Evaluation of Cardiac Function Using Myocardial Strain Analysis

Satoru Kishi , MD, FACP, FACC, FSCCT
Division of Diabetes, Department of Internal Medicine, Mitsui Memorial Hospital

Dr. Kishi is a specialist in cardiology as well as an expert in diagnostic imaging. He has therefore been playing an active role as a supervising physician in the field of cardiovascular diagnostic imaging. For a three-year period from 2011, he was engaged in research focusing mainly on the MESA* study as a research supervising physician at the Johns Hopkins University in the United States. In addition, at the annual meeting of the American College of Cardiology in 2013, his study on myocardial strain was named the "Best Poster Award Winner at ACC 13". In this report, Dr. Kishi discusses cardiac diseases, lifestyle diseases, and new methods for evaluating myocardial function.

Introduction

MRI is an advanced diagnostic imaging modality which allows detailed biological information to be obtained without exposure to ionizing radiation. However, in the field of cardiac imaging, the clinical usefulness of MRI is limited by a number of technical challenges related to artifacts arising from cardiac motion or other factors such as respiratory motion or blood flow. Echocardiography and cardiac SPECT have played a central role in the evaluation of cardiac function, and many technical improvements have been made in these imaging modalities, resulting in the accumulation of a large amount of clinical evidence. However, echocardiography suffers from restricted imaging planes due to interference from bone or lung tissue, and cardiac SPECT has a number of disadvantages such as radiation exposure and low spatial resolution. There are many challenges that remain to be overcome in the clinical evaluation of cardiac function and morphology.

In recent years, there have been many technical advances in MRI which have led to greater diagnostic accuracy in the field of cardiac imaging. A wide range of information for evaluating heart disease can now be obtained using cardiac MRI (CMR), which is useful for assessing both cardiac function and cardiac morphology. It is now possible to detect the presence of intracardiac thrombus or cardiac tumors using cine MRI, to evaluate inflammation and edema using T2-weighted images, to measure myocardial blood flow using perfusion MRI, to identify areas of infarction or fibrosis using late-enhancement imaging, and to examine the coronary arteries using coronary MRA. In particular, cine MRI allows high-contrast images to be acquired in any desired imaging planes without interference from bone or lung tissue. Its high reproducibility ensures precise evaluation, and cine MRI is therefore considered to be the most accurate method for assessing cardiac function.

Cardiac function analysis

The left ventricular ejection fraction (LVEF) is one of the most important indices in cardiac function analysis. LVEF is defined as the percentage of the blood in the left ventricle that is ejected during cardiac contraction. This index is conceptually very easy to understand and has therefore been used to evaluate cardiac function in many studies. However, the ejection fraction (EF) is only one of many indices for assessing cardiac function, and a variety of other parameters must also be taken into consideration. In addition to EF, the end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), and cardiac output (CO) are also important parameters in cardiac function analysis.[1] Because the heart operates as a pump, it is common to focus on cardiac contraction when evaluating cardiac function, but it has been reported that cardiac contraction is found to be within

* MESA: Multi-Ethnic Study of Atherosclerosis

acceptable limits in approximately 40% to 60% of patients who go on to develop heart failure, and the importance of evaluating cardiac expansion is therefore now widely recognized (Figure 1).[2]

Myocardial strain analysis, which is more useful than LVEF for detecting subtle changes in cardiac function caused by pathological processes, has recently been developed, mainly as a diagnostic technique in echocardiography.[3] CMR, on the other hand, requires the use of special scanning methods such as tagging to perform such analysis. Its use has therefore been limited to clinical research, and it has not yet gained widespread acceptance in actual clinical practice. However, using Vitrea (Canon Medical Systems Corporation, Otawara, Japan), it is now a simple matter to perform myocardial strain analysis with CMR, making it possible to perform such studies in routine clinical practice.

Myocardial strain analysis

It is known that the left ventricular myocardium is mainly composed of three layers of spirally arranged myocardial fibers. These layers are referred to as the endocardial layer, the intermediate layer, and the epicardial layer. Most of the fibers in each layer are oriented as follows: in the endocardial layer, the fibers are oriented in the vertical direction (at an angle of approximately 80° relative to the fibers in the intermediate layer); in the intermediate layer, the fibers are oriented in the circumferential direction; and in the epicardial layer, the fibers are oriented in an oblique direction (at an angle of approximately -60° relative to the fibers in the intermediate layer) (Figure 2).[4] This three-layered structure allows the myocardium to contract, twist, and expand in various directions, resulting in efficient cardiac function. Myocardial strain is an index that is calculated as the ratio of the distances between two points during expansion and contraction ($\text{strain}(\%)=(L_t - L_0)/L_0 \times 100$). In other words, it is a measure of the deformation resulting from expansion and contraction of the myocardium in each direction. The strain values in the longitudinal, circumferential, and radial directions are usually calculated as indices for the evaluation of myocardial fiber function (Figure 3).[3]

In echocardiography and other diagnostic imaging methods, deterioration in left ventricular function is mainly observed as changes in myocardial motion in the radial direction. This is because it is difficult to visually evaluate myocardial motion in the longitudinal and circumferential directions. However, it is now understood that myocardial strain analysis should be performed in each direction to obtain accurate cardiac evaluation results. In myocardial ischemia, for example, the endocardial layer of the myocardium is usually affected first, and this pathological process would therefore be expected to manifest itself initially as changes in longitudinal strain. It has also been reported that a reduction in longitudinal stain is observed during early diastole in areas supplied by coronary arteries with severe stenosis of 70% or more. Other studies have shown that myocardial strain is a more accurate index than LVEF for assessing the prognosis of patients with heart failure. The clinical importance of myocardial strain is now widely recognized.[5]

Myocardial strain analysis in CMR is usually performed using the tagging method, in which each region of the myocardium is tagged for analysis. Other methods such as strain encoding (SENC) and displacement encoding with stimulated echoes (DENSE) have also been developed, and improved imaging techniques based on these methods have been introduced. Although these methods have been available for some time, they involve complicated scan procedures and intensive data analysis, which have limited the clinical application of myocardial strain analysis using CMR.

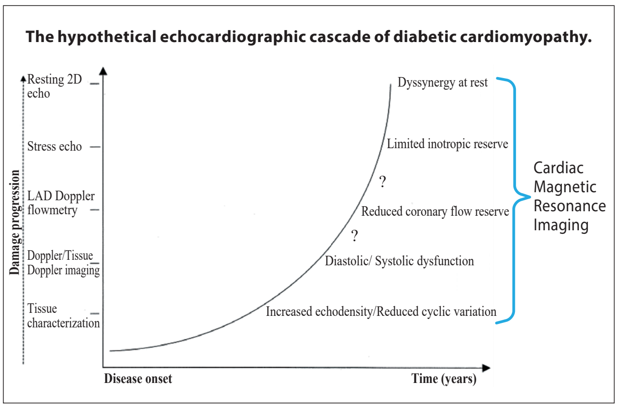

Figure 1

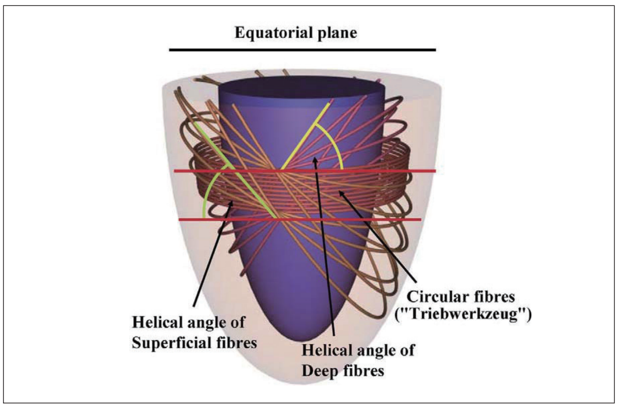

Figure 2

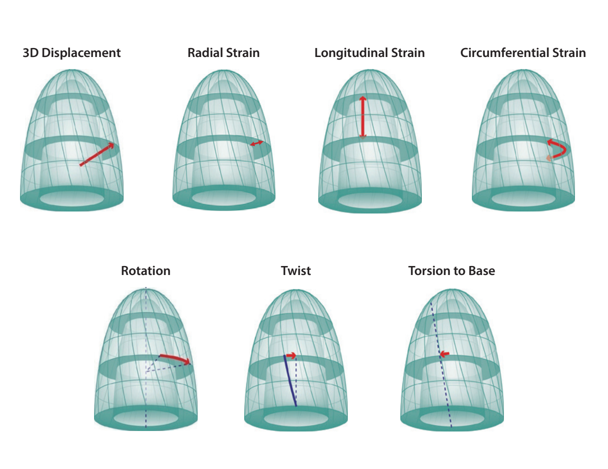

Figure 3

The Vitrea Wall Motion Tracking (WMT) software, in which strain analysis can be performed using cine MRI images acquired by conventional scanning, has now been developed (Figure 4). This method permits myocardial strain analysis to be performed more easily and more accurately, without the need to employ special scanning techniques.

Evaluation of left ventricular function

Although the contractile function of the left ventricle can be roughly evaluated by visual assessment, quantitative evaluation is required in order to obtain objective and reproducible analysis data. Quantitative evaluation methods based on geometric models, such as those employed in cardiac SPECT, M-mode echocardiography, and left ventricular contrast imaging, were the first to be developed. However, these methods suffer from the serious disadvantage that accuracy is reduced when the geometric model does not match the shape of the patient's left ventricular cavity or the patient's myocardial structure (e.g., in patients with organic heart diseases such as old myocardial infarction). Thanks to the development of improved imaging techniques in each diagnostic modality such as 3D echocardiography, cardiac CT, and CMR (the topic of the present report), more accurate volume evaluation based on the Simpson method has become possible. Among these modalities, CMR is superior to echocardiography because it allows any desired scan planes to be visualized with high reproducibility irrespective of the patient's body habitus or cardiac morphology. In addition, CMR is superior to CT because its high temporal resolution makes it possible to evaluate cardiac function more accurately. CMR is therefore the diagnostic imaging modality of choice for cardiac function analysis due to its superior accuracy and reproducibility.

Segmental strain analysis was performed using LGE and the tagging method in a patient who had suffered a myocardial infarction. The strain values were seen to be reduced in the areas indentified as LGE+.[6] CINE images of the same patient were then analyzed using the Vitrea WMT software. The strain curve obtained

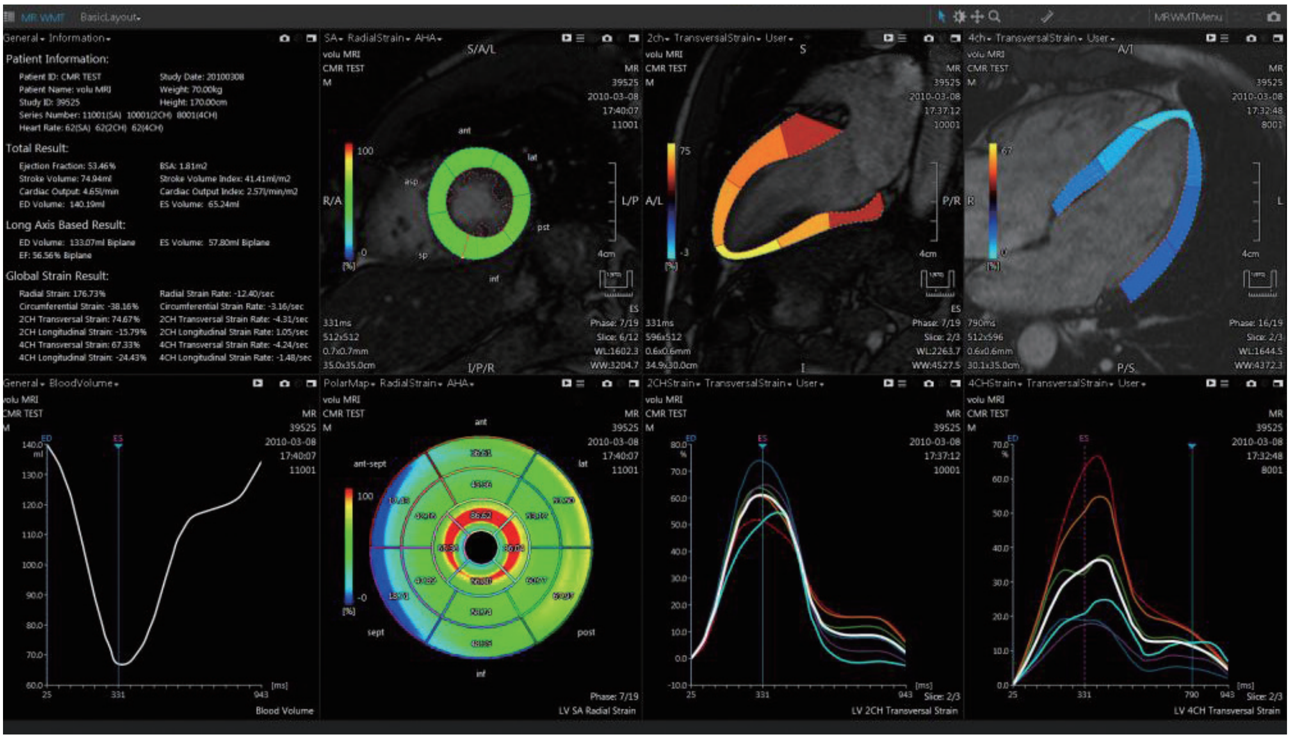

Figure 4

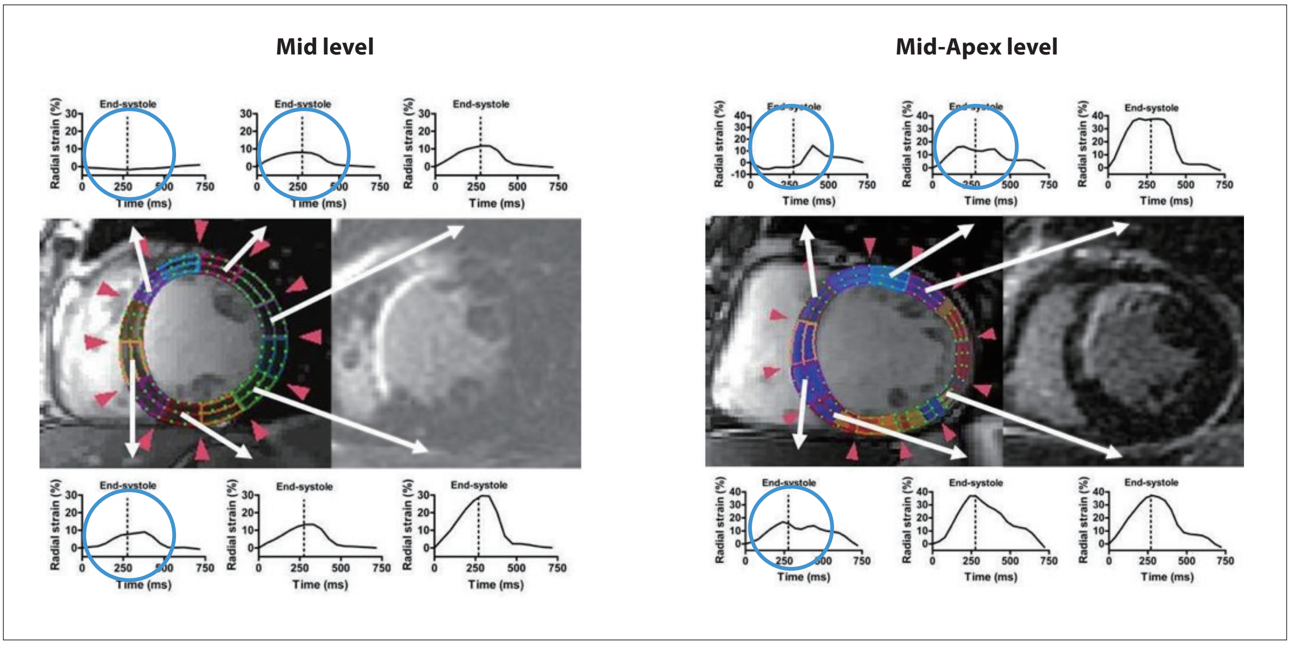

Figure 5

Table 2 **Univariate and multivariable Cox proportional hazards analysis for incident HF**

Variable	Univariate analysis			Multivariable analysis (enter)			Multivariable analysis (stepwise forward)		
	HR	95% CI	*P*-value	HR	95% CI	*P*-value	HR	95% CI	*P*-value
Age, per year	1.06	1.02–1.10	0.001	1.07	1.03–1.11	0.002	1.06	1.02–1.11	0.002
Male	1.47	0.77–2.80	0.24						
Ethnicity									
Caucasian	0.50	0.22–1.13	0.10						
African American	1.40	0.73–2.68	0.32						
Hispanic	1.38	0.71–2.68	0.35						
Chinese	0.90	0.35–2.28	0.81						
Presence of diabetes	1.71	0.79–3.72	0.18						
Diabetes status	1.36	1.05–1.77	0.02	1.17	0.87–1.57	0.31			
Hypertension	2.01	1.04–3.86	0.037	0.67	0.31–1.46	0.29			
Heart rate, per b.p.m.	1.02	0.98–1.05	0.34						
Annual family income, dollar	0.92	0.84–1.01	0.07						
Current smoking	1.22	0.48–3.12	0.68						
Hypertensive medication	1.72	0.92–3.23	0.09						
Statin use	1.23	0.57–2.70	0.60						
Aspirin use	0.75	0.35–1.64	0.47						
Estimated GFR, per mL/min	0.99	0.97–1.00	0.14						
LV mass index, per g/m^2	1.05	1.03–1.06	<0.001	1.04	1.02–1.06	<0.001	1.04	1.02–1.05	<0.001
LV mass$^{a}_{adj}$, per g	1.04	1.03–1.04	<0.001	1.03	1.02–1.04	<0.001	1.03	1.02–10.4	<0.001
LV end-diastolic volume, per mL	1.02	1.01–1.03	<0.001						
Mass/volume ratio	1.06	0.95–8.85	0.06						
LV ejection fraction, per %	0.92	0.88–0.95	<0.001	1.01	0.95–1.07	0.84			
Stroke volume, per mL	1.02	1.00–1.03	0.04						
LVESWS, per KPa	1.22	1.10–1.35	<0.001	1.13	0.98–1.31	0.10			
Interim myocardial infarction (time dependent)	19.28	9.59–38.74	<0.001	10.27	4.60–22.92	<0.001	15.84	7.45–33.70	<0.001
Ecc-global, per %	1.24	1.12–1.37	<0.001	1.15	0.002–1.33	0.047	1.14	1.00–1.30	0.045
Ecc-mid[b], per %	1.25	1.13–1.37	<0.001	1.18	1.03–1.35	0.015	1.18	1.05–1.33	0.007

See abbreviations in *Table 1*.
[a]In replacement of LV mass index.
[b]Average Ecc-global in multivariate analysis.

Figure 6

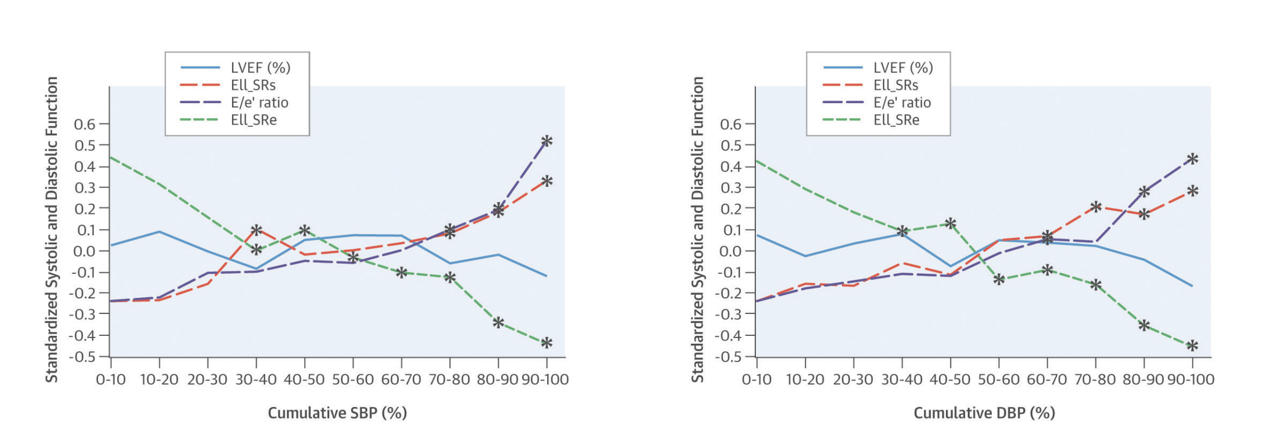

Figure 7

using the WMT software was smoother than that obtained using the tagging method, and the strain values showed good agreement (Figure 5).[6]

As discussed above, myocardial strain is considered to be a more useful index than EF for assessing the prognosis of patients with heart failure. By the end of the first decade of the 2000s, studies on the usefulness of 2D strain echocardiography for evaluating heart failure began to appear in the literature. In all of these studies, the finding of a deterioration in strain was determined to be a useful independent index for assessing the patient's prognosis with regard to cardiac events, including heart failure, as compared to LVEF, which was previously considered the gold standard. Similar studies on CMR were included in the MESA trial, a large cohort study conducted in the United States. The results obtained in this study also showed that a reduction in LVEF is a statistically significant risk factor for heart failure based on univariate analysis. Based on multivariate analysis, a reduction in strain observed using CMR was found to be more useful than LVEF as an independent prognostic index (Figure 6).[5] It has also been reported in studies employing echocardiography that patients with a blood pressure above the optimal range for a period of 25 years (Figure 7),[7] patients with a long history of diabetes,[8] and patients without diabetes but with high insulin resistance tend to develop heart failure due to an increase in afterload.[8,9] In these studies, although LVEF was maintained, deterioration in strain values was observed.

Why is strain a more useful index than LVEF for detecting deterioration in cardiac function? There is one useful reference in the literature. The relationships between LVEF, circumferential strain, and cardiac torsion were evaluated using CMR with the tagging method.

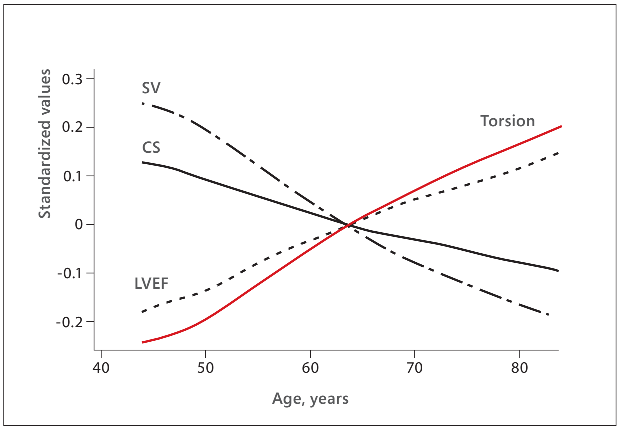

Figure 8

The results showed that when circumferential strain reflecting myocardial fiber function is reduced, there is a compensatory increase in cardiac torsion, and LVEF is maintained as a result (Figure 8).[10] However, when an area of myocardial dysfunction expands due to myocardial infarction or other pathology, decompensation may occur, leading to a reduction in LVEF. This suggests that measurement of LVEF may only be able to detect the final stage of deterioration in myocardial fiber function.

Evaluation of left atrial function

In the field of cardiovascular imaging, there have recently been a large number of reports concerning the usefulness of strain analysis for evaluating left atrial function and right ventricular function in addition to left ventricular function. The MESA trial includes a comparison of left atrial function between patients with heart failure and patients without heart failure as assessed using the Vitrea WMT software. The measured indices of left atrial function are shown in Figure 9. It has been reported that a reduction in global peak longitudinal atrial strain may be an independent contributory factor for heart failure, in addition to an increase in left atrial volume, which was identified as a contributory factor in previous studies.[11]

How is left atrial function related to heart failure? One report has described a possible pathophysiological mechanism. The relationship between the degree of left ventricular fibrosis and left atrial function, including left atrial strain, was investigated using T1 mapping / LGE.[12] This report concluded that the Vitrea WMT software is useful for analyzing left atrial function and for visualizing anatomical structures, and a clear relationship was observed between the progression of left ventricular fibrosis and the deterioration of left atrial function.

Left atrial strain analysis is also useful in patients with arrhythmias such as atrial fibrillation. Inoue et al. described the relationship between cerebral infarction and left atrial function as assessed by strain analysis using CMR/WMT (Vitrea) in patients with atrial fibrillation.[13] One of the most important findings of their study is that an increase in left atrial volume and a reduction in left atrial strain are associated with a higher risk of cerebral infarction, in addition to the CHA2DS2-VASc score, which has been widely employed to assess the risk of cerebral infarction in routine clinical practice.

A number of studies on right ventricular analysis are also currently ongoing. Various indices of right ventricular function, such as RVEF, RVEDV, RVESV, RVSV, and RVM, which are difficult to evaluate using echocardiography due to the structural characteristics of the right ventricle, can be accurately determined using CMR.

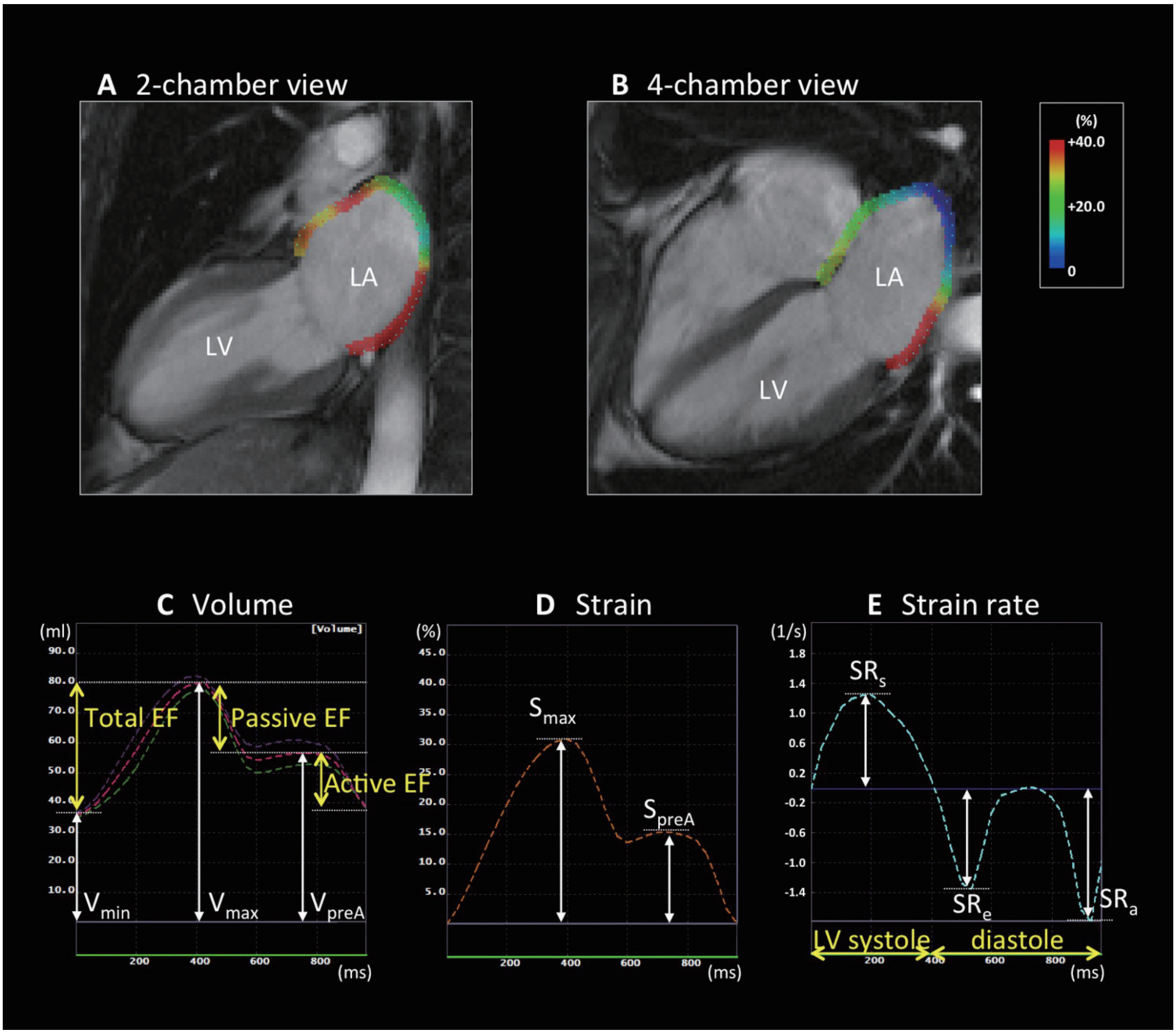

Figure 9

Conclusion

- Measurement of left ventricular volume parameters such as EF, EDV, ESV, SV, CO, and CI as well as evaluation of contractile function are possible in analysis using cine MRI.
- Noninvasive myocardial strain analysis using CMR provides higher spatial resolution than echocardiography and is a useful clinical modality for evaluating cardiac function in patients with ischemia or phase mismatch.
- Myocardial strain analysis using conventional tagging CMR is useful for the quantitative assessment of cardiac function. However, the time required for analysis is quite long due to the complicated scan procedures and intensive data analysis in this method.
- Myocardial strain analysis using cine MRI can be performed easily and has the advantages of higher temporal resolution and higher spatial resolution than conventional methods.
- The use of CMR in routine clinical practice makes it possible to evaluate cardiac dysfunction as well as to examine the coronary arteries.
- Various indices of right ventricular function, such as RVEF, RVEDV, RVESV, RVSV, and RVM, which are difficult to evaluate using echocardiography due to the structural characteristics of the right ventricle, can be accurately determined using CMR.
- In both volume evaluation and hemodynamic evaluation, CMR provides superior analysis results in terms of spatial resolution, accuracy, and reproducibility as compared to echocardiography, cardiac SPECT, and cardiac CT. Another advantage of CMR is that it does not involve exposure to ionizing radiation. At the present time, CMR is considered to be the modality of choice for cardiac function analysis.
- Many technological advances are being made in CMR for myocardial strain analysis. It is expected that clinical evidence will rapidly accumulate and that CMR will gain widespread acceptance in routine clinical practice.

References

1. Lang RM et al: Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. Journal of the American Society of Echocardiography 28 (1): 1-39, 2015
2. Yancy CW et al: 2013 ACCF/AHA guideline for the management of heart failure: A report of the American college of cardiology foundation/american heart association task force on practice guidelines. Journal of the American College of Cardiology 62: e147-e239, 2013
3. Voigt JU et al: Definitions for a common standard for 2 D speckle tracking echocardiography: Consensus document of the EACVI/ASE/industry task force to standardize deformation imaging. Journal of the American Society of Echocardiography 28 (2): 183-193, 2015
4. Anderson RH et al: The anatomical arrangement of the myocardial cells making up the ventricular mass. European journal of cardio-thoracic surgery:official journal of the European Association for Cardiothoracic Surgery 28 (4): 517-525, 2005
5. Choi EY et al: Prognostic value of myocardial circumferential strain for incident heart failure and cardiovascular events in asymptomatic individuals: the Multi-Ethnic Study of Atherosclerosis. Eur Heart J 34 (30) : 2354-2361, 2013
6. Helle-Valle TM et al: Usefulness of radial strain mapping by multidetector computer tomography to quantify regional myocardial function in patients with healed myocardial infarction. American Journal of Cardiology 106 (4): 483-491, 2010
7. Kishi S et al: Cumulative Blood Pressure in Early Adulthood and Cardiac Dysfunction in Middle AgeThe CARDIA Study. Journal of the American College of Cardiology 65 (25): 2679-2687, 2015
8. Kishi S et al: Association of Insulin Resistance and Glycemic Metabolic Abnormalities With LV Structure and Function in Middle AgeThe CARDIA Study. JACC: Cardiovascular Imaging, 2016
9. Kishi S et al: Association of Obesity in Early Adulthood and Middle Age With Incipient Left ventricular dysfunction and structural Remodeling The CARDIA Study (Coronary Artery Risk Development in Young Adults) . JACC: Heart Failure 2 (5): 500-508, 2014
10. Yoneyama K et al: Age, sex, and hypertension-related remodeling influences left ventricular torsion assessed by tagged cardiac magnetic resonance in asymptomatic individuals: the multi-ethnic study of atherosclerosis. Circulation 126 (21): 2481 - 2490, 2012
11. Habibi M et al: Association of CMR-measured la function with heart failure development: Results from the MESA study. JACC: Cardiovascular Imaging 7 (6): 570-579, 2014
12. Imai M et al: Multi-ethnic study of atherosclerosis: Association between left atrial function using tissue tracking from cine mr imaging and myocardial fibrosis. Radiology 273 (3): 703-713, 2014
13. Inoue YY et al: Quantitative tissue-tracking cardiac magnetic resonance (CMR) of left atrial deformation and the risk of stroke in patients with atrial fibrillation. Journal of the American Heart Association 4 (4), 2015

Acknowledgement

This article is based on the Eizojoho Medical magazine, Vol.48, No.14, 2016.

CANON MEDICAL SYSTEMS CORPORATION
https://global.medical.canon

MOIHI0001EAB 2021-10 CMSC/CPL/Printed in Japan

Canon Medical Systems Corporation meets internationally recognized standards for Quality Management System ISO 9001, ISO 13485.
Canon Medical Systems Corporation meets the Environmental Management System standard ISO 14001.

The results in this document are the findings of the author.
Clinical outcomes may vary dependent upon clinical use and environment.

Made For life