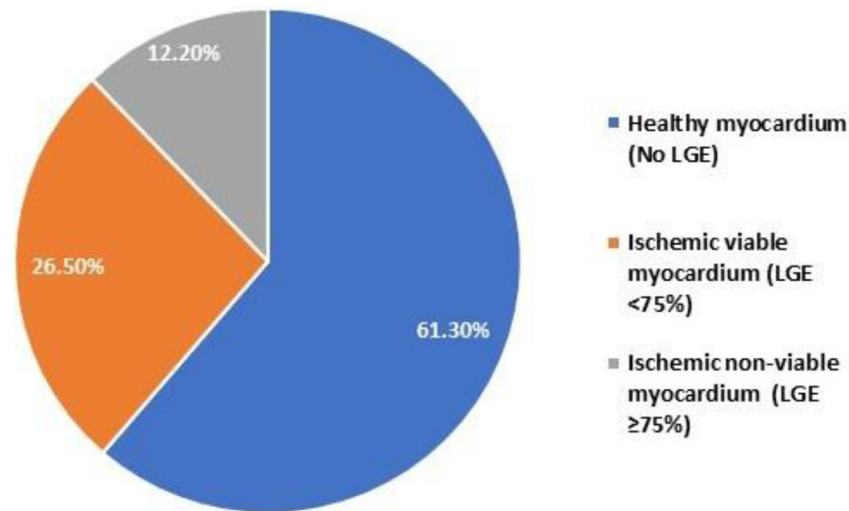


Fig. 1. Distribution of segmental myocardial viability (N = 688 segments).

Table 3. Association between T1 value and segmental myocardial viability.

Variables	Myocardial viability			P value
	Healthy myocardium (no LGE) (N = 422)	Ischemic viable myocardium (LGE <75%) (N = 182)	Ischemic nonviable myocardium (LGE ≥75%) (N = 84)	
T1 value (ms)				
Mean ± SD	1056.19 ± 30.06	1140.38 ± 21.62 ^α	1319.43 ± 39.11 ^{α β}	<0.001 ^a
Median (IQR)	1054 (1034–1074)	1174 (1107–1210)	1306.5 (1297–1337)	
Average difference from healthy myocardium (%)		≈ 84 (8%)	≈ 263 (25%)	

IQR, interquartile range.

Values with superscript ^α are significantly different from healthy myocardium using the Bonferroni post-hoc test.

Values with superscript ^β are significantly different from Ischemic viable myocardium using the Bonferroni post-hoc test.

^a P values are based on One-way ANOVA test. Statistical significance at P value less than 0.05.

Table 4. Area under the curve for analysis of T1 value for the prediction of healthy myocardium from the ischemic one.

Variable	Area	SE	P value	Cut-off point	Sensitivity	Specificity	PPV	NPV	Accuracy
T1 value	0.925	0.015	<0.001	1096.5	90.28%	91.35%	94.31%	85.56%	90.7%

NPV, negative predictive value; PPV, positive predictive value.

Table 5. Area under the curve for analysis of T1 value for the prediction of ischemic nonviable myocardium from ischemic viable one.

Variable	Area	SE	P value	Cutoff point	Sensitivity	Specificity	PPV	NPV	Accuracy
T1 value	0.903	0.023	<0.001	1280.5	91.67%	91.21%	82.8%	95.95%	91.35%

NPV, negative predictive value; PPV, positive predictive value.

displayed after the generation of motion-corrected NT1M images.

LGE images and NT1M were analyzed by two blinded readers. The segments of HM were identified as the regions showing no enhancement where reference regions of interest were drawn [11].

T1 values of infarct and HM were measured. Percentage changes in native T1 mapping values (NT1MV) of infarct relative to the HM were also calculated.

2.6. Data management

The study used SPSS for statistical analysis, comparing data using the Shapiro–Wilk test and one-way analysis of variance. It measured segmental infarct TM between LGE images and segmental NT1M, and the sensitivity and specificity of NT1MV for threshold-based detection. The interclass correlation coefficient was used to evaluate agreement between reviewers. Statistical significance was set at P value less than 0.05.

3. Results

The mean age of patients was 61.3 ± 7.59 years. About 70% of the study population were males and about 51% of them had hypertension, and about 40% had dyslipidemia. The mean body surface area was 1.96 ± 0.09 cm/kg (Table 1). In terms of infarct-related arteries, the left anterior descending was identified as the most frequently affected coronary artery (79.1%), followed by the right coronary artery (32.6%), and left circumflex artery (23.3%).

There was excellent interobserver and intra-observer agreement for segmental native T1 value. The Interclass correlation coefficient and 95% confidence interval were 0.968 (0.958–0.976) for

interobserver and 0.992 (0.967–0.998) for intra-observer agreement, respectively (Table 2).

This study included 688 myocardial segments based on the presence and degree of LGE. These segments were divided into HM (no LGE) including 422 segments (61.3%), IVM (LGE <75%) including 182 segments (26.5%) and INVM (LGE ³>75%) including 84 segments (12.2%) (Fig. 1).

There was a statistically significant difference regarding segmental NT1MV between different states of MV ($P < 0.001$). On applying the post-hoc test, segments with INVM (mean T1 = 1319.43 ± 39.11 ms) and segments with IVM (mean T1 = 1140.38 ± 121.62 ms) showed statistically higher NT1MV than HM (mean T1 = 1056.19 ± 30.06 ms) ($P < 0.001$). Moreover, segments with INVM (mean T1 = 1319.43 ± 39.11 ms) had statistically higher native T1 values than segments with IVM (mean T1 = 1140.38 ± 121.62 ms) ($P < 0.001$). Meanwhile, regarding the difference in native T1 value from the HM, there was an average increase in native T1 value by 8% for IVM and by about 25% for INVM from the HM (Table 3).

Our study showed that segmental NT1M had good sensitivity and specificity in distinguishing ischemic myocardium (with LGE) from HM (with no LGE), showing area under the curve of 0.925. A value of 1096.5 ms was the best calculated cutoff point for such discrimination giving a sensitivity of 90.28%, specificity of 91.35%, and an accuracy of 90.7% (Table 4).

Moreover, we showed that segmental NT1M had the ability to differentiate INVM from IVM when using LGE more than or equal to 75% as a reference standard to define INVM (area under the curve = 0.903). An NT1MV of 1280.5 ms was found to be the best cutoff point with a sensitivity of 91.67%, specificity of 91.21%, and an accuracy of 91.35% (Table 5; Figs. 2–8).

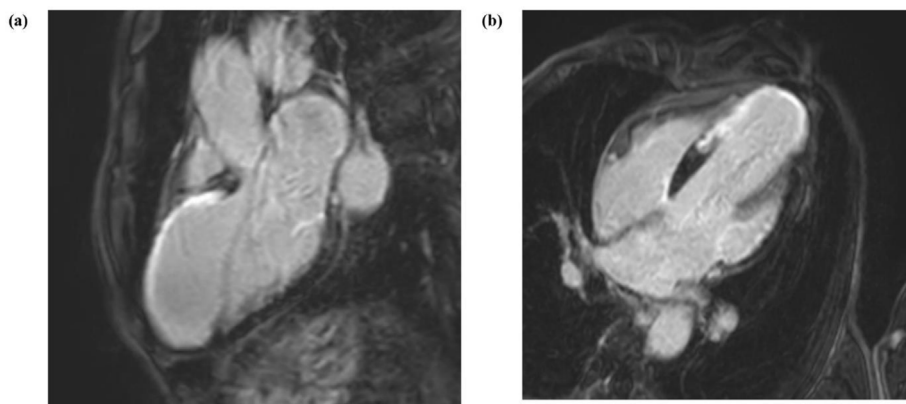


Fig. 2. A 57-year-old male patient showing ischemic nonviable myocardium along the LAD territory and subendocardial scar (<50%) at the basal anterolateral segment (LCx) was deemed viable (a) 3CH LGE and (b) 4CH LGE.

4. Discussion

The current study aims to assess the diagnostic performance of NT1MV for the detection of MV using LGE more than or equal to 75% as a reference standard to define INVM.

As the myocardial affection in MI showed regional distribution following territorial supply of the occluded/stenosed coronary artery, this study was designed to look for the accuracy of segmental-wise

analysis of NT1MV against the gold standard LGE following the AHA nomenclature.

There was excellent interobserver and intra-observer agreement for segmental NT1MV measurement, which was proven by a high ICC for both groups. These results were homogeneous with previous studies [12,13].

Out of 688 studied LV segments, 61.3% showed no LGE and were tagged as HM. Other segments were

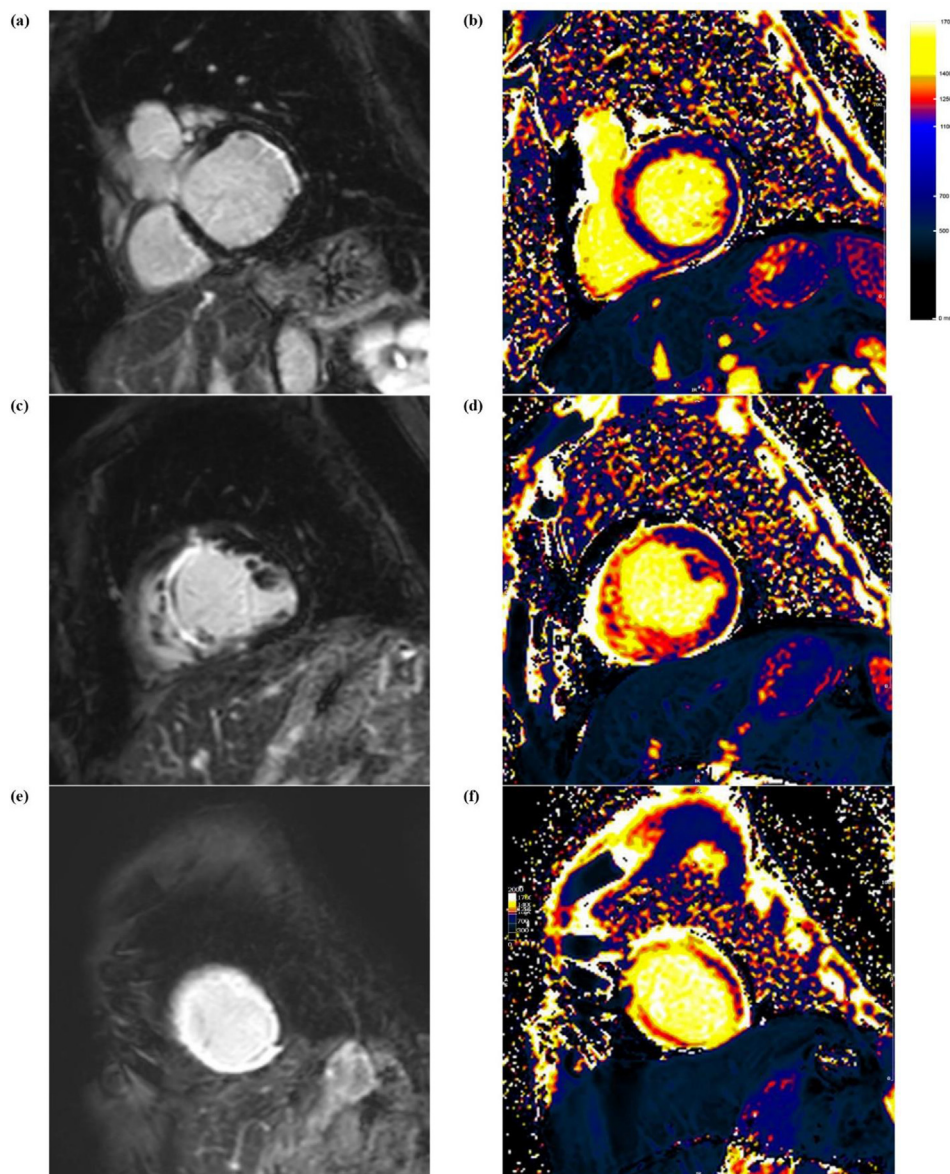


Fig. 3. A 57-year-old male patient showing ischemic nonviable myocardium along the LAD territory and subendocardial scar (<50%) at basal anterolateral segment (LCx) was deemed viable with NT1MV (ranging from 1284 to 1327 ms with corresponding areas of high signal intensity seen at the native T1 maps along NVM along the LAD territory. The areas along IVM along the LCx territory showed a native T1 map of 1094 ms with no appreciated difference from remote healthy myocardium short-axis slices at basal (3 a,b) mid-ventricular (3 c, d), and apical (3 e, f) levels. LGE images (3 a, c, e) show myocardial scars along LAD and LCX territories with changes noted at corresponding native T1 maps (3 b, d, f).

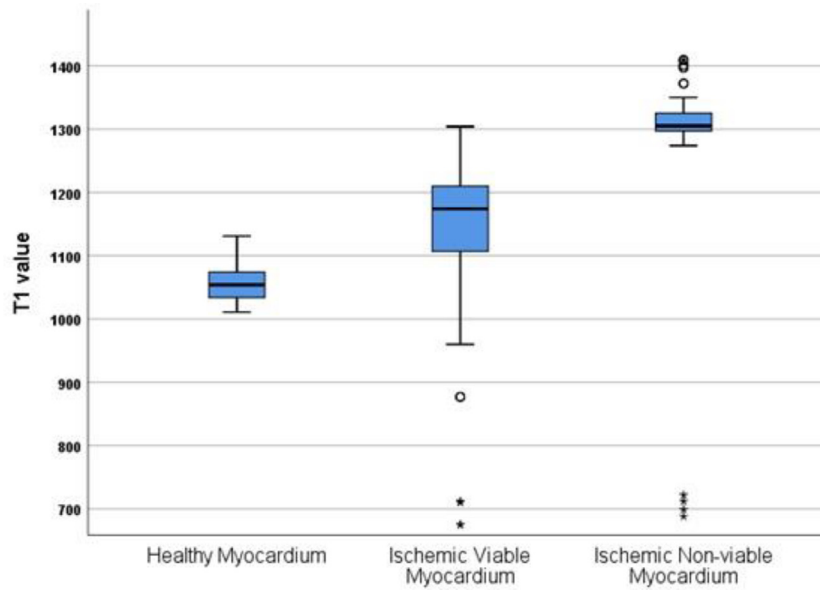


Fig. 4. Few ischemic segments had remarkably low native T1 values that were considered outliers and ranging between 685 and 876 ms. These were considered as regions of lipomatous metaplasia and associated with chemical shift artifacts in SSFP images.

divided into two groups (IVM and INVM) using LGE more than or equal to 75% TM as a reference standard, and the segmental NT1MV was compared along these groups.

The current study was conducted with a 1.5 T MRI scanner (Philips system, MOLLI 5(3)3 acquisition protocol). The mean T1 value of HM was 1056.19 ± 30.06 ms. Moreover, the T1 value of INVM was significantly higher than that of an HM by $\sim 25\%$. Similarly, the NT1MV of IVM was higher by about 8% from the HM.

These findings, regarding the percentage of increase in mean T1MV, are comparable to a study by Dastidar et al. [12], where the increase in T1 value from the HM was 17% for INVM and 7% for IVM using a 1.5 T MRI scanner. In addition, Kali et al. [14] stated that the native T1 value of INVM was 21% higher than that of HM. Moreover, the T1 value was increased by about 25% at the regions of INVM in the Liu et al. [13] study.

The mean T1 value of the INVM in our study was 1319.43 ± 39.11 ms, which is comparable to Thongsang et al. [15] (3 T scanner, Philips system, MOLLI 5(3)3 acquisition protocol), where their T1 value was 1316 ± 51 ms. A study by Okur et al. [16] also showed a comparable native T1 value of both ischemic and healthy myocardium (1314 ± 98 vs. 1099 ± 90 ms; about 20% difference) (3 T scanner, Siemens system, MOLLI). Meanwhile, our results were slightly higher than the values in the study by Dastidar et al. [12] values as their mean NT1MV of

INVM was 1206 ± 118 ms (1.5 T scanner, Siemens system, MOLLI 5(3)3 acquisition protocol).

The native T1 value enables accurate discrimination between different ischemic myocardial statuses (healthy, IVM, and INVM) as the technique had high diagnostic accuracy relative to LGE. Our study showed that segmental NT1M had good sensitivity and specificity in distinguishing ischemic myocardium (with LGE) from the healthy one (with no LGE), showing an area under the curve of 0.925. A value of 1096.5 ms was the best calculated cut-off point for such discrimination giving a sensitivity of 90.28%, specificity of 91.35%, and an accuracy of 90.7%.

Moreover, we showed that segmental NT1M could differentiate INVM from IVM when using LGE more than or equal to 75% as a reference standard to define infarcted NV myocardium (area under the curve = 0.903). An NT1MV of 1280.5 ms was found to be the best cutoff point with a sensitivity of 91.67%, specificity of 91.21%, and an accuracy of 91.35%.

Our results were comparable to the Dastidar et al. [12] study, which showed a good diagnostic accuracy of NT1M in the prediction of INVM (LGE $\geq 75\%$) with their area under the curve = 0.88, sensitivity = 88%, and specificity = 88%. Also it is comparable to the Okur et al. [16] study, where their sensitivity was 95.5% and specificity 97.7%. Chen et al. [9] reported that native T1 value had an acceptable diagnostic performance for the

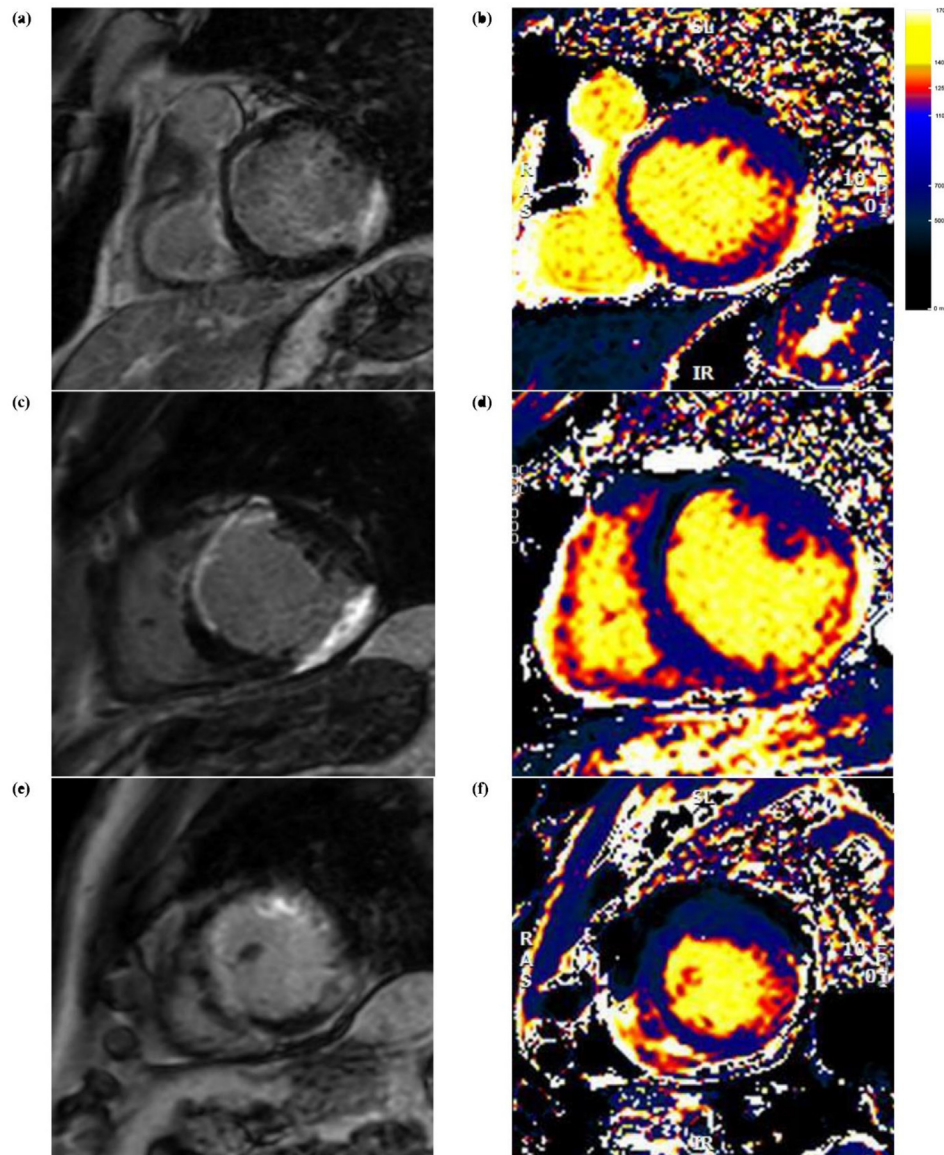


Fig. 5. A 56-year-old male patient showed significantly increased segmental NT1MV at the INVM along LCX of 1320 ms at basal, 1365 ms at mid-ventricular, and 1314 ms at apical levels with a corresponding visually detectable area of high signal on NT1M images short-axis slices at basal (5 a, b), mid-ventricular (5 c, d), and apical (5 e, f) levels. LGE images (a, c, e) show myocardial scars along LAD and LCx territories with changes noted at corresponding native T1 maps (b, d, f). The segmental NT1MV of the IVM along the LAD was unexpectedly low and even lower than the remote HM (Fig. 6). Corresponding SSFP images showed chemical shift artifacts at the same regions. The value of segmental native T1 map ranged from 695 to 780 ms with associated detectable areas of low signal in native T1 maps.

assessment of chronic myocardial infarction with an area under the curve of 0.824, sensitivity of 66%, and specificity of 97%.

A study by Thongsongsang et al. [15] aimed to assess the ability of NT1M in predicting the diseased myocardium from healthy controls. The study showed an average diagnostic performance of native T1 values for detecting the disease of the

myocardium with CAD from healthy controls, achieving an area under the curve of 0.62 and the best cutoff point was 1342 ms. However, this study did not include subgrouping of myocardial segments based on the LGE TM extension, which may explain the decrease in the NT1MV accuracy. Nonetheless, they showed a cut-off point comparable to our study.

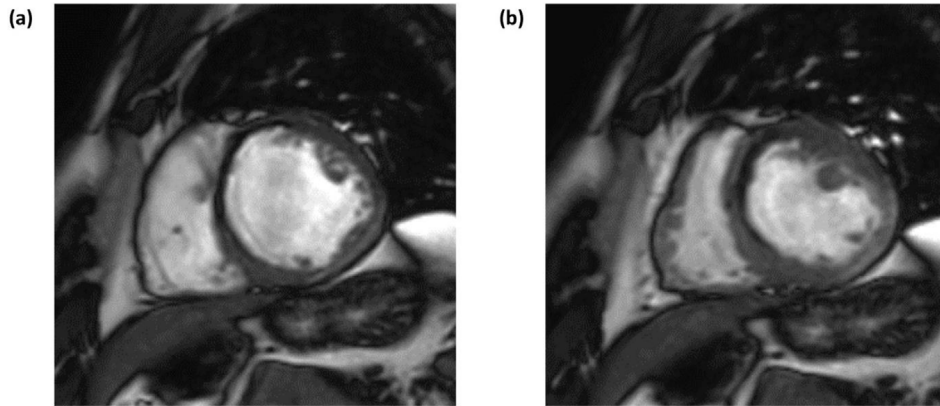


Fig. 6. A 56-year-old male patient showed significantly increased segmental NT1MV at the INVM along LCx of 1320 ms at basal, 1365 ms at mid-ventricular, and 1314 ms at apical levels with a corresponding visually detectable area of high signal on NT1M images short-axis slices at basal (5 a, b) mid-ventricular (5 c, d), and apical (5 e, f) levels. LGE images (a, c, e) show myocardial scars along LAD and LCx territories with changes noted at corresponding native T1 maps (b, d, f). The segmental NT1MV of the IVM along the LAD was unexpectedly low and even lower than the remote HM (Fig. 6). Corresponding SSFP images showed chemical shift artifacts in the same regions. The value of the segmental native T1 map ranged from 695 to 780 ms with associated detectable areas of low signal in native T1 maps.

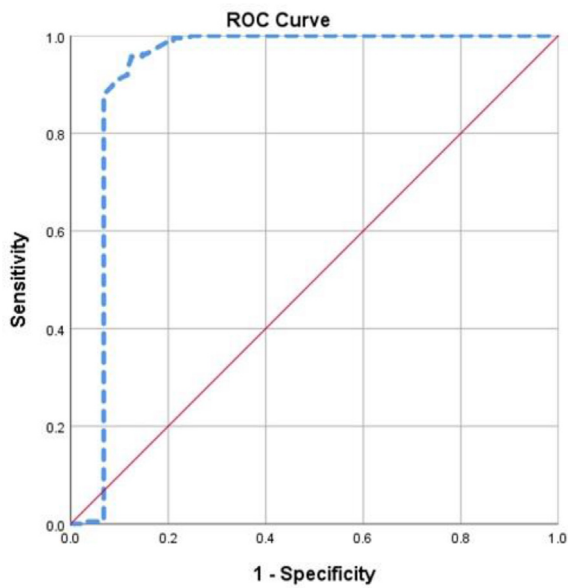


Fig. 7. Receiver-operating curve analysis of native segmental T1 value for the prediction of healthy myocardium from the ischemic one (Table 4).

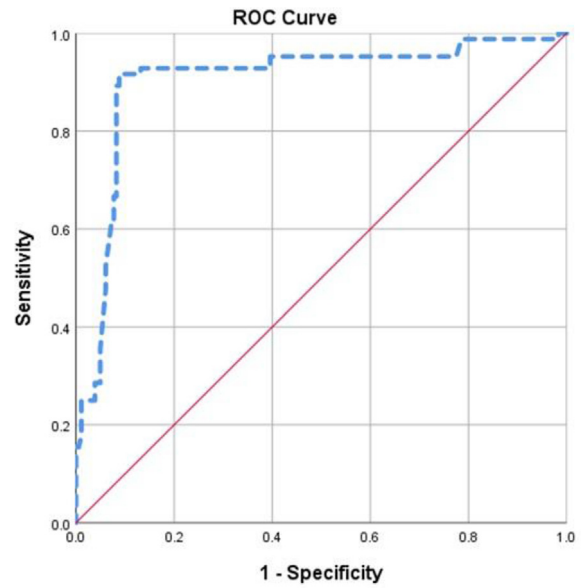


Fig. 8. Receiver-operating curve analysis of native segmental T1 value for the prediction of ischemic nonviable myocardium from the ischemic viable one.

4.1. Conclusions

NT1M correlates significantly with TM extension of ischemic myocardial scar differentiating between normal, IVM, and INVM.

4.2. Recommendations

As the main target of our study is to perform a contrast-free CMR protocol for viability assessment, further studies using other mapping parameters (postcontrast T1, ECV) are advised, as many studies report their crucial role in delineating ischemic myocardium.

Further studies aim to explore the possibility of obtaining T1 map images that exhibit good contrast between ischemic and healthy myocardium enabling visual assessment of scar tissue.

A multicenter study in a larger patient population is advised to test the reliability of the approach for clinical applications.

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Conflicts of interest

There are no conflicts of interest.

References

- [1] Romero J, Xue X, Gonzalez W, Garcia MJ. CMR imaging assessing viability in patients with chronic ventricular dysfunction due to coronary artery disease: a meta-analysis of prospective trials. *JACC Cardiovasc Imag* 2012;5:494–508.
- [2] Kali A, Cokic I, Yang HJ, Sharif B, Dharmakumar R. Accuracy and precision of chronic myocardial infarct characterization with native T1 mapping at 3T. *J Cardiovasc Magn Reson* 2015;17:1–2.
- [3] Hinderer S, Schenke-Layland K. Cardiac fibrosis – a short review of causes and therapeutic strategies. *Adv Drug Deliv Rev* 2019;146:77–82.
- [4] Dastidar AG, Rodrigues JCL, Baritussio A, Bucciarelli-Ducci C. MRI in the assessment of ischaemic heart disease. *Heart* 2016 Feb;102(3):239–52.
- [5] Layne KA, Dargan PI, Archer JRH, Wood DM. Gadolinium deposition and the potential for toxicological sequelae – a literature review of issues surrounding gadolinium-based contrast agents. *Br J Clin Pharmacol* 2018;84:2522–34.
- [6] Ibrahim MA, Hazhirkarzar B, Dublin AB. Gadolinium magnetic resonance imaging. *StatPearls*; 2021.
- [7] Taylor AJ, Salerno M, Dharmakumar R, Jerosch-Herold M. T1 mapping: basic techniques and clinical applications. *JACC Cardiovasc Imag* 2016;9:67–81.
- [8] Bucciarelli-Ducci C, Auger D, Di Mario C, Locca D, Petryka J, O'Hanlon R, et al. CMR guidance for recanalization of coronary chronic total occlusion. *JACC Cardiovasc Imag* 2016;9:547–56.
- [9] Chen YY, Ren DY, Zeng MS, Yang S, Yun H, Fu CX, et al. Myocardial extracellular volume fraction measurement in chronic total coronary occlusion: association with myocardial injury, angiographic collateral flow, and functional recovery. *J Magn Reson Imag* 2016;44:972–82.
- [10] Bulluck H, Rosmini S, Abdel-Gadir A, Bhuva AN, Treibel TA, Fontana M, et al. Redefining viability by cardiovascular magnetic resonance in acute ST-segment elevation myocardial infarction. *Sci Rep* 2017;7:1–7.
- [11] Carrick D, Haig C, Rauhala S, Ahmed N, Mordi I, McEntegart M, et al. Pathophysiology of LV remodeling in survivors of STEMI: inflammation, remote myocardium, and prognosis. *JACC Cardiovasc Imag* 2015;8:779.
- [12] Dastidar AG, Harries I, Pontecorvoli G, Bruno VD, De Garate E, Moret C, et al. Native T1 mapping to detect extent of acute and chronic myocardial infarction: comparison with late gadolinium enhancement technique. *Int J Cardiovasc Imag* 2019;35:517–27.
- [13] Liu X, Hou JL, Yang ZG, Xia CC, Xie LJ, Ye PF, et al. Native T1 mapping for characterization of acute and chronic myocardial infarction in swine: comparison with contrast-enhanced MRI. *J Magn Reson Imag* 2018;47:1406–14.
- [14] Kali A, Choi EY, Sharif B, Kim YJ, Bi X, Spottiswoode B, et al. Native T1 mapping by 3-T CMR imaging for characterization of chronic myocardial infarctions. *JACC Cardiovasc Imaging* 2015;8:1019–30.
- [15] Thongsongsang R, Songsangjinda T, Tanapibunpon P, Krittayaphong R. Native T1 mapping and extracellular volume fraction for differentiation of myocardial diseases from normal CMR controls in routine clinical practice. *BMC Cardiovasc Disord* 2021;21:1–17.
- [16] Okur A, Kantarci M, Kizrak Y, Yildiz S, Pirimoğlu B, Karaca L, et al. Quantitative evaluation of ischemic myocardial scar tissue by unenhanced T1 mapping using 3.0 Tesla MR scanner. *Diagn Interv Radiol* 2014;20:407.