Diagnostic and prognostic values of cardiac magnetic resonance imaging tissue mapping in acute myocardial infarction

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KEYWORDS

Cardiac magnetic resonance tissue mapping, acute myocardial infarction, Left ventricular remodeling.

ABSTRACT

Background: The unique capacity to non-invasively examine the myocardium is unique to magnetic resonance imaging of the heart, which has emerged as the gold standard for determining myocardium viability.

Objective: In patients with ischemic heart disease, the native and post-contrast T1 maps of cardiac magnetic resonance imaging (CMRI) are extensively used, along with the T2 map, to diagnose myocardial edema and necrosis in cases following primary percutaneous coronary intervention (PCI) for patients acute myocardial infarction and their prognostic value is examined.

Patients and methods: Between December 2021 and April 2023, 90 individuals had elective CMRI appointments scheduled. Our patients arrived at the cardiology department with a clinical diagnosis of an acute myocardial infarction requiring amenable for primary PCI. One to two days after PCI, they were referred to the radiology department for CMRI as part of a research study. Three to four months later, a follow-up CMRI was carried out.

Results: The mean age of the 64 male participants and 26 female participants in this study was 55 (±5 years). With a P value of 0.001, distinct tissue mapping values in our investigation demonstrated a significant statistical difference between hyper-enhanced (HE) and remote segments. 70 patients (63%) had microvascular blockage, which we found. In patients with microvascular obstruction (MVO), there was a difference in tissue mapping values between segments with MVO and segments without MVO that was highly amplified, with a propensity to pseudo-normalize the tissue mapping values of the MVO segments, but this difference was not statistically significant. With 81% sensitivity, 72% specificity, 75% positive predictive value, 79% negative predictive value, and 77% accuracy, the suggested cutoff value for the T2 map was 53.2ms (millisecond).

Two recommended cut-off values for the native T1 map were: The first one had a 1076.9 ms time window, an accuracy of 77%, sensitivity of 69%, specificity of 81%, positive predictive value of 78%, and negative predictive value of 72%.

The second one had a 1069.3 ms time window, an accuracy of 75%, sensitivity of 76%, specificity of 74%, positive predictive value of 74%, and negative predictive value of 75%.

The extracellular volume (ECV) proposed cut-off value displayed 85% accuracy, 89% positive predictive value, 80% negative predictive value, 79% sensitivity, and 90% specificity.

Conclusion: the use of tissue mapping to identify STEMI individuals with salvageable myocardial tissue post-primary PCI, and obtain cutoff values with adequate sensitivity, specificity, and accuracy in the early and late follow-up of myocardial evaluation
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Introduction:

The foremost leading cause of death and reduction in Disability Adjusted Life Years (DALYs) globally is coronary artery disease (CAD). **(Ralapanawa and Sivakanesan., 2021**

CMR offers a unique chance to evaluate the myocardium non-invasively and has become the gold standard for assessing survival. **(Ibanez B, et al 2018).** CMR is used to evaluate early and late post-myocardial infarction (MI) changes in ventricular volume and function and offers crucial information for tissue characterization **(AmanoY, et al 2020).**

Late gadolinium enhancement CMR and tissue edema imagining using T2 sequences had been used to assess the myocardial viability despite multiple restrictions. **(Wamil M, et al 2019).**

Currently, the T1 and T2 sequences used in CMR tissue mapping have shown to be useful in the evaluation of acute myocardial infarction. **(Eyyupkoca, et al 2022).**

Additionally, the quantitative T2 mapping enhances sensitivity and specificity in the diagnosis of myocardial edema and overcomes significant obstacles associated with T2W imaging of the heart. **(Kramer CM et all 2020).**

After six months, T1 and ECV measurements may be used to gauge the extent of myocardial injury and predict functional recovery. **(Basmah Safdar, et al 2018) (Robinson AA, et al 2019).**

Our study aimed to evaluate the diagnostic and prognostic use of CMRI tissue mapping in acute ischemic heart disease following primary PCI to discriminate between myocardial edema and myocardial necrosis.

Patients and Methods:

Between December 2021 and April 2023, 90 individuals had elective CMRI appointments scheduled. Our patients arrived at the cardiology department with a clinical diagnosis of an acute myocardial infarction requiring PCI. One to two days after PCI, they were referred to the radiology department for CMRI as part of a research study. Three to four months later, a follow-up CMRI was carried out.

Written consent to participate in our medical research and publish the results was taken from the patients after medical control of acute infarction.

All hemodynamically stable patients were exposed to the percutaneous coronary intervention (PCI), to assess and restore patency of infarct-related artery (IRA). The angiography procedure, findings, and intervention maneuvers were recorded by our cardiology Coauthor.

Inclusion criteria:

- Patients with the clinical picture of an acute myocardial infarction, diagnosed by our cardiology co-author, after primary PCI and clinical control, were included in our study.

Exclusion criteria:

- Contraindications for MR Imaging, including cardiac pacemakers**,** cochlear implant**,** extremely irregular heart rate, inability to sustain a breath hold, and claustrophobia.
- Contraindication for MR contrast material, in cases of renal insufficiency (GFR< 30 ml/min/1.73 m2)
- Haemdynamicly unstable patients

One to two days after primary PCI, they were referred to the radiology department for CMRI as part of a research study. Three to four months later, a follow-up CMRI was carried out.

Scanner: 1.5-T scanner (Philips Achieva, Netherland).

ECG pads were placed on the anterior chest wall.

Contrast material: Injection of 0.15 mmol/Kg body weight gadolinium-based contrast agent.

Post-processing imaging analysis using dedicated Philips Intellispace Portal version 8.0 software.

Image acquisition:

Scout with proper field of view (FOV) covers the heart in the three orthogonal planes for planning the subsequent images.

Cine images using the bright blood steady-state free precession (SSFP) sequences were acquired in the horizontal long axis (4 chambers), vertical long axis (2 chambers), short axis

(SAX) from the mitral valve plane through the apex covering the entire ventricles., (3 chamber) and left ventricular outflow tract (LVOT) planes.
All MRI imaging was ECG gated during a gentle expiratory breath-hold.
The long-axis views during end-diastole were used to assess the basal cuts at the level of the atrioventricular (AV) junction.
Short axis stack in both the 2-chamber and 4-chamber views were parallel to the mitral valve or perpendicular to the interventricular septum (IVS). Slice thickness of 8 mm and interslice gaps of 0 mm were used for SAX Parallel imaging for accurate detection of the thinned-out segments, measurement of the ejection fraction, and left ventricular (LV).
T2 quantification mapping was performed with a gradient-based sequence in short-axis images (apical, ventricular, and basal cuts).
Pre and post-contrast T1 quantification mapping was done using the modified sequence Look-Locker Inversion recovery (MOLLI) short-axis images (apical, mid-ventricular, and basal cuts).
T1 and T2 quantification mapping images were acquired in the same cardiac phases at late diastole and with the same imaging parameters.
Late gadolinium enhancement (LGE): 6-10 minutes after contrast injection using gradient echo sequences for detection of hyper-enhancement (fibrosis).

Post-processing:

Assessment of Left ventricle wall Thickness and Function: Using Philips Intellispace Portal (version 8.0.) workstation. In the short axis view, well manually contoured the endocardial borders at end-diastole and end-systole for measuring the ejection fraction (EF), the stroke volume (SV) the end-diastolic volume (EDV), and the end-systolic volume (ESV),

Assessment of myocardium in late gadolinium enhancement (LGE) sequences: to identify the hyper-enhanced segments(fibrosis) and segments of MVO.

Assessment of Myocardial ECV and T2 map: Short-axis tissue map (T2 map, T1 pre-contrast, T1 post-contrast map) images at the apical, mid-ventricular, and basal levels were manually assessed and divided into 16 segments based on the 17 cardiac segments' model (excluding the true apex). ECV was calculated by drawing the ROI in the blood pool in the pre and post-contrast T1 map images to obtain the signal shortening of the blood.
Three to four months later Follow-up: MRI examination was done for assessment of the myocardial wall thickness, left ventricular volume, and function.
Complications in our study were expressed in terms of thinning of the myocardium in case of > 50% thickness loss in the follow-up MRI compared to the initial MRI. Left ventricular remodeling is defined as based on EDV change: >20% increase in baseline EDV, based on ESV change: >15% increase in baseline ESV, and based on EF change: >5% drop in baseline EF.
Statistical analysis: we used R statistical package version 3.5.1 and SPSS version 25. Statistical significance was considered if the two p-values were < 0.05.

Results

A total number of 90 patients diagnosed with an acute myocardial infarction & underwent primary PCI were scheduled for elective CMRI between December 2021 and April 2023.

Patient characteristics:

This study involved a total of 90 patients: 64 males and 26 females with a mean age of 55 (± 5) years.

Primary PCI data:

Left anterior descending (LAD) was the main vessel in 56 (62.3%) patients. While the right coronary artery (RCA) was the main vessel in 23 (25.5%) patients and the left circumflex (LCX) was the main vessel in 11 (12.2%) patients.
The site of vessel affection was proximal in 51 patients (56.7%) and the mid-segment in 39 patients (43.3%).
Thrombectomy was performed in 44 patients. No PCI-related complications were encountered. The number of diseased vessels ranged from a single vessel to three vessels. The Syntax score was 22 ± 7.9 while the mean residual Syntax score was 5.2 ± 8.7.

LAD was the main vessel affected especially at the proximal part (Table 1).

Table (1): PCI data.

Parameters		**Count**	**%**
Main vessel	**LAD**	**56**	**62.3%**
	RCA	**23**	**25.5%**
	LCX	**11**	**12.2%**
Lesion site	**Proximal**	**51**	**56.7%**
	Mid	**39**	**43.3 %**
Thrombectomy	**Thrombus aspiration**	**44**	**48.9%**
	Conventional PCI without aspiration	**46**	**51.1%**

MRI follow-up results in the second visit:
In our study, about 45 patients (50%) were complicated by myocardial thinning, 40 patients (44.4%) were complicated by left ventricular (LV) remodeling (ESV change definition), 38 patients (42.3%) were complicated by LV remodeling (EDV change definition) & only 12 patients (13.3%) were complicated by LV remodeling (EF drop definition) (Table 2).
Table (2): MRI follow-up results in the second visit.

Parameters	**Count**	**%**
myocardial thinning	**45**	**50%**
left ventricular (LV) remodeling (ESV change definition)	**40**	**44.4%**
LV remodeling (EDV change definition)	**38**	**42.3%**
LV remodeling (EF drop definition)	**12**	**13.3%**

Tissue mapping in the hyper-enhanced versus remote segments:
Different tissue mapping values in our study demonstrated a significant statistical difference between hyper-enhanced (HE) and remote segments with a P value of 0.001. (Table 3).

Table (3): Tissue mapping in the hyper-enhanced VS remote segments.

Area Characteristics	**HE area**	**Remote area**	**P value**

T2	58.6 ± 5.7	50.2 ± 3.5	<0.001
Native T1	1110 ± 103	1064 ± 52.5	<0.001
Post contrast T1	352.7 ± 78.6	375.2 ± 65.6	<0.001
ECV	45.1 ± 16.7	32.1 ± 3.3	<0.001

Tissue mapping in hyper-enhanced segments and microvascular obstruction:
We found Microvascular obstruction in 70 patients (63%) In patients with MVO, there was a difference in tissue mapping values between segments of MVO & hyper-enhanced segments with no MVO, (yet not statistically significant). There was also a propensity for the tissue mapping values of the MVO segments to become pseudo-normalized (Table 4).

Table (4): Tissue mapping in the hyper-enhanced VS segments with MVO

Segment / Characteristics	**HE segments with MVO (N =70)**	**HE segments with no MVO. (N=20)**	**P value**
T2	55.2 ± 7.5	57.5 ± 6.1	0.135
Native T1	1053.1 ± 103	1073.5 ± 97.3	0.502
Postcontrast T1	315.8 ± 70.5	295.6 ± 68.2	0.270
ECV	44.3 ± 37.5	45.8 ± 4.3	0.610

The suggested cut-off value for the diagnosis of myocardial edema/hyperenhancement:
T2 map suggested cut-off value: With 81% sensitivity, 72% specificity, 75% positive predictive value, 79% negative predictive value, and 77% accuracy, the suggested cutoff value for the T2 map was 53.2ms (millisecond), with the area under the curve (AUC) is 0.796 (Table 5).

Table (5): Suggested T2 map cut-off value for diagnosis of myocardial edema.

Patients / T2 map	All patients (N = 90)	Patients with MVO (N = 70)	Patients with no MVO (N = 20)
Cut off value	53.2	53.7	53.2
Sensitivity	0.81	0.68	1.00
Specificity	0.72	0.78	0.72
PPV	0.75	0.65	0.59
NPV	0.79	0.80	1.00
Accuracy	0.77	0.74	0.81

B) Native T1 map suggested cut-off value: In our study, there are two suggested cut-off values of the native T1 map:
1) The first one had a 1076.9 ms time window, an accuracy of 77%, sensitivity of 69%, specificity of 81%, positive predictive value of 78%, and negative predictive value of 72%. The AUC is 0.744 (**Table 6).**
2) The second one had a1069.3 ms time window, had an accuracy of 75%, sensitivity 76%, specificity 74%, positive predictive value 74%, and negative predictive value 75%. with the AUC is 0.744 **(Table 6).**

Table (6): Suggested T1 map cut-off value for diagnosis of myocardial edema.

Patients / Native T1	All patients (N = 90)	Patients with MVO (N = 70)		Patients with no MVO (N = 20)
Cut off value	1076.9	1069.3	1069.3	1088.4
Sensitivity	0.69	0.75	0.76	0.88
Specificity	0.81	0.73	0.74	0.84
PPV	0.78	0.73	0.74	0.66
NPV	0.72	0.74	0.75	0.95
Accuracy	0.77	0.74	0.75	0.85

C) ECV suggested cut-off value: Extracellular volume (ECV) proposed cut-off value displayed 85% accuracy, 89% positive predictive value, 80% negative predictive value, 79% sensitivity, and 90% specificity, with the AUC being 0.859. The suggested ECV cut-off value shows the highest specificity, positive predictive value, negative predictive value & accuracy as compared to that of the T2 and native T1 maps (even in patients with MVO) (Table 7).

Table (7): Suggested ECV cut-off value for diagnosis of myocardial edema.

Patients / ECV	All patients (N = 90)	Patients with MVO (N = 70)	Patients with no MVO (N = 20)
Cut off value	36.4	36.6	36.4
Sensitivity	0.79	0.71	0.94
Specificity	0.90	0.60	0.90
PPV	0.89	0.81	0.77
NPV	0.80	0.84	0.98
Accuracy	0.85	0.83	0.91

Cases:

Case 1

Clinical history: A 43-year-old male patient came with acute myocardial infarction eligible for primary PCI. Smoker. Not diabetic nor hypertensive. Dyslipidemic. Negative family history of ischemic heart disease.

ECG: Acute anterior ST-elevation myocardial infarction (STEMI).

Troponin peak: > 50 ng/ml.

Primary PCI: mid-LAD lesion (culprit lesion). Stenting was performed.

MRI findings (first visit):

Hyperenhanced segments: segments 2, 3, 7, 8, 9, 10, 13, 14 & 15.

MVO: segments 2, 3, 7, 8, 9, 10, 13, 14 & 15. (Mico vascular occlusion from 1- the vasoconstrictor mediators following revascularization or 2- microvascular distal embolization during embolectomy)

Values of tissue mapping:

Table 8: Tissue mapping values in the case.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
T2 map (%)	45	46	45	46	46	45	55	60	58	52	47	49	61	62	58	56
native T1 (ms)	1034	1069	1068	1064	1084	1051	1022	1095	1115	1101	1063	968	1005	1122	1095	961
Postcontrast T1(ms)	500	412	476	467	468	497	370	412	386	423	526	478	353	399	380	368

ECV (%)	28	41	32	33	33	29	47	41	46	40	26	29	54	47	50	49

MRI findings (2nd visit):
Thinned out segments: yes (segments 8, 9, 13 & 13).
LV remodeling (EDV definition): yes.
LV remodeling (ESV definition): yes.
LV remodeling (EF definition): no.

Table 9: case 1 LV volumes & functions in the first & second visits.

	EF (%)	EDV (ml)	ESV (ml)	SV (ml)
1st Visit	**29**	**174**	**124**	**50**
2nd Visit	**27**	**227**	**166**	**61**

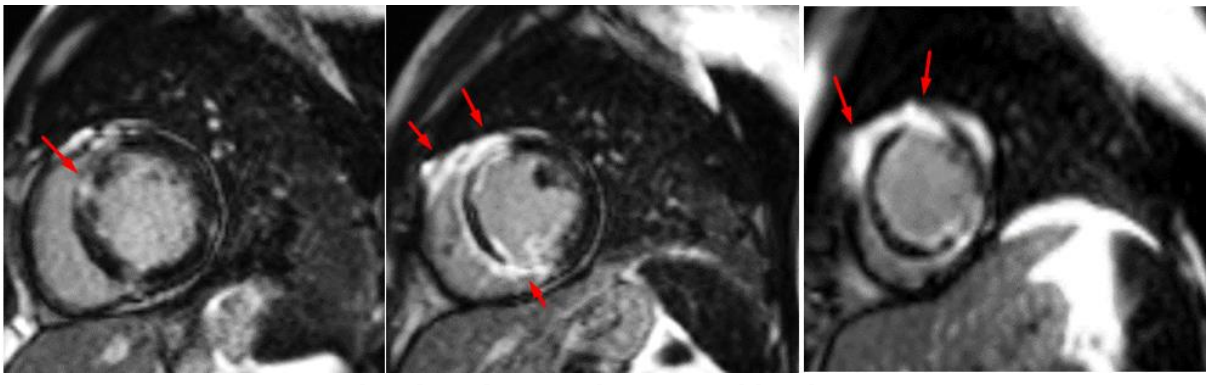

Figure 1: LGE images at basal, midventricular & apical levels.

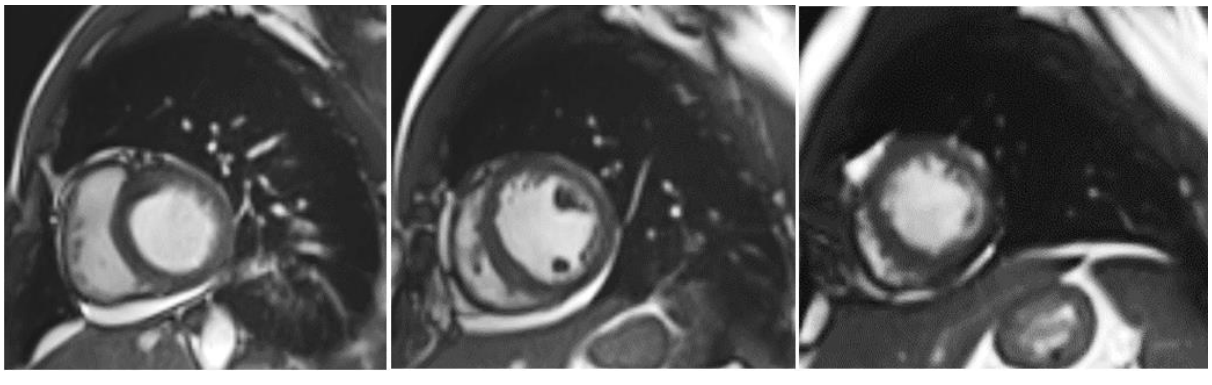

Figure 2: CINE images at basal, midventricular & apical levels (first visit).

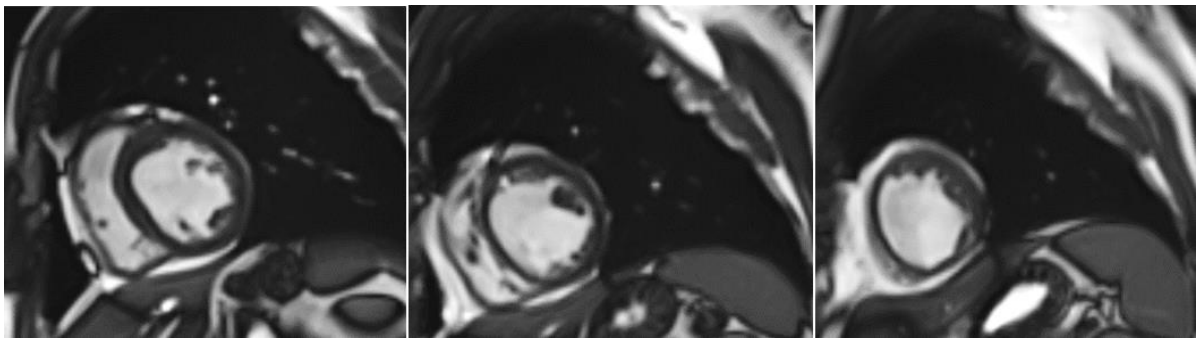

Figure 3: CINE images at basal, midventricular & apical levels (2nd visit).

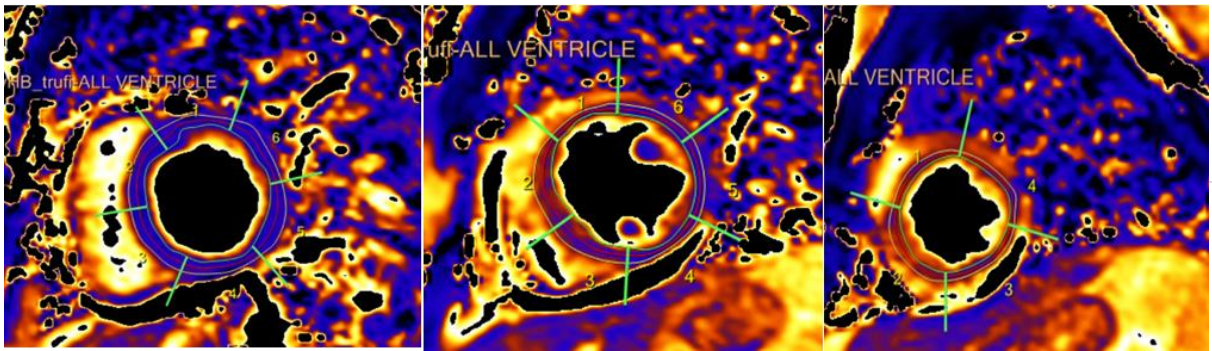

Figure 4: T2 map images at basal, midventricular & apical levels (first visit).

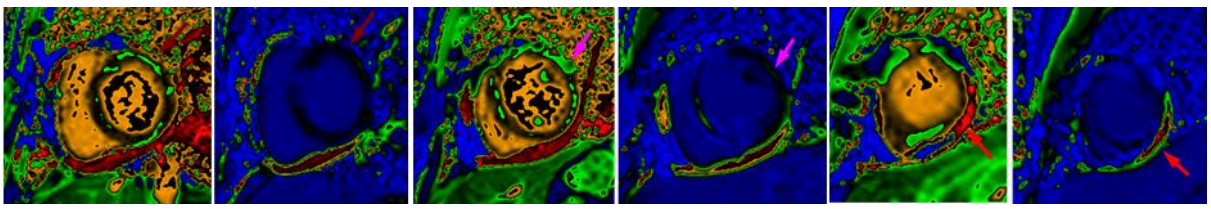

Figure 5: T1 map (native & post-contrast) images at basal, midventricular & apical levels (first visit).

Case 2

Clinical history: A 53-year-old male patient came with acute myocardial infarction eligible for primary PCI. Smoker. Not diabetic nor hypertensive. Dyslipidemic with a positive family history of ischemic heart disease.

ECG: Acute anterior STEMI.

Troponin peak: = 29.4 ng/ml.

Primary PCI: proximal LAD lesion (culprit lesion). Stenting was performed.

MRI findings (first visit):

Hyperenhanced segments: segments 8, 9, 14 & 15.

MVO: No.

Values of tissue mapping:

Table 10: Tissue mapping values in case 2.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16
T2 map (%)	56	53	51	48	50	53	61	68	62	52	56	59	60	69	59	60
native T1 (ms)	991	1059	1013	999	993	950	956	1172	1171	1088	980	936	1011	1170	1112	969
postcontrast T1(ms)	434	333	403	313	334	414	427	291	299	458	440	431	373	286	393	437
ECV (%)	27	43	31	46	42	29	29	57	55	28	28	28	38	59	37	28

MRI findings (2nd visit):

Thinned out segments: No.

LV remodeling (EDV definition): No.

LV remodeling (ESV definition): No.

LV remodeling (EF definition): No.

Table 11: case 2 LV volumes & functions in the first & second visit

	EF	**EDV**	**ESV**	**SV**
1st Visit	**47**	**154**	**81**	**72**
2nd Visit	**66**	**142**	**49**	**93**

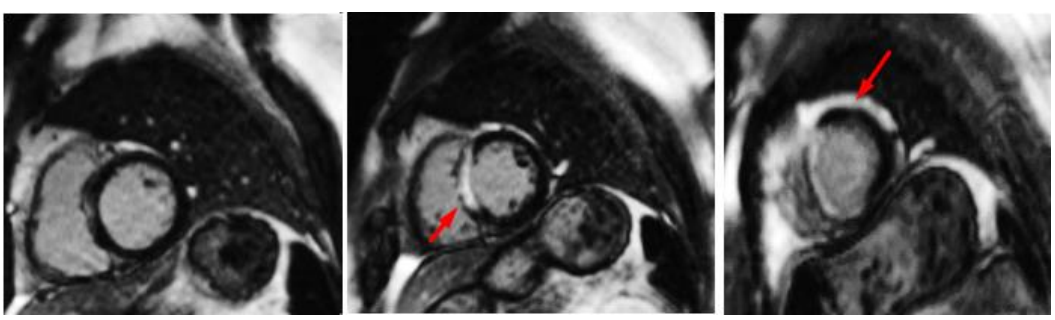

Figure 6: LGE images at basal, midventricular & apical levels (first visit).

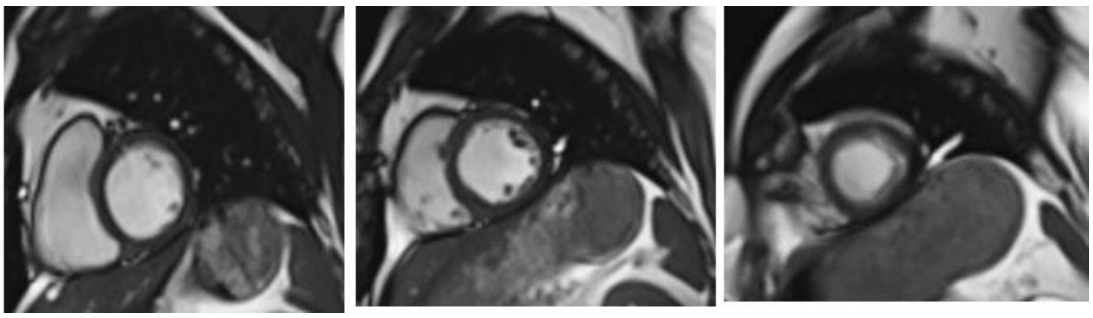

Figure 7: CINE images at basal, midventricular & apical levels (first visit).

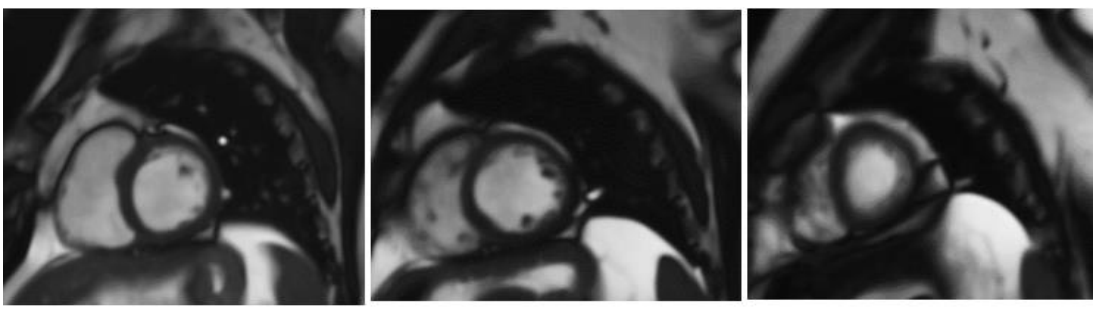

Figure 8: CINE images at basal, midventricular & apical levels (2nd visit).

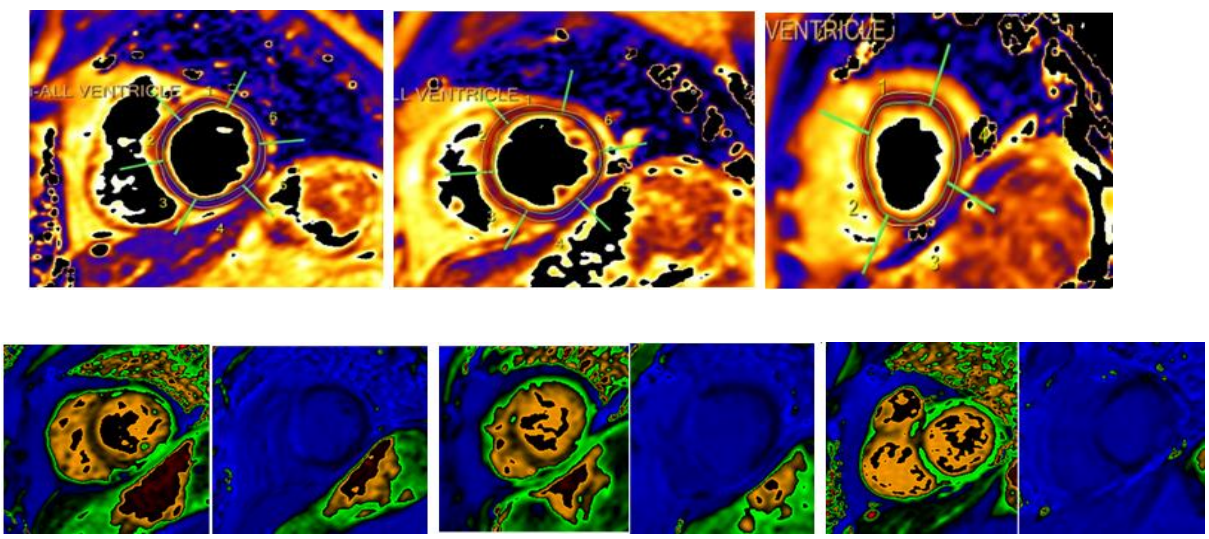

Figure 9: T2 map images at basal, midventricular & apical levels (first visit).

Figure 10: T1 map (native & post-contrast) images at basal, midventricular & apical levels (first visit).

Discussion

The clinical history and imaging, particularly trans-thoracic echocardiography (TTE), are often delayed in diagnosing acute coronary syndrome. Instead, early electrocardiographic changes and elevated cardiac enzyme levels are typically applicable for STEMI diagnosis. **(Baritussio et al. 2018).**

The size of the jeopardized area that is in danger offers predictive information that could be a therapeutic target, even in early and successful revascularization. **(Göransson C, et al. 2019).**

Using T2WI CMR imaging, myocardial edema has been used to differentiate between acute and chronic myocardial infarction. Some of the T2 sequences' drawbacks include phased

array coils, slow-moving chamber blood that interferes with T2 in the sub-endocardial region, motion artifacts, and subjective interpretation of the T2 image.

T2 mapping offers a technique for enhancing myocardial edema identification accuracy and gets beyond the drawback of T2W heart imaging. **(Spieker M et al., 2017)**

The importance of the T2 map in the identification of myocardial edema was highlighted by Granitz M et al in 2019. Additionally, it enables quantitative assessment of the myocardium, allowing accurate tracking of disease progress and/or treatment. The T2 of the human myocardium, according to their findings, was 52.18 3.4 ms (range: 48.96 ms to 55.67 ms).

In our analysis, we recommended a 53.2 ms T2 map cut-off value. This value had respectable specificity (71%), positive predictive value (74%), negative predictive value (78%) and accuracy (76%), and it reached 100% in individuals who had no MVO.

The recommended T2 map cut-off value in our analysis is similar to the **Granitz M et al. (2018)** cut-off value (52 ms), which demonstrated 82% sensitivity and 85% specificity.
Our investigation found that MVO declined the T2 map's sensitivity, positive predictive value, and accuracy. We concurred with **Aherne E et al. (2020)** that the remote and hyper-enhanced regions had statistically significant differences in native T1 values.

In our investigation, the remote segments' mean native T1 value was 1046 58.3 ms while the hyperenhanced segments' mean native T1 value was 1107 103 ms, with a P value of 0.001. **Aherne E et al. (2020)** found that the remote segments had a mean native T1 value of 1196 56 ms while the hyper-enhanced segments had a mean native T1 value of around 1257 97 ms. A 3T CMR was used in their study.

Bulluck et al. (2017) performed an investigation with a 3 T CMR with a T1 cut-off value of 83% sensitivity and 80% specificity for areas of myocardial necrosis. The suggested cut-off value in our investigation demonstrated 73% specificity and 75% sensitivity.

In our study, post-contrast T1 and ECV showed marked statically differences between hyper-enhanced and remote segments.

We concurred with **Aherne E et al. (2020)** that the T1 value of the segment with MVO showed a T1 value higher than the remote myocardium and lower than the hyper-enhanced segments without MVO, but we did not demonstrate a significant statistical difference between the MVO segments and the hyper enhanced segments without MVO. This resulted from our study's segmental method of measurement, which included both an area of MVO with hyperenhancement and an area without it in the same segment. In contrast, the ROI technique of measurement merely took into account the MVO area.

In our investigation, hyper-enhanced and remote segments displayed clear statically different post-contrast T1 and ECV images.

To identify the area in danger, Garg et al. (2018) chose a cut-off value for ECV of 33%. This is close to the recommended ECV cutoff value from our study, which was 36.4% and had the following results: 78% sensitivity, 89% specificity, 88% positive predictive value, 80% negative predictive value, and 84% accuracy.

Additionally, we concurred with Garg et al. (2018) that MVO results in lower ECV than the hyper-enhanced area. Although we did not demonstrate a significant statistical difference, the portions of the MVO displayed pseudonormalization of the ECV and post-contrast T1 values. They demonstrated that a follow-up improvement in segmental function had 81% sensitivity and 65% specificity for an infarct ECV of less than 50%.

Our research shows that MVO reduced the native T1 and ECV's sensitivity, positive predictive value, and accuracy. This was in agreement with Garg et al. (2018), who thought MVO opposed T1 mapping since it led to a pseudo-normalization of T1 values in this region.

Conclusion

We concluded that the use of tissue mapping to identify STEMI individuals with salvageable myocardial tissue post-primary PCI and obtain cutoff values with adequate sensitivity, specificity, and accuracy in early and late follow-up of myocardial evaluation.

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