DOI: https://doi.org/10.70749/ijbr.v3i4.1056

INDUS JOURNAL OF BIOSCIENCE RESEARCH
https://induspublishers.com/IJBR
ISSN: 2960-2793/ 2960-2807

Assessment of Myocardial Viability in Patients with Chronic Total Occlusion Using Cardiac MRI Scan

Syed Akmal Shah[1], Syed Yasser Javaid[1], Qamar uz Zaman Bhatti[1], M Bilal Siddique[2], M Waleed Ghous[1], Shaheer Farhan[1], Naseem Azad[3]

[1]Department of Adult Cardiology, Armed Forces Institute of Cardiology/ National Institute of Heart Disease, Rawalpindi, Punjab, Pakistan.
[2]Department of Adult Cardiology, Combined Military Hospital (CMH) Kharian, Pakistan.
[3]Research Department, Armed Forces Institute of Cardiology/ National Institute of Heart Disease, Rawalpindi, Punjab, Pakistan.

ARTICLE INFO

Keywords
Coronary Artery Disease, Chronic Total Occlusion, Cardiac Magnetic Resonance Imaging, Late Gadolinium Enhancement, Myocardial Viability, Revascularization.

Corresponding Author: Syed Akmal Shah,
Department of Adult Cardiology, Armed Forces Institute of Cardiology, NIHD Rawalpindi, Punjab, Pakistan.
Email: syedakmalshah@gmail.com

Declaration
Authors' Contribution: SAS: Manuscript drafting, study concept and approval of the final version to be published.
Conflict of Interest: No conflict of interest.
Funding: No funding received by the authors.

Article History
Received: 11-03-2025, Revised: 12-04-2025
Accepted: 15-04-2025, Published: 30-04-2025

ABSTRACT

Objective: To assess myocardial viability in patients with chronic total occlusion using cardiac MRI scan. **Study Design:** Prospective cross-sectional study. **Place and Duration of Study**: Armed Forces Institute of Cardiology/National Institute of Heart Disease Rawalpindi Pakistan, 1st Dec 2024 to 1st March 2025. **Methodology:** Seventy-two patients with chronic total occlusion confirmed on coronary angiography were enrolled and further assessed using cardiac MRI. Initial imaging was performed for heart positioning, followed by acquiring standard cardiac planes for anatomical assessment. Gadolinium contrast was administered to evaluate myocardial viability. After a delay of 10–15 minutes, late gadolinium enhancement (LGE) imaging was conducted to detect scar and fibrosis. The LGE images were analyzed to determine the location, extent, and transmurality of the scar. Myocardial segments corresponding to the affected vascular territories were systematically assessed to differentiate between viable (<50% LGE) and non-viable (>50% LGE) myocardium. **Results:** The study included 72 participants, with a predominant representation of males, 63(87.5%), The mean age of participants was 65.97±8.39 years. Cx had the highest viability 64(88.9%), followed by the RCA 52(72.2%) and LAD 46(63.9%). Conversely, non-viability was least prevalent in LCx 8(11.1%) and highly prevalent in LAD 26(36.1%), indicating that the LAD artery exhibited the most compromised viability among the three major coronary arteries. **Conclusion:** Cardiac MRI is a valuable tool for assessing myocardial viability in patients with chronic total occlusion, aiding in clinical decision-making for revascularization. The study highlights that the LAD artery exhibits the most compromised viability.

INTRODUCTION

Coronary artery disease (CAD) remains the leading cause of mortality worldwide, contributing to over 50% of congestive heart failure (CHF) cases.[1] Accurate assessment of myocardial viability is crucial in managing CHF secondary to CAD, as viable but dysfunctional myocardium may recover function following revascularization, leading to improved ventricular performance and long-term survival.[2]

Chronic total occlusion (CTO) is a significant subset of CAD, accounting for approximately 20% of cases. It is defined as complete coronary artery occlusion with Thrombolysis in Myocardial Infarction (TIMI) grade 0 flow, within a major epicardial coronary artery of at least 2.5 mm and an estimated duration of ≥3 months.[3] While collateral circulation is often used as an indicator of viability,[4] coronary angiography alone cannot reliably assess myocardial ischemia and infarction in CTO-affected regions, limiting its utility in viability evaluation.[5]

Various imaging modalities, including nuclear imaging, stress echocardiography, and stress electrocardiography, have been utilized to assess myocardial viability and detect ischemia. However, cardiac magnetic resonance imaging (CMR) has emerged as a superior non-invasive modality due to its high spatial resolution and lack of radiation exposure. CMR offers a comprehensive assessment through cine imaging for cardiac morphology and contractile function, perfusion studies (with or without vasodilators) for myocardial perfusion, and contrast-enhanced imaging for infarct detection and tissue characterization.[6] Notably, CMR provides a more accurate assessment of left ventricular ejection fraction,[7] and late gadolinium enhancement (LGE) allows for the non-invasive evaluation of myocardial viability.[8]

Despite the growing use of CMR, limited data exist on its application specifically for viability assessment in CTO cases. Thus the study aims to evaluate myocardial viability in patients with CTO using LGE imaging on cardiac MRI. A more precise assessment could aid in identifying patients who may benefit from revascularization, ultimately improving clinical outcomes.

METHODOLOGY

This prospective cross sectional study was conducted at the Armed Forces Institute of Cardiology/National Institute of Heart Disease, Rawalpindi Pakistan, from December 01, 2024 to March 01, 2025, after formal approval from Institutional Ethical Board (IERB) (Reg#9/2/R&D/2023/292; Dated: November 06, 2023), and Synopsis approval by CPSP with ref CPSP/REU/CRD-2022-113-2840. dated November 30, 2024.

Informed consent was obtained from all patients and Consecutive sampling technique was used to collect data.

The sample size of 72 was calculated using the WHO sample size calculator, with a 95% confidence level, 5% absolute precision, and a population proportion of 94.93% (0.9493) for patients with ≤50% LGE.[4]

Inclusion Criteria: Both male and female patients aged >18 years and <90 years, with stable/unstable angina, coronary angiography evidence of CTO in at least one of major vessels including LAD, LCX and RCA were included.

Exclusion Criteria: Patients with MRI contraindications, gadolinium allergy, deranged renal function, acute myocardial infarction, congenital/valvular heart disease, myocarditis and SYNTAX score ≥33 were excluded from study.

Patients were evaluated through a detailed history, including symptoms such as chest pain, shortness of breath, palpitations, orthopnea, paroxysmal nocturnal dyspnea, sweating, and apprehension. Transthoracic echocardiography (TTE) was performed to rule out congenital and valvular heart disease as well as myocarditis. High-sensitivity troponin levels and electrocardiography (ECG) were conducted to identify acute ischemic changes, including ST elevations, to exclude acute myocardial infarction.

Patients with suspected coronary artery disease (CAD) underwent coronary angiography after obtaining informed consent. In the catheterization lab, a diagnostic catheter was used under fluoroscopic guidance to assess all major coronary vessels, including the left main stem (LMS), left anterior descending (LAD), left circumflex (LCX), and right coronary artery (RCA). Vessels with chronic total occlusion (TIMI 0 flow for >3 months) were further evaluated using cardiac magnetic resonance imaging (CMR).

Before CMR, renal function was assessed, and contraindications such as pacemakers were ruled out. Patients were monitored via ECG throughout the procedure. Initial imaging was performed to determine heart positioning and obtain standard cardiac planes for anatomical assessment. Myocardial viability was assessed using late gadolinium enhancement (LGE) imaging. Gadolinium contrast was administered, and after a 10–15 minute delay, LGE images were acquired to evaluate scar location, extent, and transmurality.

Myocardial segments were analyzed based on vascular territories:

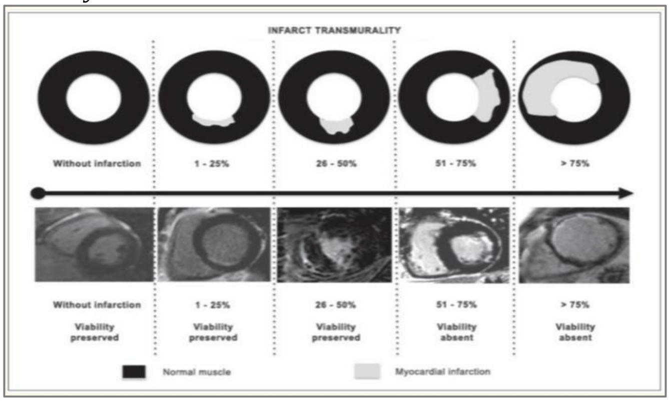
- **LAD**: apex, apical anterior, mid anterior, basal anterior, apical septal, mid anterior septal, basal anterior septal
- **RCA**: apical inferior, mid inferior, basal inferior, mid inferior septal, basal inferior septal
- **LCX**: apical lateral, mid anterior lateral, basal anterior lateral, mid inferior lateral, basal inferior lateral

A myocardium exhibiting ischemic dysfunction but retaining salvageable tissue upon revascularization was considered viable. Segments with <50% LGE were classified as viable, while those with >50% LGE were deemed non-viable.[9,10] (Figure)

Data analysis was performed at Statistical Package for Social Sciences (SPSS) version 23.00. For categorical variables such as (gender, hypertension, diabetes, HBA1C levels, fatigue, coronary artery disease, viability segments involved) frequency and percentages were calculated. Quantitative variables such as age and creatinine levels were presented as Mean±SD. Chi square test was applied to find association of categorical variables with myocardial viability. $p<0.05$ was taken as significant.

Figure 1

Normal vs. Infarct Artery Based On LGE and Myocardial Viability



RESULTS

The study included 72 participants, with a predominant representation of males, 63(87.5%), compared to females, 9(12.5%). The mean age of participants was 65.97±8.39 years. Among clinical symptoms, chest pain was reported in 45(62.5%) and shortness of breath was prevalent in 58(80.6%). Palpitations were observed in 27(37.5%), and sweating and apprehension were each noted in 23(31.9%). Regarding comorbidities, majority of participants were hypertensive 59(82.0%), and diabetics 52(72.2%). Fatigue was reported by 41(56.9%). The median creatinine level was 1.28 mg/dl (IQR: 1.10-1.50). Median HbA1C was 6.90% (IQR: 5.90-8.19), with 43(59.7%) having HbA1C levels ≥6.5% and 29(40.3%) below this threshold. Majority showed high blood pressure readings 48(66.7%). Double vessel disease was more common in study subjects 32(44.4%) in comparison to single and triple vessel disease. (Table-I)

Table I

Baseline characteristics of study participants (n=72)

Variables			Frequency (%)
Demographics	Gender	Male	63(87.5%)
		Female	9(12.5%)
	Age (years) (Mean±SD)		65.97±8.39
Comorbids	Chest Pain	Yes	45(62.5%)
		No	27(37.5%)
	Shortness of Breath	Yes	58(80.6%)
		No	14(19.4%)
	Palpitations	Yes	27(37.5%)
		No	45(62.5%)
	Sweating	Yes	23(31.9%)
		No	49(68.1%)
	Apprehension	Yes	23(31.9%)
		No	49(68.1%)
	Hypertension	Yes	59(82.0%)
		No	13(18.0%)
	Diabetes Mellitus	Yes	52(72.2%)
		No	20(27.8%)
	Fatigue	Yes	41(56.9%)
		No	31(43.1%)
Creatinine (mg/dl) [Median(IQR)]			1.28(1.10-1.50)
HbA1C [Median(IQR)]			6.90(5.90-8.19)
HbA1C		≥6.5%	43(59.7%)
		<6.5%	29(40.3%)
Blood Pressure		≥140/90 mmHg	48(66.7%)
		<140/90 mmHg	24(33.3%)
Coronary Artery Disease		SVCAD	23(31.9%)
		DVCAD	32(44.4%)
		TVCAD	17(23.6%)

SVACD= Single Vessel Coronary Artery Disease; DVCAD=Double Vessel Coronary Artery Disease; TVCAD=Triple Vessel Coronary Artery Disease

Regarding overall vessel outcomes, LCx had the highest viability 64(88.9%), followed by the RCA 52(72.2%) and LAD 46(63.9%). Conversely, non-viability was least prevalent in LCx 8(11.1%) and highly prevalent in LAD 26(36.1%), indicating that the LAD artery exhibited the most compromised viability among the three major coronary arteries. (Table-II)

Table II

Myocardial Viability of Coronary Vessels and Segments (n=72)

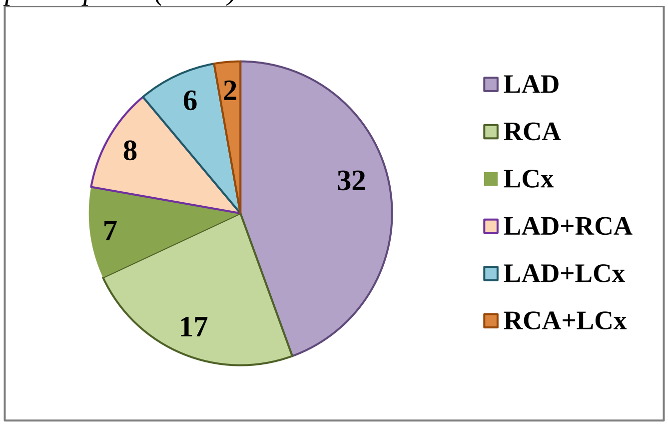
Variables		Frequency (%)
LAD Outcome	Viable	46(63.9%)
	Non-Viable	26(36.1%)
RCA Outcome	Viable	52(72.2%)
	Non-Viable	20(27.8%)
LCx Outcome	Viable	64(88.9%)
	Non-Viable	8(11.1%)

LAD=Left Anterior Descending Artery; RCA= Right Coronary Artery; LCx=Left Circumflex

According to the figure-1, the most frequently affected vessel is the LAD, accounting for 32(44.4%) cases, which represents the largest proportion of the study sample. Among the participants, multi-vessel occlusions were also noted: LAD+RCA in 8(11.1%) cases, LAD+LCx in 6(8.3%) cases, and RCA+LCx in only 2(2.8%) cases, making it the least common finding. This distribution highlights the predominance of LAD involvement in chronic total occlusion cases.

Figure 2

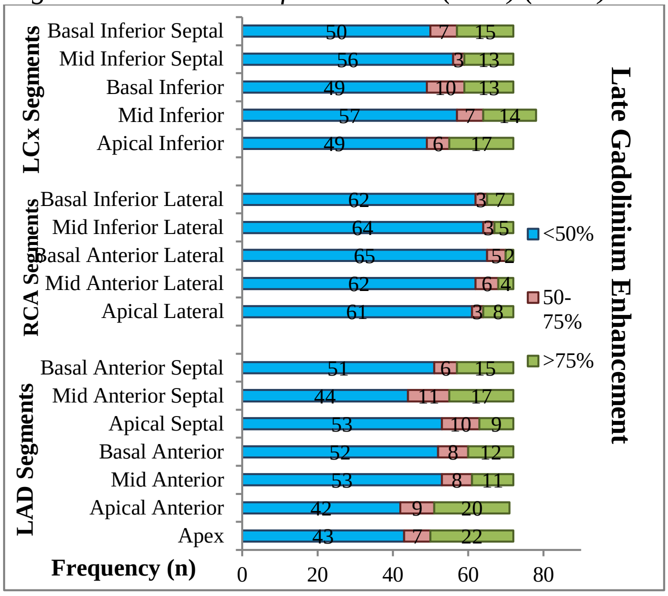
Distribution of Chronic total occluded vessel of study participants (n=72)



According to the findings shown in figure-2, in the LAD segments, the Apex 22(30.6%) showed the least viability (>75% LGE), whereas the Basal Anterior Septal was viable in majority of patients 51(70.8%) exhibited the highest viability (<50% LGE). Overall, lower viability was predominantly found in apical regions, while basal and mid-inferior segments demonstrated higher viability, reflecting regional perfusion variations. In the RCA segments, >75% LGE was least frequent, with the Apical Lateral 8(11.1%) exhibiting the highest values. Most segments, including Basal Anterior Lateral 65(90.3%) and Mid Inferior Lateral 64(88.9%), had higher viability with <50% LGE, suggesting high perfusion. In the LCx segments, the lowest viability (>75% LGE) was observed in the Apical Inferior segment 17(23.6%), while the Mid Inferior 57(79.2%) had the highest viability (<50% LGE).

Figure 3

Distribution of Myocardial Viability across Coronary Segments Based on Perfusion Levels (LGE) (n=72)



The findings from table-III indicate that age was significantly higher in patients with non-viable LCx viability (73.2±9.30) compared to viable cases (65.06±7.89, p=0.008). Fatigue was notably more frequent in non-viable RCA viability (8/8, 100.0%) compared to viable cases (33/64, 51.6%, p=0.009), suggesting a potential association. Although hypertension and diabetes mellitus were common among all groups, no statistically significant differences were observed in their distribution p>0.05). Blood pressure levels (≥140/90 mmHg) were notably prevalent in both viable and non-viable cases across all viability groups, though no strong statistical association was found p>0.05). HbA1C levels were slightly elevated in non-viable LCx cases [Median(IQR: 8.20(6.40-9.75), p=0.15], suggesting a possible metabolic influence. Among coronary artery disease patterns, double-vessel disease (DVCAD) was slightly more frequent in non-viable cases across all segments, though not significantly different (p>0.05)

Table III

Comparison of baseline characteristics with LAD Viability (n=72)

Variables		LAD Viability			RCA Viability			LCX Viability		
Demographics		**Viable (n=46)**	**Non-Viable (n=26)**	**p-value**	**Viable (n=64)**	**Non-Viable (n=8)**	**p-value**	**Viable (n=52)**	**Non-Viable (n=20)**	**p-value**
Gender	Male	39(84.8%)	24(92.3%)	0.47	55(85.9%)	8(100%)	0.58	46(88.5%)	17(85.0%)	1.00
	Female	7(15.7%)	2(7.7%)		9(14.1%)	-		6(11.5%)	3(15.0%)	
Age (years) (Mean±SD)		64.67±8.26	68.26±8.29	0.08	65.83±7.85	66.35±9.89	0.81	65.06±7.89	73.2±9.30	0.008
Comorbids										
Chest Pain		32(69.6%)	13(50.0%))	0.13	42(65.6%)	3(37.5%)	0.244	33(63.5%)	12(60.0%)	1.00
Shortness of Breath		37(80.4%)	21(80.8%)	1.00	51(79.7%)	7(87.5%)	0.69	41(78.8%)	17(85.0%)	0.74
Palpitations		16(34.8%)	11(42.3%)	0.62	23(35.9%)	4(50.0%)	0.70	18(34.6%)	9(45.0%)	0.59
Sweating		15(32.6%)	8(30.8%)	1.00	19(29.7%)	4(50.0%)	0.42	17(32.7%)	6(30.0%)	1.00
Apprehension		15(32.6%)	8(30.8%)	1.00	18(28.1%)	5(62.5%)	0.12	18(34.6%)	5(25.0%)	0.58
Hypertension		35(76.1%)	24(92.3%)	0.14	51(79.7%)	7(87.5%)	1.00	43(82.7%)	15(75.0%)	0.64
Diabetes Mellitus		33(71.7%)	19(73.1%)	1.00	46(71.9%)	6(75.0%)	1.00	37(71.2%)	15(75.0%)	0.78
Fatigue		22(47.8%)	19(73.1%)	0.05	33(51.6%)	8(100%)	0.009	28(53.8%)	13(65.0%)	0.44
Creatinine (mg/dl) [Median(IQR)]		1.20 (1.10-1.45)	1.40 (1.20-1.50)	0.08	1.20 (1.10-1.40)	1.38 (1.20-1.95)	0.01	1.24 (1.10-1.50)	1.40 (1.05-1.48)	0.87
HbA1C [Median(IQR)]		6.55 (5.70-8.10)	7.00 (6.00-8.30)	0.36	6.70 (5.80-7.90)	7.70 (6.00-9.80)	0.08	6.70 (5.90-8.00)	8.20 (6.40-9.75)	0.15
HbA1C	≥6.5%	24(52.2%)	19(73.1%)	0.13	37(57.8%)	6(75.0%)	0.46	29(55.8%)	14(70.0%)	0.40
	<6.5%	22(47.8%)	7(26.9%)		27(42.2%)	2(25.0%)		23(44.2%)	6(30.0%)	
Blood Pressure	≥140/90 mmHg	30(65.2%)	18(69.2%)	0.79	42(65.6%)	6(75.0%)	0.71	35(67.5%)	13(65.0%)	1.00
	<140/90 mmHg	16(34.8%)	8(30.8%)		22(34.4%)	2(25.0%)		17(32.7%)	7(35.0%)	
Coronary Artery Disease	SVCAD	15(32.6%)	8(30.8%)		20(31.3%)	3(37.5%)		15(28.8%)	8(40.0%)	
	DVCAD	23(50.0%)	9(34.6%)	0.26	27(42.2%)	5(62.5%)	0.30	23(44.2%)	9(45.0%)	0.49
	TVCAD	8(30.8%)	9(34.6%)		17(26.6%)	-		14(26.9%)	3(15.0%)	

SVACD= Single Vessel Coronary Artery Disease; DVCAD=Double Vessel Coronary Artery Disease; TVCAD=Triple Vessel Coronary Artery Disease

DISCUSSION

Our study findings revealed LAD as the frequently affected vessel with CTO, followed by LCx and RCA. Multi-vessel occlusions were also noted, where LAD+RCA CTO was common among others; LAD+LCx and RCA+LCx. This distribution highlights the predominance of LAD involvement in chronic total occlusion cases. Regarding overall vessel outcomes, LCx had the highest viability noted in majority of patients (88.9%), followed by the RCA (72.2%) and LAD (63.9%). Thus, the LAD artery exhibited the most compromised viability among the three major coronary arteries. While similar studies in the literature are limited, our findings are consistent with the available evidence, reinforcing the need for further research in this area.

Our study showed male majority 63(87.5%) and composite mean age as 65.97±8.39 years indicated older study subjects who had CTO and underwent CMR study. Shokry et al., also showed male dominance (70%) and older participants (58.0±6 years). Additionally, they reported viability of LAD in 72% patients and RCA and LCx both showed 14% patients in viable group.[11] The higher viability rates in LCx and RCA suggest that these vessels might offer greater potential for myocardial recovery post-revascularization. The use of CMR with LGE provides a non-invasive, highly accurate method for viability assessment, which can guide clinicians in selecting patients most likely to benefit from revascularization.[12,13] This approach not only improves clinical outcomes but also helps avoid unnecessary interventions in patients with predominantly non-viable myocardium, ultimately enhancing resource allocation and patient care.

Myocardial non-viability, particularly in the LAD, RCA, and LCx segments**,** was significantly more common in older patients and those experiencing fatigue ($p<0.05$) in our study. This finding aligns with the study by Shokry et al., where the mean age in the non-viable group was higher than in the viable group (57 ± 6 vs. 56 ± 8 years)**.** The slightly higher mean age in non-viable patients across both studies suggests that age-related factors, such as reduced myocardial regenerative capacity, microvascular dysfunction, and prolonged ischemic burden, may contribute to lower viability in older individuals**.** Additionally, fatigue as a prevalent symptom in these patients indicates underlying myocardial dysfunction**,** reinforcing the role of viability assessment in symptomatic individuals.[14] Clinically, these findings highlight the importance of advanced imaging modalities like CMR in older CTO patients to accurately assess myocardial viability, helping guide revascularization decisions and prevent unnecessary interventions in non-viable cases while optimizing treatment for those with salvageable myocardium.

Our study showed patients in which Angina symptoms were present in 45(62.5%) & most commonly involved vessel was LAD (44.4%). Among multi-vessels involved with CTO segments LAD+LCX were involved in 6(8.3%) patients of our study. In consistent to these findings, Jiang et al., reported multivessel CTO in 3(5.9%) patients.[15] Similarly a study by Li and colleagues, reported angina symptoms in 33(55.9%) patients & most commonly vessel LAD (45.8%) [16] Since the LAD artery supplies a large portion of the myocardium, its occlusion is associated with significant left ventricular dysfunction and adverse cardiovascular outcomes.[17] Identifying patients with LAD CTO and persistent angina symptoms is crucial, as revascularization in viable myocardium can improve symptoms, restore cardiac function, and enhance survival rates.

Our study revealed non-viable segments in the LAD (36.1%), RCA (27.8%), and LCx (11.1%), findings that are comparable to a similar study which reported non-viable segments in the LAD (31%), RCA (57%), and LCx (12%).[15] While both studies indicate LAD as a major site of myocardial non-viability, our study showed a relatively lower percentage of RCA non-viability (27.8% vs. 57%), possibly due to differences in patient demographics, disease severity, or collateral circulation. The clinical significance of these findings lies in their impact on treatment decisions and prognosis. Patients with a higher proportion of non-viable myocardium, especially in the LAD territory, may derive less benefit from revascularization, whereas those with predominantly viable myocardium could experience functional recovery post-intervention. This indicate the importance of Cardiac MRI with LGE in accurately assessing myocardial viability, ensuring optimal patient selection for revascularization, reducing unnecessary procedures, and improving long-term cardiac outcomes.

In a study titled Evaluation of Myocardium by CMR in Patients with Chronic Total Occlusion, among 149 CTO lesions, only 11.5% exhibited transmural infarction, while 58.6% showed no delayed enhancement.[18] Similarly, in the present study, non-viability was observed in various segments of the LAD, RCA, and LCx using CMR. However, the majority demonstrated less than 50% LGE, indicating viable myocardium, which suggests the potential for functional recovery upon revascularization. This finding explains that clinical identification of viable myocardium in CTO patients is crucial for guiding revascularization decisions, optimizing treatment strategies, and improving long-term cardiac function and patient outcomes.

Thus, CMR is a highly effective modality for assessing myocardial viability, particularly in patients with CTO. Its strengths lie in its high spatial resolution and ability to provide comprehensive clinical data, including ventricular function, myocardial perfusion, viability, and intra-cardiac thrombus detection.[19] Unlike other imaging techniques, CMR utilizes magnetic fields and radiofrequency pulses, eliminating exposure to ionizing radiation. The viability assessment techniques using LGE have been validated at both the cellular level and through large-scale multicenter clinical trials.[20,21] Additionally, CMR offers detailed evaluation of microvascular obstruction and the area at risk, making it a promising tool not only for CTO assessment but also for viability evaluation following acute myocardial infarction. Given its non-invasive nature, diagnostic accuracy, and prognostic value, CMR plays a crucial role in guiding revascularization strategies in CTO patients.

Incorporating CMR viability assessment into routine clinical practice could significantly impact the management of CTO patients by offering a reliable, radiation-free alternative for assessing myocardial viability and predicting revascularization benefits.

Limitations

CMR viability assessment relies on late gadolinium enhancement, which may not fully differentiate between viable but stunned myocardium and truly infarcted tissue. Furthermore, the lack of long-term follow-up data limits the ability to correlate viability findings with clinical outcomes post-revascularization.

CONCLUSION

Cardiac MRI is useful in assessing viable segments among totally occluded coronary vessels which will help us to guide revascularization in the form of Angioplasty or CABG of the occluded vessel and will improve the quality of life and reduce mortality and morbidity.

Acknowledgement

We are really grateful to our consultants for their guidance and support that greatly assisted this research. We also want to share our gratitude for Comdt. Exec Dir. AFIC/NIHD for their support and contribution in completion of the research paper.

REFERENCES

1. Pagliaro, B. R., Cannata, F., Stefanini, G. G., & Bolognese, L. (2019). Myocardial ischemia and coronary disease in heart failure. *Heart Failure Reviews*, *25*(1), 53–65. https://doi.org/10.1007/s10741-019-09831-z
2. Kwon, D. H., Obuchowski, N. A., Marwick, T. H., Menon, V., Griffin, B., Flamm, S. D., & Hachamovitch, R. (2018). Jeopardized Myocardium Defined by Late Gadolinium Enhancement Magnetic Resonance Imaging Predicts Survival in Patients With Ischemic Cardiomyopathy: Impact of Revascularization. *Journal of the American Heart Association*, *7*(22). https://doi.org/10.1161/jaha.118.009394
3. Koelbl, C. O., Nedeljkovic, Z. S., & Jacobs, A. K. (2018). Coronary Chronic Total Occlusion (CTO): A Review. *Reviews in Cardiovascular Medicine*, *19*(1), 38–44. https://doi.org/10.31083/j.rcm.2018.01.896
4. Schumacher, S. P., Everaars, H., Stuijfzand, W. J., Huynh, J. W., van Diemen, P. A., Bom, M. J., de Winter, R. W., van Loon, R. B., van de Ven, P. M., van Rossum, A. C., Opolski, M. P., Nap, A., & Knaapen, P. (2020). Coronary collaterals and myocardial viability in patients with chronic total occlusions. *EuroIntervention*, *16*(6), e453–e461. https://doi.org/10.4244/eij-d-19-01006
5. Wang, L., Lu, M.-J., Feng, L., Wang, J., Fang, W., He, Z.-X., Dou, K.-F., Zhao, S.-H., & Yang, M.-F. (2019). Relationship of myocardial hibernation, scar, and angiographic collateral flow in ischemic cardiomyopathy with coronary chronic total occlusion. *Journal of Nuclear Cardiology*, *26*(5), 1720–1730. https://doi.org/10.1007/s12350-018-1241-8
6. Pica, S., Giovine, G. D., Bollati, M., Testa, L., Bedogni, F., Camporeale, A., Pontone, G., Andreini, D., Monti, L., Gasparini, G., Grancini, L., Secco, G. G., Maestroni, A., Ambrogi, F., Milani, V., & Lombardi, M. (2018). Cardiac magnetic resonance for ischaemia and viability detection. Guiding patient selection to revascularization in coronary chronic total occlusions: The CARISMA_CTO study design. *International Journal of Cardiology*, *272*, 356–362. https://doi.org/10.1016/j.ijcard.2018.08.061
7. Arnold, J. R., & McCann, G. P. (2019). Cardiovascular magnetic resonance: applications and practical considerations for the general cardiologist. *Heart*, *106*(3), 174–181. https://doi.org/10.1136/heartjnl-2019-314856
8. Zhao, L., Lu, A., Tian, J., Huang, J., & Ma, X. (2020). Effects of Different LVEF Assessed by Echocardiography and CMR on the Diagnosis and Therapeutic Decisions of Cardiovascular Diseases. *Frontiers in Physiology*, *11*. https://doi.org/10.3389/fphys.2020.00679
9. Yap, J., Lim, F. Y., Gao, F., Wang, S. Z., Low, S. C., Le, T. T., & Tan, R. (2020). Effect of myocardial viability assessed by cardiac magnetic resonance on survival in patients with severe left ventricular dysfunction. *Circulation Reports*, *2*(6), 306-313. https://doi.org/10.1253/circrep.cr-19-0126
10. Katikireddy, C. K., & Samim, A. (2022). Myocardial viability assessment and utility in contemporary management of ischemic cardiomyopathy. *Clinical Cardiology*, *45*(2), 152-161. https://doi.org/10.1002/clc.23779
11. Shokry, K. A., Farag, E. M., Salem, A. M., Abdelaziz, M., El-Zayat, A., & Ibrahim, I. M. (2020). Relationship between quality of coronary collateral and myocardial viability in chronic total occlusion: A magnetic resonance study. *The International Journal of Cardiovascular Imaging*, *37*(2), 623-631. https://doi.org/10.1007/s10554-020-02027-9
12. Canton, L., Suma, N., Amicone, S., Impellizzeri, A., Bodega, F., Marinelli, V., Ciarlantini, M., Casuso, M., Bavuso, L., Belà, R., Salerno, J., Armillotta, M., Angeli, F., Sansonetti, A., Attinà, D., Russo, V., Lovato, L., Tuttolomondo, D., Gaibazzi, N., … Pizzi, C. (2024). Clinical impact of multimodality assessment of myocardial viability. *Echocardiography*, *41*(7). https://doi.

org/10.1111/echo.15854

13. Meier, C., Eisenblätter, M., & Gielen, S. (2024). Myocardial late gadolinium enhancement (LGE) in cardiac magnetic resonance imaging (CMR)—An important risk marker for cardiac disease. *Journal of Cardiovascular Development and Disease*, *11*(2), 40. https://doi.org/10.3390/jcdd11020040
14. Baccouch, W., Hadidi, T., Benameur, N., Lahidheb, D., & Labidi, S. (2024). Convolution neural network for objective myocardial viability assessment based on regional wall thickness quantification from Cine-MR images. *IEEE Access*, *12*, 112381-112396. https://doi.org/10.1109/access.2024.3442080
15. Jiang, M., Chen, Y., Su, Y., Guo, H., Zhou, X., Luo, M., Zeng, M., & Hu, X. (2023). Assessment of Myocardial Viability and Risk Stratification in Coronary Chronic Total Occlusion: A Qualitative and Quantitative Stress Cardiac MRI Study. *Journal of Magnetic Resonance Imaging*, *59*(2), 535-545. https://doi.org/10.1002/jmri.28783
16. Li, K., Zhao, W., Liu, H., Zhang, J., He, D., Luo, M., Guo, H., Zhou, X., Chen, Z., & Zeng, M. (2024). Myocardial viability under various ischemic burdens in chronic total occlusions: A stress-cardiac magnetic resonance study. *Meta-Radiology*, *2*(3), 100097. https://doi.org/10.1016/j.metrad.2024.100097
17. Otaal, P. S., Shah, A., Batta, A., Sood, A., & Pal, A. (2021). Clinical and Angiographic prophesy of hemodynamic status in patients with acute anterior wall ST-segment-Elevation myocardial infarction and totally occluded left anterior descending artery. *Integrated Blood Pressure Control*, *14*, 89-97. https://doi.org/10.2147/ibpc.s315050
18. Yang, X. Y., LI, J. N., Han, Y., HE, Y., Zhang, L. J., Wang, Y. L., & Song, X. T. (2019). Evaluation of myocardium viability by cardiac magnetic resonance in patients with chronic total occlusion lesions. *Chinese Journal of Interventional Cardiology*, 28-34. https://pesquisa.bvsalud.org/portal/resource/pt/wpr-744558
19. Liang, K., Nakou, E., Del Buono, M. G., Montone, R. A., D'Amario, D., & Bucciarelli-Ducci, C. (2022). The role of cardiac magnetic resonance in myocardial infarction and non-obstructive coronary arteries. *Frontiers in Cardiovascular Medicine*, *8*. https://doi.org/10.3389/fcvm.2021.821067
20. Eichhorn, C., Koeckerling, D., Reddy, R. K., Ardissino, M., Rogowski, M., Coles, B., Hunziker, L., Greulich, S., Shiri, I., Frey, N., Eckstein, J., Windecker, S., Kwong, R. Y., Siontis, G. C., & Gräni, C. (2024). Risk stratification in Nonischemic dilated cardiomyopathy using CMR imaging. *JAMA*, *332*(18), 1535. https://doi.org/10.1001/jama.2024.13946
21. Petersen, S. (2021). The Future of Cardiac Magnetic Resonance Clinical Trials: Society for Cardiovascular Magnetic Resonance White Paper. *Qmul.ac.uk*. https://doi.org/1876-7591