CARDIOLOGIE TUNISIENNE

ARTICLE ORIGINAL

Global Longitudinal Strain as a Non-Invasive Marker of Myocardial Injury in Acute Myocarditis: Correlation With Cardiac Magnetic Resonance Findings

Strain global longitudinal comme marqueur non invasif de lésion myocardique dans la myocardite aiguë : corrélation avec les résultats de l'imagerie par résonance magnétique cardiaque

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Summary

Introduction: Cardiac magnetic resonance (CMR) is the reference non-invasive imaging modality for diagnosing acute myocarditis. However, its limited availability highlights the need for complementary diagnostic tools. Global longitudinal strain (GLS), assessed by speckle-tracking echocardiography, may detect subtle myocardial dysfunction even when left ventricular ejection fraction (LVEF) is preserved. This study aimed to investigate the relationship between GLS and CMR findings in patients with acute myocarditis.

Methods: We conducted a retrospective single-center study including consecutive patients with CMR-confirmed acute myocarditis admitted between January 2022 and January 2025. Clinical, laboratory, echocardiographic, and CMR data were analyzed. GLS measurements were obtained using two-dimensional speckle-tracking echocardiography whenever image quality was adequate. Correlations between GLS, CMR findings, ventricular function, and clinical outcomes were evaluated.

Results: Sixty-four patients (mean age 37.9 ± 9.2 years, 71.9% male) were included. Although only 14.1% had left ventricular systolic dysfunction (LVEF ≤40%), abnormal GLS was observed in 92.5% of patients with available strain analysis. CMR demonstrated late gadolinium enhancement in all patients, predominantly with a subepicardial inferolateral distribution. Baseline GLS showed a significant inverse correlation with CMR-derived LVEF ($r = -0.598$, $p < 0.01$) and was also associated with follow-up LVEF ($r = -0.503$, $p = 0.005$) and follow-up GLS ($r = 0.403$, $p = 0.03$). Patients who experienced major adverse cardiovascular events had significantly lower echocardiographic and CMR-derived LVEF and greater hemodynamic compromise at presentation.

Conclusions: Global longitudinal strain is strongly associated with myocardial injury detected by CMR in acute myocarditis and provides incremental information beyond conventional echocardiographic parameters. The combined use of GLS and CMR may improve the evaluation of disease severity and facilitate longitudinal follow-up in patients with acute myocarditis.

Keywords

Acute myocarditis - Global longitudinal strain - Speckle-tracking echocardiography - Cardiac magnetic resonance - Left ventricular function - Myocardial injury

Résumé

Introduction : L'imagerie par résonance magnétique cardiaque (IRM cardiaque) constitue la méthode de référence non invasive pour le diagnostic de la myocardite aiguë. Toutefois, sa disponibilité limitée justifie la recherche d'outils complémentaires. Le strain longitudinal global (GLS), obtenu par échocardiographie de speckle tracking, permet de détecter des anomalies subcliniques de la fonction myocardique même lorsque la fraction d'éjection ventriculaire gauche est préservée. Cette étude avait pour objectif d'évaluer la relation entre le GLS et les anomalies observées en IRM cardiaque chez des patients présentant une myocardite aiguë.

Méthodes : Nous avons réalisé une étude rétrospective monocentrique incluant des patients consécutifs atteints de myocardite aiguë confirmée par IRM cardiaque entre janvier 2022 et janvier 2025. Les données cliniques, biologiques, échocardiographiques et d'IRM ont été analysées. Le GLS a été mesuré par échocardiographie bidimensionnelle avec speckle tracking lorsque la qualité des images le permettait. Les corrélations entre le GLS, les paramètres de l'IRM, la fonction ventriculaire et les événements cliniques ont été étudiées.

Résultats : Soixante-quatre patients (âge moyen : 37,9 ± 9,2 ans ; 71,9 % d'hommes) ont été inclus. Alors que seulement 14,1 % présentaient une dysfonction systolique ventriculaire gauche (FEVG ≤40 %), un GLS altéré était observé chez 92,5 % des patients ayant bénéficié d'une analyse du strain. L'IRM mettait en évidence un rehaussement tardif au gadolinium chez tous les patients, principalement de localisation sous-épicardique inférolatérale. Le GLS initial était significativement corrélé de façon inverse à la FEVG mesurée en IRM ($r = -0,598$; $p < 0,01$) et était également associé à la FEVG ($r = -0,503$; $p = 0,005$) et au GLS ($r = 0,403$; $p = 0,03$) lors du suivi. Les patients présentant des événements cardiovasculaires majeurs avaient une FEVG significativement plus basse et une instabilité hémodynamique plus marquée à l'admission.

Conclusion : Le strain longitudinal global est étroitement associé aux lésions myocardiques mises en évidence par l'IRM cardiaque dans la myocardite aiguë et apporte des informations complémentaires aux paramètres échocardiographiques conventionnels. L'association du GLS et de l'IRM cardiaque pourrait améliorer l'évaluation de la sévérité de la maladie ainsi que le suivi évolutif des patients.

Mots-clés

Myocardite aiguë - Strain longitudinal global - Échocardiographie de speckle tracking - Imagerie par résonance magnétique cardiaque - Fonction ventriculaire gauche - Lésion myocardique

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INTRODUCTION

Acute myocarditis is an inflammatory disease of the myocardium characterized by a highly heterogeneous clinical presentation, ranging from mild chest pain to acute heart failure, malignant arrhythmias, cardiogenic shock, and sudden cardiac death. Viral infections remain the most common cause, although autoimmune disorders, toxic agents, medications, and immune-mediated mechanisms may also be involved. Owing to its variable presentation and the absence of a single definitive non-invasive diagnostic test, the diagnosis of acute myocarditis remains challenging (1–7).

Cardiac magnetic resonance (CMR) has become the reference non-invasive imaging modality for the diagnosis of acute myocarditis. The revised Lake Louise Criteria have improved diagnostic accuracy through the assessment of myocardial edema, hyperemia, necrosis, and fibrosis (8,9). Beyond diagnosis, CMR provides valuable information regarding the extent and distribution of myocardial injury, contributing to risk stratification and clinical management (9–13). However, its limited availability, cost, and restricted accessibility for serial evaluations may limit its widespread use in routine practice(8,9).

Transthoracic echocardiography remains the first-line imaging technique for the initial assessment and follow-up of patients with suspected myocarditis (2,5,7). Nevertheless, conventional parameters such as left ventricular ejection fraction (LVEF) may remain normal despite ongoing myocardial inflammation. Speckle-tracking echocardiography has emerged as a sensitive tool for the detection of subtle myocardial dysfunction. In particular, global longitudinal strain (GLS) has demonstrated greater sensitivity than conventional echocardiographic indices for identifying myocardial impairment and has shown promising correlations with myocardial abnormalities detected by CMR (14–16).

Given the growing interest in myocardial deformation imaging, the present study aimed to investigate the relationship between GLS and CMR findings in patients with CMR-confirmed acute myocarditis and to evaluate the complementary role of these imaging modalities in the assessment of myocardial injury and ventricular function.

METHODS

Study Design and Population (figure 1)

This retrospective observational study was conducted at the Department of Cardiology of Hedi Chaker University Hospital, Sfax, Tunisia. Consecutive patients admitted with a diagnosis of acute myocarditis between January 2022 and January 2025 were screened for inclusion.

The diagnosis of acute myocarditis was confirmed by cardiac magnetic resonance (CMR) according to the revised Lake Louise Criteria (8,9). Patients were eligible if they presented with a clinical syndrome suggestive of acute myocarditis, including acute chest pain, dyspnea, palpitations, arrhythmias, or acute heart failure, associated with elevated cardiac biomarkers and CMR findings consistent with myocardial inflammation.

Patients without CMR confirmation, those with an alternative diagnosis established by CMR, and those with incomplete clinical or imaging data were excluded.

The study protocol complied with the principles outlined in the Declaration of Helsinki. Patient confidentiality was preserved through anonymization of all collected data.

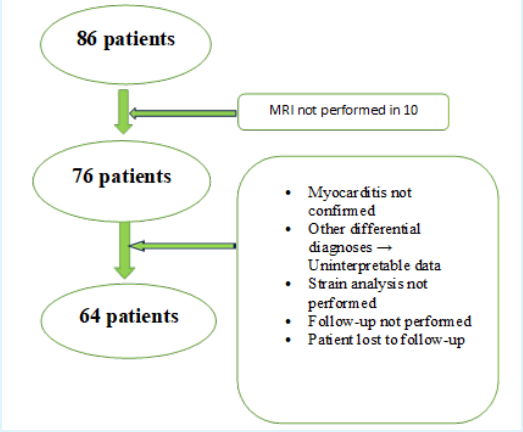

Figure 1. Study design

Clinical and Laboratory Assessment

Demographic characteristics, cardiovascular risk factors, medical history, presenting symptoms, physical examination findings, electrocardiographic data, and treatment information were retrospectively extracted from medical records.

Hemodynamic parameters recorded at admission included systolic blood pressure, diastolic blood pressure, and heart rate.

Laboratory investigations included complete blood count, serum creatinine, blood urea nitrogen, C-reactive protein (CRP), high-sensitivity cardiac troponin, and creatine phosphokinase (CPK) levels. Peak troponin values recorded during hospitalization were used for analysis.

Transthoracic Echocardiography

All patients underwent comprehensive transthoracic echocardiography (TTE) during the acute phase of hospitalization.

Standard measurements were performed according to current recommendations of the American Society of Echocardiography and the European Association of Cardiovascular Imaging.

The following parameters were collected:

- Left ventricular end-diastolic diameter (LVEDD)
- Left ventricular end-systolic diameter (LVESD)
- Left ventricular ejection fraction (LVEF)
- Presence of segmental wall motion abnormalities
- Right ventricular systolic function assessed by tricuspid annular plane systolic excursion (TAPSE)
- Presence of pericardial effusion

Left ventricular systolic dysfunction was defined as an LVEF ≤40%.

Speckle-Tracking Echocardiography

Two-dimensional speckle-tracking echocardiography was performed whenever image quality was adequate for strain analysis.

Global longitudinal strain (GLS) was calculated from standard apical two-, three-, and four-chamber views. Endocardial borders were manually traced and myocardial tracking was generated using dedicated software.

The average peak systolic longitudinal strain of all analyzable segments was used to calculate GLS. Reduced GLS was considered indicative of subclinical myocardial dysfunction.

Cardiac Magnetic Resonance Imaging

All All included patients underwent CMR during the index hospitalization.

CMR examinations included:

- Cine steady-state free-precession sequences for ventricular volumes and function
- T2-weighted short tau inversion recovery (STIR) sequences for myocardial edema assessment
- Early gadolinium enhancement (EGE) imaging for hyperemia evaluation
- Late gadolinium enhancement (LGE) imaging for myocardial necrosis and fibrosis characterization

Left ventricular ejection fraction was measured from cine sequences using standard volumetric analysis.

The presence, localization, and distribution pattern of myocardial edema and LGE were recorded. LGE distribution was classified as subepicardial or transmural. Enhancement morphology was categorized as linear, patchy, or diffuse.

Follow-Up Assessment

Patients underwent clinical and echocardiographic follow-up after hospital discharge.

Clinical assessment focused on symptom recurrence, rehospitalization, arrhythmic events, and survival status.

Follow-up echocardiography was performed when available to reassess left ventricular systolic function and GLS.

Study Objectives

The primary objective of the study was to evaluate the relationship between global longitudinal strain (GLS) and cardiac magnetic resonance (CMR) findings in patients with acute myocarditis.

Specifically, we sought to investigate the association between GLS, myocardial injury patterns identified by CMR, and left ventricular systolic function.

Secondary objectives included the evaluation of the relationship between baseline GLS and follow-up echocardiographic parameters, as well as the occurrence of major adverse cardiovascular events (MACE).

MACE was defined as a composite of:

- All-cause mortality
- Recurrent myocarditis
- Hospitalization for heart failure
- Sustained ventricular arrhythmias during follow-up

Statistical Analysis

Statistical analyses were performed using SPSS software (IBM Corp., Armonk, NY, USA).

Continuous variables were expressed as mean ± standard deviation or median with range according to data distribution. Categorical variables were presented as frequencies and percentages.

Comparisons between groups were performed using Student's t-test or Mann–Whitney U test for continuous variables and Chi-square or Fisher's exact test for categorical variables, as appropriate.

Pearson correlation analysis was used to evaluate associations between GLS, conventional echocardiographic parameters, laboratory findings, and CMR characteristics.

A two-sided p-value <0.05 was considered statistically significant.

RESULTS

Baseline Characteristics (Table 1)

Between January 2022 and January 2025, 86 patients were admitted with suspected acute myocarditis. After exclusion of patients without CMR confirmation and those with alternative diagnoses, 64 patients were included in the final analysis.

The mean age was 37.9 ± 9.2 years, and 46 patients (71.9%) were male. Smoking was the most prevalent cardiovascular risk factor, affecting 29 patients (45.3%).

Prodromal symptoms were reported in 36 patients (56.2%), predominantly influenza-like syndrome.

Chest pain was the most common presenting symptom, occurring in 49 patients (76.6%), followed by palpitations, dyspnea, and heart failure manifestations.

Electrocardiographic abnormalities were observed in 42 patients (65.6%), with ST-segment elevation being the predominant finding (73.3%).

Elevated troponin levels were documented in 60 patients (93.8%), while CRP elevation was observed in 53 patients (82.8%).

Table 1. Baseline Characteristics of the Study Population

Variable	Value
Age (years)	37.9 ± 9.2
Male sex	46 (71.9%)
Smoking	29 (45.3%)
Diabetes	7 (10.9%)
Hypertension	6 (9.4%)
Dyslipidemia	3 (4.7%)
Alcohol use	7 (10.9%)
Cannabis use	7 (10.9%)
Prodromal syndrome	36 (56.2%)
Chest pain	49 (76.6%)
Palpitations	5 (7.8%)
Heart failure presentation	5 (7.8%)
Elevated troponin	60 (93.8%)
Elevated CRP	53 (82.8%)

Echocardiographic Findings (Table 2)

At admission, median echocardiographic LVEF was 60% (range 15–65%). Left ventricular systolic dysfunction (LVEF ≤40%) was observed in 9 patients (14.1%).

Segmental wall motion abnormalities were identified in 25 patients (39.1%), predominantly involving the inferolateral and inferior walls.

Speckle-tracking analysis was available in 40 patients. Abnormal GLS values were observed in 37 patients (92.5%), indicating a high prevalence of subclinical myocardial dysfunction despite largely preserved conventional systolic function.

Cardiac Magnetic Resonance Findings (Table 2)

CMR confirmed the diagnosis of acute myocarditis in all patients. (Figure 2)

Median CMR-derived LVEF was 50% (range 13–67%).

Myocardial edema on T2-weighted STIR sequences was present in 34 patients (53.1%).

Early gadolinium enhancement was detected in 40 patients (62.5%).

Late gadolinium enhancement was observed in all patients and was predominantly subepicardial (95.3%).

The inferolateral wall was the most frequently involved region, followed by the anterolateral wall. Basal and mid-ventricular segments were most commonly affected.

Linear enhancement represented the predominant LGE pattern (81.3%).

Table 2. Baseline Characteristics of the Study Population

Variable	Value
TTE LVEF, %	60 (15–65)
LVEF ≤40%, n (%)	9 (14.1%)
Segmental wall motion abnormalities, n (%)	25 (39.1%)
GLS analysis available, n	40
Abnormal GLS, n (%)	37 (92.5%)
Median GLS, %	-19 (-22 to -4)
Right ventricular dysfunction, n (%)	6 (9.4%)
Pericardial effusion on TTE, n (%)	11 (17.2%)
CMR LVEF, %	50 (13–67)
Myocardial edema (STIR), n (%)	34 (53.1%)
Early gadolinium enhancement (EGE), n (%)	40 (62.5%)
Late gadolinium enhancement (LGE), n (%)	64 (100%)
Subepicardial LGE, n (%)	61 (95.3%)
Transmural LGE, n (%)	3 (4.7%)
Predominant LGE location	Inferolateral wall
Predominant involved segments	Basal and mid-ventricular
Linear LGE pattern, n (%)	52 (81.3%)
Patchy LGE pattern, n (%)	6 (9.4%)
Diffuse LGE pattern, n (%)	3 (4.7%)

CMR: cardiac magnetic resonance; GLS: global longitudinal strain; LGE: late gadolinium enhancement; EGE: early gadolinium enhancement; STIR: short tau inversion recovery; TTE: transthoracic echocardiography.

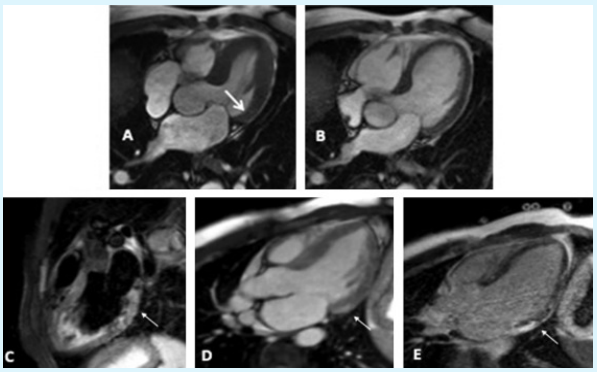

Figure 2. MRI examination phases and Lake Louise diagnostic criteria of acute myocarditis in a 21-year-old patient presenting with an "ACS-like" clinical syndrome.

A and B: SSFP cine sequences (A. End-diastole and B. End-systole) showing inferobasal hypokinesia. C: T2-weighted STIR image demonstrating focal inferobasal myocardial edema. D: Early gadolinium enhancement (EGE) 3 minutes after contrast injection in the same segment. E: Subepicardial late gadolinium enhancement (LGE) corresponding to the regions of T2 and EGE abnormalities.

Clinical Outcomes

The median duration of follow-up was 9 months (range 3–36 months).

Complicated myocarditis occurred in 8 patients (12.5%), including 4 patients (6.3%) with fulminant myocarditis.

In-hospital mortality was observed in 2 patients (3.1%).

During follow-up, major adverse cardiovascular events occurred in 7 patients (10.9%), including recurrent myocarditis, heart failure hospitalization, ventricular arrhythmias, and death.

Comparative Analysis According to Clinical Outcomes (Table 3)

Table 3. Comparison According to Major Adverse Cardiovascular Events (MACE)

Variable	No MACE	MACE	p-value
Systolic blood pressure (mmHg)	127.8 ± 14.4	109.9 ± 19.9	0.002
Heart rate (bpm)	84.3 ± 14.4	111.3 ± 38.9	<0.001
Hemodynamic instability (%)	0	100	<0.001
Arrhythmias (%)	6.8	93.2	<0.001
TTE LVEF (%)	55.2 ± 11.4	34.0 ± 18.0	<0.001
CMR LVEF (%)	50.8 ± 7.4	33.8 ± 17.6	0.020
Urea (mmol/L)	4.27 ± 2.10	6.33 ± 1.80	0.009
Absence of EGE (%)	70	30	0.021

MACE: major adverse cardiovascular events; LVEF: left ventricular ejection fraction; CMR: cardiac magnetic resonance; EGE: early gadolinium enhancement.

Patients who experienced MACE demonstrated significantly greater hemodynamic compromise at admission, with lower systolic blood pressure (109.9 ± 19.9 vs. 127.8 ± 14.4 mmHg, p = 0.002) and higher heart rate (111.3 ± 38.9 vs. 84.3 ± 14.4 bpm, p < 0.001).

Patients presenting with palpitations, acute heart failure, or cardiogenic shock were significantly more likely to develop MACE (p < 0.001).

Baseline echocardiographic LVEF was significantly lower in patients with MACE (34.0 ± 18.0% vs. 55.2 ± 11.4%, p < 0.001). Similarly, CMR-derived LVEF was significantly reduced in patients experiencing adverse events (33.8 ± 17.6% vs. 50.8 ± 7.4%, p = 0.020).

Relationship Between GLS and CMR Findings

A significant positive correlation was observed between echocardiographic and CMR-derived LVEF (r = 0.483, p < 0.01). Baseline GLS demonstrated a strong inverse correlation with CMR-derived LVEF (r = –0.598, p < 0.01), indicating that impaired myocardial deformation was associated with more severe ventricular dysfunction. Baseline GLS also showed significant associations with follow-up echocardiographic parameters, including follow-up LVEF (r = –0.503, p = 0.005) and follow-up GLS (r = 0.403, p = 0.03). These findings demonstrate a close relationship between myocardial deformation assessed by GLS and tissue characterization provided by CMR, supporting the complementary role of these imaging modalities in the assessment of acute myocarditis. (Table 4)

Table 4. Correlation Analysis Between GLS and Functional Parameters

Variables	Pearson r	p-value	p-value
TTE LVEF vs CMR LVEF	0.483	<0.01	0.002
Baseline GLS vs CMR LVEF	-0.598	<0.01	<0.001
Baseline GLS vs Follow-up LVEF	-0.503	0.005	<0.001
Baseline GLS vs Follow-up GLS	0.403	0.03	<0.001

GLS: global longitudinal strain; LVEF: left ventricular ejection fraction; CMR: cardiac magnetic resonance imaging; TTE: transthoracic echocardiography.

DISCUSSION

This study highlights the complementary role of speckle-tracking echocardiography and cardiac magnetic resonance imaging in the evaluation of acute myocarditis. Our findings demonstrate that global longitudinal strain (GLS) is closely associated with markers of myocardial injury detected by CMR and provides clinically relevant information beyond conventional left ventricular ejection fraction (LVEF) (14–16).

The study population was characterized by a predominance of young male patients, with a mean age of approximately 38 years and chest pain as the most frequent presenting symptom. These findings are consistent with previous reports indicating that acute myocarditis predominantly affects young adults and commonly presents with an infarct-like syndrome characterized by chest pain and elevated cardiac biomarkers (2,17–19).

Although conventional echocardiography showed preserved LVEF in most patients, GLS was abnormal in the vast majority of cases. This observation supports previous studies demonstrating that myocardial deformation imaging is more sensitive than conventional systolic parameters for detecting subtle myocardial dysfunction in acute myocarditis (14–16). Indeed, myocardial inflammation frequently involves the subepicardial and mid-myocardial layers, resulting in regional impairment that may not significantly affect global ejection fraction during the acute phase (9,20).

A major finding of our study was the significant association between GLS impairment and CMR-derived functional parameters. Baseline GLS showed a moderate inverse correlation with CMR-derived LVEF, indicating that worsening myocardial deformation was associated with more severe ventricular dysfunction. Similar findings have been reported by Meindl et al. and Supel et al., who demonstrated that GLS abnormalities correlate with the extent of myocardial injury detected by CMR, even in patients with preserved LVEF (15,16). These observations reinforce the concept that GLS reflects early myocardial involvement and may serve as a surrogate marker of disease severity.

Our results also demonstrated significant associations between GLS impairment and biological markers of myocardial injury. Troponin elevation reflects the extent of myocyte injury, whereas LGE identifies areas of necrosis and fibrosis (11,20). Both biomarkers and imaging findings contribute to the assessment of myocardial injury severity in acute myocarditis.

Furthermore, segmental wall motion abnormalities and late gadolinium enhancement frequently involved similar myocardial regions, supporting the relationship between functional abnormalities detected by echocardiography and structural myocardial injury identified by CMR, thereby emphasizing the complementary value of both imaging modalities (15,21).

Cardiac magnetic resonance remains the reference non-invasive imaging modality for the diagnosis of acute myocarditis. In our cohort, all patients fulfilled CMR diagnostic criteria, with LGE predominantly involving the inferolateral wall and displaying a subepicardial distribution. This pattern is consistent with previously published CMR studies and represents the classical imaging phenotype of viral myocarditis (9,20,21). However, despite its diagnostic and prognostic value, CMR remains limited by availability, cost, and accessibility, particularly in low-resource settings (8,9).

Myocardial edema detected on T2-weighted STIR sequences was observed in more than half of the patients. STIR imaging reflects active myocardial inflammation and remains an important component of the revised Lake Louise Criteria for the diagnosis of acute myocarditis. Consequently, STIR imaging complements late gadolinium enhancement by providing information on active inflammatory myocardial injury rather than chronic fibrosis (8–10).

These limitations highlight the potential value of echocardiographic strain imaging as a complementary and widely available tool (14–16).

Another important finding was the significant association between baseline GLS and subsequent echocardiographic parameters. Patients with more impaired GLS during the acute phase tended to exhibit lower follow-up LVEF and persistently altered GLS values. Although the study was not designed to establish independent prognostic predictors, these findings suggest that myocardial deformation imaging may provide useful information regarding subsequent ventricular functional evolution.

Patients who experienced major adverse cardiovascular events (MACE) exhibited significantly lower baseline echocardiographic and CMR-derived LVEF values, emphasizing the prognostic importance of ventricular dysfunction in acute myocarditis. In addition, hemodynamic instability at admission was strongly associated with adverse outcomes. These findings are consistent with previous studies identifying reduced LVEF and fulminant presentation as major determinants of prognosis (12,13,22). However, the relatively small number of events in our cohort limited the ability to evaluate the independent prognostic value of GLS through multivariable analysis.

Taken together, our findings support the complementary use of GLS and CMR in the assessment of acute myocarditis. While CMR provides unparalleled tissue characterization and diagnostic confirmation, GLS offers a rapid, non-invasive, and widely accessible method for detecting myocardial dysfunction and monitoring patients over time (15,16). The integration of both modalities may therefore improve diagnostic evaluation and contribute to more refined patient assessment in acute myocarditis.

CONCLUSION

Global longitudinal strain is closely associated with cardiac magnetic resonance findings in patients with acute myocarditis and appears to reflect both functional and structural myocardial injury. Significant correlations between GLS and CMR-derived LVEF, as well as follow-up echocardiographic parameters, support the value of myocardial deformation imaging in the assessment of disease severity and ventricular functional recovery.

While cardiac magnetic resonance remains the reference non-invasive imaging modality for tissue characterization, GLS provides a simple, widely available, and reproducible method for detecting myocardial dysfunction. The combined use of GLS and CMR may improve the comprehensive evaluation of patients with acute myocarditis and facilitate longitudinal follow-up in routine clinical practice.

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