Left and right ventricular strain in the course of acute myocarditis: a cardiovascular magnetic resonance study

Links- und rechtsventrikulärer Strain im Krankheitsverlauf der akuten Myokarditis: Eine kardiale MRT Studie

Authors
Julian A. Luetkens, Pauline Petry, Daniel Kuetting, Darius Dabir, Frederic C. Schmeel, Rami Homsi, Hans H. Schild, Daniel Thomas

Affiliation
Radiology, University of Bonn, Germany

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Correspondence
Dr. Julian A. Luetkens
Radiology, University of Bonn,
Sigmund-Freud-Str.25, 53127 Bonn, Germany
Tel.: +49/228/28 71 44 14
Fax: +49/228/28 71 59 60
julian.luetkens@ukbonn.de

ZUSAMMENFASSUNG
Ziel Gegenstand der Studie war die Untersuchung im Rahmen einer Verlaufsbeobachtung der akuten Myokarditis dahingehend, ob Beeinträchtigungen in links- (LV) und rechtsventrikulären (RV) Strainparametern vorhanden sind. Darüber hinaus war beabsichtigt, die Strainparameter hinsichtlich ihrer Voraussagekraft für eine Funktionsnormalisierung in der Nachuntersuchung zu evaluieren.

Material und Methoden Es wurden 69 Patienten mit Myokarditis in der Akutphase (Baseline) und nach durchschnittlich 92,5 ± 50,4 Tagen mittels kardialer Magnetresonanztomografie untersucht. Die „Lake Louise“ Kriterien (T2 Signalintensitätsverhältnis, „early gadolinium enhancement ratio“ und „late gadolinium enhancement“) und LV und RV myokardiale Strainparameter wurden ausgewertet. Eine logistische Regressionsanalyse wurde durchgeführt, um Prädiktoren für eine Funktionsnormalisierung in der Nachuntersuchung zu finden.

Ergebnisse Alle inflammatorischen Parameter verbesserten sich deutlich in der Nachuntersuchung (P < 0,001 für alle Parameter). Entsprechend war auch die LV und RV Funktion in der Nachuntersuchung signifikant verbessert (LV Ejektionsfraktion: 53,5 ± 12,7 % vs. 61,3 ± 9,5 %; P < 0,001, RV Ejektionsfraktion: 54,1 ± 10,0 % vs. 59,4 ± 6,3 %; P < 0,001). LV und RV Strainparameter (longitudinaler, zirkumferentieller und radialer Strain) verbesserten sich ebenfalls in der Nachuntersuchung signifikant im Vergleich zur initialen Untersuchung (P < 0,05 für alle Parameter). Der initiale LV globale systolische longitudinale Strain war der einzige Parameter in der multivariaten Regressionsanalyse, der unabhängig eine Funktionsverbesserung in der Nachuntersuchung vorausgesagen konnte (OR: 0,303; P = 0,007).


Kernaussagen
- Beeinträchtigungen des myokardialen Strains bei Myokarditis erholen sich meist im Verlauf.
- Eine RV Dysfunktion kann in der Akutphase häufig beobachtet werden.
- Der LV longitudinale Strain kann eine Funktionsnormalisierung in der Verlaufsuntersuchung voraussagen.

ABSTRACT
Purpose To investigate the degree of impairment in left (LV) and right ventricular (RV) myocardial strain parameters over the course of acute myocarditis and to evaluate its value for the prediction of functional recovery upon follow-up.

Materials and Methods 69 patients with acute myocarditis underwent cardiac magnetic resonance imaging during the acute stage (baseline) and after a mean 92.5 ± 50.4 days follow-up. Standard “Lake Louise” criteria (T2 signal intensity ratio, early gadolinium enhancement ratio and late gadolinium enhancement) and feature tracking derived LV and RV strain parameters were assessed. Logistic regression analysis was used to find predictors of functional recovery upon follow-up.
Results All inflammatory parameters showed a considerable decrease over the course of the disease (P<0.001 for all parameters). LV and RV function significantly improved on follow-up CMR (LV ejection fraction: 53.5 ± 12.7 % vs. 61.3 ± 9.5 %; P<0.001, RV ejection fraction: 54.1 ± 10.0 % vs. 59.4 ± 6.3 %; P<0.001). LV and RV myocardial strain (longitudinal, circumferential and radial strain) significantly improved from baseline to follow-up (P<0.05 for all parameters). On multivariate analysis, LV global peak systolic longitudinal strain (OR: 0.303; P = 0.007) was the only independent predictor of functional recovery upon follow-up.

Conclusion Alterations in LV and RV functional strain parameters occur frequently during the acute stage of myocarditis. During the course of the disease, a significant improvement in LV and RV strain parameters can be observed. It further appears that initial LV longitudinal strain may serve as a new parameter for the prediction of functional recovery upon follow-up.

Key Points
- Myocardial strain parameters significantly improve during the course of acute myocarditis.
- RV dysfunction can frequently be observed during the acute stage of myocarditis.
- LV longitudinal strain can independently predict functional recovery upon follow-up.

Citation Format

Introduction

Myocarditis accounts for up to 20 % of sudden unexpected deaths in young adults and has been identified as a substantive cause of cardiac mortality and morbidity [1]. The course of myocarditis is subject to substantial individual variations and the clinical management remains difficult [2]. Healed myocarditis can often be indirectly assumed in the absence of persisting symptoms if myocardial function and biomarkers have normalized [3]. However, in some cases, dilated cardiomyopathy may result from persistent myocardial inflammation [4]. Although confirming the presence of myocarditis is primarily a histopathological diagnosis [5], cardiac magnetic resonance (CMR) is more and more considered to be an alternative option for the diagnostic evaluation of patients presenting with symptoms of acute myocarditis [6, 7]. In the follow-up of acute myocarditis, CMR can identify patients with ongoing inflammation of the myocardium who ultimately require an additional endomyocardial biopsy for an optimized therapeutic regime [8]. Also, CMR can provide important information regarding the prognosis of patients suffering from myocarditis. The initial presence of myocardial oedema has been described to strongly predict left ventricular (LV) functional recovery [9], whereas the presence of non-ischemic necrosis on late gadolinium enhancement (LGE) imaging is regarded as an independent predictor of all-cause and cardiac mortality [10]. Another newer CMR technique, which also adds important information to multiparametric myocarditis CMR, is the determination of myocardial strain and deformation parameters using a feature tracking technique [6, 11]. Myocardial strain parameters are typically reduced during early-stage pathogenesis [12, 13], however, the predictive value of strain parameters for the recovery of LV function is not known. In addition, the predictive value of right ventricular (RV) functional parameters for outcome prediction has only been addressed by a few studies [14], and little is known about RV deformation analysis over the course of acute myocarditis. The aim of this study was to evaluate: (1) whether RV dysfunction can be observed during the course of acute myocarditis, and (2) the predictive value of several CMR parameters including myocardial strain analysis for the prediction of functional recovery upon follow-up.

Methods

Ethics commission approval was obtained for this retrospective study. The requirement to obtain written informed consent was waived. This study included the datasets of 69 patients with clinically suspected myocarditis who underwent an initial CMR after admission and a follow-up CMR between June 2008 and April 2016 at our department. Acute myocarditis was diagnosed based on diagnostic criteria for clinically suspected myocarditis as recommended of the European Society of Cardiology Working Group on myocardial and pericardial diseases [5, 6]. All patients had the diagnosis of acute myocarditis at hospital discharge. Patients with coronary artery disease, previous myocarditis or myocardial infarction were not included in this study.

CMR scans

CMR investigations were conducted on clinical whole body CMR scanners (Intera 1.5 Tesla, Ingenia 1.5 Tesla or Ingenia 3 Tesla, Philips Healthcare, Best, The Netherlands). ECG-gated steady-state free precession cine images were acquired for functional measurements and strain analysis. Cine images were obtained in short axis, 4-chamber and 2-chamber views. Short axis views of T2-weighted short-tau inversion-recovery (STIR) sequences were acquired in order to visualize myocardial oedema and to calculate T2 signal intensity (SI) ratio. For the assessment of myocardial hyperaemia (early gadolinium enhancement), axial fast spin echo T1-weighted images were acquired in free-breathing directly before and after contrast administration [15]. For LGE imaging, segmented inversion-recovery gradient-echo sequences were acquired in short axis, 4-chamber and 2-chamber views. Contrast was given as a bolus of 0.2 mmol/kg of body weight of gadobutrol (Gadovist, Bayer Healthcare, Leverkusen, Germany). Typical sequence parameters are summarized in ►Table S1 (online-only supplement).

Analysis of CMR images

Analysis of CMR images and data was performed by two blinded, experienced radiologists. Image analysis was conducted using a...
A dedicated CMR software (IntelliSpace Portal 9.0, Philips Medical Systems, Best, The Netherlands). LV and RV function was analysed based on the recommendations of the Society for Cardiovascular Magnetic Resonance (SCMR) [16]. LV functional recovery was defined as an ejection fraction on follow-up of ≥ 55 %. The presence of segmental myocardial oedema on T2 STIR images was visually evaluated by consensus agreement of two radiologists. The presence of inflammatory lesions in a non-ischemic distribution on LGE were also visually assessed. In addition, a semi-quantitative analysis of LGE images was performed. The endocardial and the epicardial contours of short axis LGE images were contoured manually and the enhanced volume percentage was calculated using the full width at half maximum (FWHM) technique [16]. T2 SI ratio as a marker of diffuse myocardial oedema and early gadolinium enhancement ratio (EGER) as a marker of inflammation-induced hyperaemia were calculated as recommended for the assessment of the “Lake Louise” criteria [15].

Analysis of left and right ventricular myocardial strain

CMR feature tracking strain measurements were derived from cine images using a dedicated software (Image-Arena 4.6, TomTec Imaging Systems, Unterschleissheim, Germany). Short axis cine images were used to derive circumferential and radial strain and strain rate measures of the left and right ventricle. Basal, mid-ventricular, and apical short axis images were analysed for circumferential and radial strain assessment. The 4-chamber cine images were used to obtain LV and RV longitudinal strain and strain rate measures. Global systolic radial, circumferential and longitudinal strain and strain rate values were calculated from peak segmental data. Measurements were performed as previously described [13].

Statistics

Prism 7 (GraphPad Software, La Jolla, CA, USA) and SPSS Statistics 23 (IBM, Armonk, NY, USA) were used for statistical analysis. Continuous variables are presented as mean ± standard deviation. Dichotomous variables are given as absolute frequency with percentages in parentheses.

Results

General results

The datasets of 69 patients were analysed in this study. Mean age of the study population was 41.8 ± 18.8 years (range: 18 – 76). Clinical parameters at baseline are presented in Table 1. After admission to the hospital, initial CMR was performed after 5.6
±6.5 days. Patients with myocarditis were followed up 92.5 ± 50.4 days after initial CMR. During the study period, no deaths or heart transplantations occurred.

CMR results

All inflammatory CMR parameters showed a significant decrease from baseline compared to follow-up (see Table 2): T2 SI ratio (1.9 ± 0.4 vs. 1.7 ± 0.3; \(P<0.001\)); EGEr (4.5 ± 4.1 vs. 2.5 ± 1.2; \(P<0.001\)). Quantitative LGE also significantly declined over time (7.1 ± 5.0 % vs. 6.1 ± 4.7 %; \(P=0.002\)) (see Fig. 1). On visual analysis, LGE was still present in 65 % (45/69) of all patients on follow-up. LV ejection fraction showed a significant improvement from baseline to follow-up (53.5 ± 12.7 vs. 61.3 ± 9.5; \(P<0.001\)). On baseline, 24/69 (34.9 %) patients presented with a reduced RV function (RV ejection fraction < 52 %). Furthermore, baseline RV function was significantly correlated with baseline LV ejection fraction (\(r = 0.668; P<0.001\)). Also, RV global peak longitudinal strain was significantly correlated with RV function (\(r = -0.411; P=0.001\)) and LV longitudinal strain (\(r = 0.558; P<0.001\)) (see Fig. 2). Over the course of the disease, RV ejection fraction significantly improved from baseline to follow-up (54.1 ± 10.0 vs. 59.4 ± 6.3; \(P<0.001\)). Except RV global peak systolic radial strain, all myocardial LV and RV strain parameters (longitudinal strain, circumferential strain and radial strain) significantly improved from baseline to follow-up (\(P<0.05\) for all parameters) (see Fig. 3, 4). 30/69 (43 %) of all patients presented with an impaired LV ejection fraction at baseline. Patients with a reduced baseline LV ejection fraction also had reduced RV ejection fraction (54.1 ± 10.0 vs. 59.4 ± 6.3; \(P<0.001\)) and reduced LV and RV strain parameters (\(P<0.05\) for all parameters) compared to patients with preserved LV ejection fraction at baseline (see Table 3). Interestingly, no differences were observed in visible myocardial oedema (77 % vs. 85 %; \(P=0.701\)) and visible late gadolinium enhancement (83 % vs. 92 %; \(P=0.219\)) between both groups. 18/69 (26 %) of all patients had positive “Lake Louise” criteria at follow-up, as a CMR sign of ongoing myocarditis. Patients with positive “Lake Louise” criteria on follow-up had a comparable LV and RV function compared to without positive “Lake Louise” criteria (LV ejection fraction: 61.9 ± 8.0 vs. 61.2 ± 10.0; \(P=0.758\); RV ejection fraction: 59.6 ± 7.4 vs. 59.4 ± 5.9;
P = 0.918). Also, no differences were observed in myocardial strain parameters (P > 0.05 for all parameters).

Impact of different CMR parameters for the prediction of functional recovery

59/69 (85.5 %) of all patients had a normal LV myocardial function (LV ejection fraction > 55 %) upon follow-up. In the univariate logistic regression analysis, LV (OR: 1.232 (CI: 1.088 – 1.395); P = 0.001) and RV ejection fraction (OR: 1.190 (CI: 1.064 – 1.331); P = 0.002), visible myocardial oedema (5.778 (CI: 1.219 – 27.388); P = 0.027) and LV and RV global peak strain parameters (P < 0.05 for all parameters) showed a predictive value for a functional recovery upon follow-up. In the multivariate model, LV global peak systolic longitudinal strain (OR: 0.303 (CI: 0.128 – 0.718); P = 0.007) was the only independent predictor of functional recovery upon follow-up. The results of the univariate and multivariate logistic regression analysis are summarized in Table 4. Using a cut-off of < -16.9 %, LV global peak systolic longitudinal strain had a sensitivity of 90.0 % and a specificity of 75.4 % for the prediction of functional recovery upon follow-up.

Also in patients with initially reduced LV ejection fraction, LV global peak systolic longitudinal strain remained the only significant multivariate predictor of functional recovery upon follow-up (OR: 0.296 (CI 0.102 – 0.858); P = 0.025) (see Table 5). In these patients, LV global peak systolic longitudinal strain had a sensitivity of 85.7 % and a specificity of 95.5 % (cut-off: < -12.3 %) for the prediction of functional recovery upon follow-up (see Fig. 5).

Discussion

In this retrospective follow-up study in patients with acute myocarditis, we described the changes of various CMR parameters including LV and RV myocardial strain over the course of the disease and evaluated their value for the prediction of functional recovery. The main findings of our study are that (1) RV dysfunction may frequently be observed during the acute stage of myocarditis, (2) LV longitudinal strain was the only independent predictor of functional recovery upon follow-up.
Lake Louise criteria

CMR is increasingly used for the diagnosis, evaluation, and follow-up of patients suffering from myocarditis [7, 8, 13]. Using standard “Lake Louise” criteria, CMR can reliably detect inflammatory myocardial alteration in the acute setting. In follow-up investigations, CMR can monitor inflammatory activity of the heart muscle and may help to identify patients with persistent signs of myocardial inflammation, who might require a subsequent endomyocardial biopsy for a more specific therapy [8]. Several CMR studies have described the temporal evolution of the “Lake Louise” criteria [8, 9]. In this regard, EGe is a CMR parameter of active inflammation, which is mostly elevated in the acute stage of the disease. As was observed in this study, a recovery of EGe is seen fairly quickly in most of the cases [8, 17, 18].

Comparable to myocardial hyperaemia, myocardial oedema also represents a sign of active myocardial inflammation [19]. During the course of myocarditis, myocardial oedema is mainly visible in the acute phase and often dissolves quickly [20]. In a recently published study, myocardial oedema was only visible in 4% of all patients after a 16 weeks’ follow-up [8]. In this study, myocardial oedema was visible in 9% of all patients after a 90 days’ follow-up. Vermes et al. described the presence of myocardial oedema to be associated with LV function recovery following acute myocarditis [9]. In this study, regional myocardial oedema could also predict functional recovery, but only on the univariate analysis. In acute myocarditis, myocardial oedema should be regarded as a marker of reversibly injured myocardium as an improvement of global and regional myocardial function closely follows the regression of myocardial oedema [9, 21].

In the acute setting, LGE is a CMR marker of myocardial necrosis and represents irreversible myocardial injury [8, 22]. During the healing process, this necrotic tissue is replaced by a fibrotic scar [9, 22]. This persistence of scar tissue leads to relatively high percentage of patients with positive LGE on follow-up investigations, even in patients without any signs of ongoing inflammation (e.g. myocardial oedema) [8, 23]. Accordingly, 66% of all patients had a persistence of LGE on follow-up in our study. Although positive LGE is considered to be a good predictor of sudden cardiac death and all-cause mortality in myocarditis, it surprisingly does not play a role in the prediction of incomplete recovery [10], as also shown in our study. The association between LGE and sudden cardiac death might be explained by the essential role of myocardial fibrotic remodelling as a substrate for cardiac arrhythmia [24], which seems to be independent of LV functional improvement.

Ventricular function and strain

Although myocardial inflammation in acute myocarditis is assumed to involve the left and the right ventricle, only very few studies investigated right ventricular function in the course of the disease. A follow-up study in patients with biopsy-proven myocarditis found initial abnormal right ventricular function to be a good predictor of poor outcome [14]. In our study, global RV function
was distinctly decreased at baseline compared to follow-up. Com-
parably, RV strain indices were also markedly reduced. We also
found positive correlations between baseline RV functional
parameters and LV functional parameters. Therefore, our results
indicate that right ventricular involvement in acute myocarditis
may be a frequent finding, which is associated with left ventricular
functional impairment. This thesis is supported by the fact that
histopathological diagnosis of myocarditis is often obtained from
right ventricular biopsy specimens indicating a not insubstantial
load of inflammatory activity in the right ventricle [25].

Myocardial strain analysis can detect regional and global myo-
cardial dysfunction in acute myocarditis and may serve as a new
diagnostic CMR target [13, 26]. Several case-control studies have
described myocardial strain indices to be decreased in acute myo-
carditis, even in patients with preserved ejection fraction [12, 13].
In our follow-up study on patients with myocarditis, we could
show that myocardial strain indices significantly improved from
baseline to follow-up. Myocardial strain analysis might therefore
be suitable for intraindividual disease monitoring, when a normal-
isation of myocardial strain parameters should be expected upon
follow-up. Interestingly, we found LV global systolic longitudinal
strain to be the only predictor of full functional recovery upon fol-
low-up on multivariate analysis. Despite the established role of
LV ejection fraction for outcome prediction, several other studies
indicated an incremental value of LV longitudinal strain for risk
stratification in patients with various cardiac diseases (e.g. in dilat-
ted cardiomyopathy or acute myocardial infarction) [27, 28]. The
prognostic value of global longitudinal strain for predicting major
adverse cardiac events is regarded to be superior compared to
standard ejection fraction alone [27]. Arejia et al. reported lon-
titudinal strain to be an independent parameter for outcome and
offers incremental information beyond LV ejection fraction and
the presence of myocardial fibrosis in patients with dilated cardio-
myopathy [28]. This superiority of longitudinal strain was also
shown in an analysis of the right ventricle [29]. Using the feature
tracking technique, longitudinal strain has been reported to be
the only independent prognostic parameter in patients with dilat-
ed cardiomyopathy, surpassing the prognostic value of radial and
circumferential strain [30]. Also, previous feature tracking CMR
studies reported global longitudinal strain to offer a more robust
intra- and inter-observer variability compared to other strain
parameters (e.g. global radial strain values) [31, 32]. Further-
more, feature tracking global longitudinal strain has been report-
ed to offer a very low inter-study reproducibility [31].

In patients with acute myocarditis, only a few studies evaluated
the prognostic value of strain parameters: An echocardiographic
study described longitudinal and circumferential strain to be sig-
nificant predictors of cardiac outcome following acute myocardi-
tis [33]. Recently, Lee et al. reported that radial long-axis strain
can predict major adverse cardiovascular events and incomplete
LV functional recovery [26].

In summary, our results indicate an increasing evidence that
myocardial strain analysis can also provide additional information
regarding outcome prediction in patients with acute myocarditis.
In this regard, it is also important to mention that myocardial strain analysis using the feature tracking technique can be performed using routinely acquired cine CMR images and without the need of additional contrast administration.

Limitations

Although endomyocardial biopsy is regarded as the reference standard for the diagnosis of myocarditis, it was not performed in this study. Instead, as reported previously in multiple CMR studies, the initial diagnosis of acute myocarditis was mainly made based on clinical parameters [6, 7]. Alterations of myocardial strain parameters are non-specific and can be detected in many acute and chronic cardiac diseases and conditions (e.g. in patients longstanding chronic disease [34] or significant coronary artery disease [35]). Due to the retrospective study design, patients were investigated at three different CMR scanners, which might have influenced some quantitative measurements (e.g. myocardial strain analysis). However, differences in the magnitude of longitudinal and circumferential strains at different field strengths have been reported to be rather small [36].

Conclusions

In patients with acute myocarditis, CMR strain analysis may be a new tool to monitor LV and RV functional impairment over the course of the disease. Furthermore, LV longitudinal strain has the potential to become a new CMR parameter for the independent prediction of functional recovery.

Conflict of Interest

The authors declare that they have no conflict of interest.


**Widmung**

Diese Arbeit ist Herrn Professor Hans H. Schild gewidmet, bei dem wir uns herzlich für die langjährige und stete Unterstützung in allen klinischen und wissenschaftlichen Belangen bedanken möchten.

**References**


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**Table 4** Baseline CMR predictors of functional recovery upon follow-up for the whole study population (n = 69).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Univariate</th>
<th></th>
<th>Multivariate</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LV ejection fraction</td>
<td>1.232 (1.088 – 1.395)</td>
<td>0.001</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RV ejection fraction</td>
<td>1.190 (1.064 – 1.331)</td>
<td>0.002</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>T2 SI ratio</td>
<td>3.344 (0.355 – 31.535)</td>
<td>0.292</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Early gadolinium enhancement ratio</td>
<td>0.901 (0.767 – 1.058)</td>
<td>0.203</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Late gadolinium enhancement (%)</td>
<td>1.109 (0.917 – 1.343)</td>
<td>0.286</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Visible regional myocardial oedema</td>
<td>5.778 (1.219 – 27.388)</td>
<td>0.027</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Visible late gadolinium enhancement</td>
<td>3.056 (0.501 – 18.645)</td>
<td>0.228</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Positive Lake Louise criteria</td>
<td>0.320 (0.066 – 1.544)</td>
<td>0.156</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>LV global peak systolic longitudinal strain</td>
<td>0.303 (0.128 – 0.718)</td>
<td>0.007</td>
<td>0.303 (0.128 – 0.718)</td>
<td>0.007</td>
</tr>
<tr>
<td>LV global peak systolic circumferential strain</td>
<td>0.494 (0.295 – 0.826)</td>
<td>0.007</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>LV global peak systolic radial strain</td>
<td>1.227 (1.078 – 1.397)</td>
<td>0.002</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RV global peak systolic longitudinal strain</td>
<td>0.702 (0.563 – 0.877)</td>
<td>0.002</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RV global peak systolic circumferential strain</td>
<td>0.737 (0.584 – 0.929)</td>
<td>0.010</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RV global peak systolic radial strain</td>
<td>1.353 (1.093 – 1675)</td>
<td>0.006</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

CMR = cardiac magnetic resonance, LV = left ventricular, RV = right ventricular. Predictors of functional recovery upon follow-up were determined by using binary logistic regression analysis. Significant univariate predictors were entered into the multivariate model. Odds ratios are given with 95% confidence interval.

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**Fig. 5** Receiver operating characteristic (ROC) curves for left ventricular longitudinal strain for the prediction of functional recovery. ROC curves are given for the whole study population (n = 69) and for patients with initially impaired left ventricular ejection fraction (LVEF) (n = 30).

**Abb. 5** Receiver-Operating-Charakteristik-Kurven (ROC-Kurven) des linksventrikulären, longitudinalen Strains für die Prädiktion einer Funktionsnormalisierung. Es werden ROC-Kurven für die gesamte Studienpopulation und für Patienten mit initial eingeschränkter linksventrikulärer Ejektionsfraktion (LVEF) gezeigt.


[19] Ferreira VM, Piechnik SK, Dall’Armellina E et al. Non-contrast T1-mapping detects acute myocardial edema with high diagnostic accuracy: a comparison to T2-weighted cardiovascular magnetic resonance. Journal of cardiovascular magnetic resonance: official journal of the Society for...


