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Evaluation of cardiac dyssynchrony with longitudinal strain analysis in 4-chamber cine MR imaging

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ABSTRACT

Purpose: We investigated the clinical performance of evaluation of cardiac mechanical dyssynchrony with longitudinal strain analysis using four-chamber (4CH) cine magnetic resonance imaging (MRI).
Materials and methods: We retrospectively enrolled 73 chronic heart failure patients (41 men, 32 women; mean age, 57 years, NYHA 2, 3, and 4) who underwent a cardiac MRI in the present study. The left ventricular dyssynchrony (LVD) and interventricular dyssynchrony (IVD) indices were calculated by longitudinal strain analysis using 4CH cine MRI. The LVD and IVD indices were compared by the Wilcoxon rank-sum test between the patients with indication for cardiac resynchronization therapy (CRT) ($n = 13$) and without indication for CRT ($n = 60$), with LGE ($n = 40$) and without LGE ($n = 27$), the CRT responders ($n = 8$) and non-responders ($n = 6$), respectively.
Results: LVD in the patients with indication for CRT were significantly longer than those without indication for CRT (LVD: 92 ± 65 vs. 28 ± 40 ms, $P < .01$). LVD and IVD were significantly longer in the patients with LGE than those without LGE (LVD: 54 ± 58 vs. 21 ± 30 ms, $P < .01$ and IVD: 51 ± 39 vs. 23 ± 34 ms, $P < .01$). LVD and IVD in the CRT responders were significantly longer than the CRT non-responders (LVD: 126 ± 55 vs. 62 ± 55 ms, $P < .01$ and IVD: 96 ± 39 vs. 52 ± 40 ms, $P < .05$).
Conclusion: Longitudinal strain analysis with 4CH cine MRI could be useful for clinical examination in the evaluation of cardiac mechanical dyssynchrony.

1. Introduction

Cardiac resynchronization therapy (CRT) is one of effective treatments for heart failure (HF) patients with mechanical dyssynchrony [1–5]. CRT patients are selected according to the established selection criteria as follows: (1) New York Heart Association (NYHA) functional class III or IV, (2) left ventricular (LV) ejection fraction (LVEF) $\leq 35\%$, and (3) wide QRS complex with interventricular conduction disorder (QRS ≥ 120 ms) [6]. However, approximately 20–30% of patients do not respond to CRT [7]. In order to predict the response to CRT, several echocardiographic parameters for mechanical dyssynchrony have been proposed [8,9]. Strain analysis with tissue Doppler echocardiography provides direct information of the timing of onset and peak of myocardial contraction,

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and allows evaluation of cardiac mechanical dyssynchrony [10,11]. Although the strain imaging with the echocardiogram is restricted in patients with poor acoustic windows and to the narrow field of view (FOV), magnetic resonance imaging (MRI) does not have these restrictions.

Left and right ventricular motion images through a cardiac cycle can be obtained by using four-chamber (4CH) cine MRI during one breath hold (10–20 s). Therefore, cardiac dyssynchrony could be evaluated with strain analysis using 4CH cine MRI without restrictions of poor acoustic windows and narrow FOV. In the present study, we evaluated cardiac dyssynchrony with longitudinal strain analysis using 4CH cine MRI, and investigated the clinical performance of the method in patients with moderate to severe HF patients.

2. Materials and methods

2.1. Patients

The study protocol was reviewed and approved by the institutional review board, and written informed consent was obtained from all patients.

We retrospectively enrolled 73 consecutive chronic HF patients (NYHA functional class II, III, IV, 41 males and 32 females, 57 ± 15 years-old), who underwent cardiac MRI incorporating cine and late gadolinium enhancement (LGE) imaging in this study. Cine MRI were performed in all patients. LGE-MRI were performed in 67 out of 73 patients because 6 patients had a decline of renal function. Twenty-three patients had ischemic cardiomyopathy (ICM), 50 patients had non-ischemic cardiomyopathy (NICM). Fourteen out of 73 patients underwent CRT. The patients who observed clinical improvement (defined by an improvement in NYHA functional class and 6-min walking distance) were considered as responders, and the others were considered as non-responders. Table 1 shows baseline characteristics of all patients.

Table 1
Patients characteristics.

	All patients (n = 73)
Clinical characteristics	
Age (mean)	57 ± 15
Male	41 (56%)
QRS duration (ms)	114 ± 27
NYHA (mean)	2.5 ± 0.6
Class II	47
Class III	21
Class IV	5
ICM	23
NICM	50
CMR characteristics	
LVEDV (ml)	169 ± 95
LVESV (ml)	116 ± 93
LVEF (%)	38 ± 19

Baseline characteristics of all patients are shown.
NYHA: New York Heart Association, ICM: ischemic cardiomyopathy, NICM: non-ischemic cardiomyopathy, CMR: cardiac magnetic resonance, LVEDV: left ventricular end diastole volume, LVEDV: left ventricular end systole volume, LVEF: left ventricular ejection fraction.

2.2. MRI protocol

MRI with 3.0-T MR unit (Achieva 3.0 T TX; Philips Medical Systems, Best, the Netherlands) and 32-channel phased-array coil was used for all patients. Cine and LGE MRI were performed with electrocardiographic gating during the patients' breath holding (approximately 10–20 s). Scout images were obtained in the axial, coronal, and sagittal orientations. Cine MRI was performed using a steady-state free precession sequence in the 4CH, short- and long-axis orientations with the following parameters: TR = 2.9 millisecond (ms), TE = 1.5 ms, flip angle = 45°, slice thickness = 8 mm, spatial resolution = 2.16 × 2.34 mm^2. LGE-MRI were scanned at 10 min after 0.2 mmol/kg of gadolinium injection (Magnevist, Bayer Healthcare, Osaka, Japan) with follow parameters: TR = 3.9 ms, TE = 1.2 ms, flip angle = 15°, slice thickness = 4 mm, spatial resolution = 1.32 × 1.79 mm^2. The inversion time was adjusted to optimally null the myocardium as previously described [12].

2.3. Longitudinal strain analysis of 4CH cine-MRI

On 4CH cine MR imaging, the longitudinal lengths of LV and right ventricular (RV) free-walls and interventricular septum (IVS) were measured by an expert radiologist (M.N.), who had 10 years experience of cardiac imaging, at 20 time points through the entire cardiac cycle (Fig. 1a). In the measurement, the patient's information regardless of CRT schedule or LGE presence was not informed to the radiologist. The measured lengths were normalized on the basis of length in the timing of the onset of myocardial contraction. The longitudinal strain curves were obtained from normalized length of LV, RV free-walls and IVS (Fig. 1b). The index of LV dyssynchrony (LVD) was defined as the difference in millisecond between the times of the minimum LV free-wall length and IVS length. The index of interventricular dyssynchrony (IVD) was defined as the difference in millisecond between the times of the minimum LV and RV free-wall lengths.

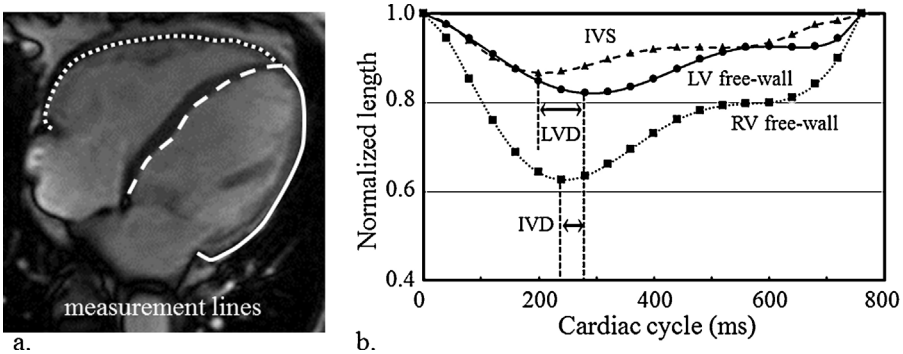

Fig. 1. Definition of LVD and IVD indices (a) the longitudinal lengths of the LV free-wall (solid line), the IVS (dashed line), and the RV free-wall (dotted line) were measured at 20 time points throughout a cardiac cycle on the 4CH cine MR imaging. (b) The longitudinal strain curves were obtained from normalized length of LV, RV free-walls and IVS on the basis of length in the timing of the onset of myocardial contraction. The index of LVD was defined as the difference between the times of the minimum LV free-wall length and IVS length. The index of IVD was defined as the difference between the times of the minimum LV and RV free-wall lengths.