Case Report | Cardiovascular Imaging

http://dx.doi.org/10.3348/kjr.2013.14.5.727
pISSN 1229-6929 · eISSN 2005-8330
Korean J Radiol 2013;14(5):727-732

Korean Journal of Radiology
KJR

Diagnosis of Acute Global Myocarditis Using Cardiac MRI with Quantitative T1 and T2 Mapping: Case Report and Literature Review

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The diagnosis of myocarditis can be challenging given that symptoms, clinical exam findings, electrocardiogram results, biomarkers, and echocardiogram results are often non-specific. Endocardial biopsy is an established method for diagnosing myocarditis, but carries the risk of complications and false negative results. Cardiac magnetic resonance imaging (MRI) has become the primary non-invasive imaging tool in patients with suspected myocarditis. Myocarditis can be diagnosed by using three tissue markers including edema, hyperemia/capillary leak, and necrosis/fibrosis. The interpretation of cardiac MR findings can be confusing, especially when the myocardium is diffusely involved. Using T1 and T2 maps, the diagnosis of myocarditis can be made even in cases of global myocarditis with the help of quantitative analysis. We herein describe a case of acute global myocarditis which was diagnosed by using quantitative T1 and T2 mapping.

Index terms: *Myocarditis; Magnetic resonance imaging; T1 map; T2 map*

INTRODUCTION

Myocarditis is an inflammatory disease of the myocardium (1), most commonly caused by viral infections or post-viral immune reactions (2). Symptoms of myocarditis can range from subclinical to cardiac failures (3). Diagnosis of this condition is often difficult when the symptoms, clinical exam findings, electrocardiogram (ECG) results, biomarkers, and echocardiogram results are non-specific. Endomyocardial biopsy is an established tool for diagnosing myocarditis, though it has several limitations including sampling errors, risk of complications, and lack of standardized diagnostic criteria (4). Cardiac magnetic resonance imaging (MRI) has recently become the primary non-invasive imaging tool for patients with suspected myocarditis (2). However, the interpretation of cardiac MRI findings is challenging if there is global involvements of the myocardium. Using quantitative T1 and T2 maps, the diagnosis of myocarditis can be made even in cases of diffuse myocarditis. In this study, we report a case of acute global myocarditis in a 28-year-old male that was diagnosed on cardiac MR with quantitative T1 and T2 map sequences.

Received December 3, 2012; accepted after revision June 20, 2013.

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CASE REPORT

A 28-year-old male was presented to the emergency department complaining of dyspnea, dizziness, and chest tightness over the preceding 24 hours. He had no significant past medical history. His body temperature was 37.2°C, blood pressure was 104/72 mm Hg, heart rate was

95 beats per minute (bpm), and his physical examination was gernally normal. Laboratory studies showed a WBC count of 16.2 x 10^3/μL (reference range, 4.0-10.8 x 10^3/μL) and platelets of 219 x 10^3/μL (reference range, 150-400 x 10^3/μL). Additionally, troponin T was found to be 0.958 mcg/L (reference range, 0-0.014 mcg/L), and C-reactive protein (CRP) was 14.7 mg/L (reference range, 0.1-6.0 mg/L). Chest X-ray showed mild pulmonary congestion and cardiomegaly. ECG on admission revealed normal sinus rhythm at a rate of 79 bpm with T-wave abnormalities. Transthoracic echocardiography showed reduced global left ventricular systolic function with an ejection fraction (EF) of 34%, diffusely increased myocardial echogenicity, and a small pericardial effusion. Based on these results, acute myocarditis was suggested as a clinical diagnosis.

A cardiac MRI was performed on the third day of admission using a 1.5-T MR scanner (Magnetom Avanto; Siemens Medical Solutions, Erlangen, Germany). After scout images were taken, the cine MRI was performed with balanced steady-state free precession (b-SSFP) to obtain horizontal long-axis, vertical long-axis, 3-chamber view, and contiguous short-axis images. T2-weighted images were obtained by using a triple inversion recovery black-blood turbo spin-echo sequence along the contiguous short-axis planes from the apex to the base of the left ventricle (LV). Quantitative T2 mapping with a T2-prepared SSFP pulse sequence and pre-T1 mapping with a modified Look and Locker technique were performed during the mid-diastolic phase along the same short-axis planes as the T2-weighted images. The acquisition parameters for T2 mapping were: T2 preparation times = 0 ms, 24 ms, and 55 ms; repetition time (TR) = 3 x R-R ms; echo time (TE) = 0 ms, 24 ms, and 55 ms; acquisition matrix = 126 x 192; acquisition time = 7 x R-R; single-shot acquisition; flip angle = 70°; and bandwidth = 916 Hz/pixel. The acquisition parameters for T1 mapping were: TR = 740 msec, TE = 1.06 msec, flip angle = 35°, acquisition matrix = 192 x 124, field of view = 320 x 400 mm, slice number = 10 slices. Late gadolinium enhancement-MRI (LGE-MRI) was performed using a magnitude and phase-sensitive inversion recovery (PSIR) prepared by fast gradient echo sequence with the inversion time adjusted to null the normal myocardium. LGE-MR images were obtained along the same axis plane and with the same slice thickness as in the cine-MRI, 10 minutes after the administration of 0.2 mmol/kg of a gadoterate meglumine (Dotarem®; Guerbet, France). The acquisition parameters were: TR = 600 ms, TE = 3.4 ms, flip angle = 25°, acquisition matrix = 156 x 256, field of view = 320 x 400 mm, slice number = 10 slices, cardiac phase = mid-diastole. After obtaining the LGE-MR images, the post-T1 mapping was performed 15 minutes after the contrast media injection, using the same slice axis and parameters as pre-T1 mapping. T2-pixel maps and pre-post T1-pixel maps were generated after motion corrections using commercially available software on the scanner's workstation (Syngo; Siemens Medical Solutions, Erlangen, Germany).

On cine images, global systolic dysfunction resulted in an EF of 30%. Bilateral pleural effusions and a pericardial effusion were also noted (Fig. 1A, B). On T2WI, there was not a patchy region of increased signal intensity (SI) in the LV myocardium, but global edema was presented with a ratio of myocardium to skeletal muscle of > 2.0 (Fig. 1C). On the TI scout images, it was difficult to determine the optimal nulling time for the LV. We ultimately selected 270 ms as the nulling time (Fig. 1D). On LGE images with a magnitude and PSIR (Fig. 1E, F), global hyper SI throughout the LV myocardium was suggested, though it was uncertain whether the increased SI was due to incomplete myocardial nulling or diffuse myocardial delayed enhancements. The T2 and T1 values were measured according to AHA myocardial segmentation with the exception of the apex (Table 1) (5). On quantitative T2 map images, myocardial T2 values remarkably increased to about 91.4 ± 6.1 milliseconds (ms) (reference value, 55.5 ± 2.3) (Fig. 1G) (6). The pre-contrast T1 value of the myocardium also increased to 1276.6 ± 32.4 ms (reference value, 1034.1 ± 53.1) (Fig. 1H) (7). On post-T1 mapping images, the mean myocardial T1 value was 625 ± 12.4 ms, which was similar to the T1 value of the LV cavity (623 ms) (Fig. 1I). The myocardial extracellular volume (ECV) fraction was calculated as follows: ECV fraction = (ΔR1 of myocardium / ΔR1 of LV blood pool) x (1 - hematocrit), R1 = 1 / T1, ΔR1 = Post-contrast R1 - Pre-contrast R1 (8). The pre-T1 value of the LV cavity was approximately 1520 ms. The patient's hematocrit was 43.6%. The calculated mean ECV fraction for the LV myocardium was 45.9 ± 1.9% (range: 43-49.7%). Thus, it was concluded that diffusely high myocardial SI on the LGE-MR images was not caused by incomplete nulling of the myocardium, but rather by ECV expansion of the myocardium.

The patient's final diagnosis was myocarditis based on clinical symptoms, ECG results, biomarkers, echocardiogram results, and cardiac MR findings. Follow-up echocardiography was performed one week after initiating conservative care,

Korean Journal of Radiology
KJR

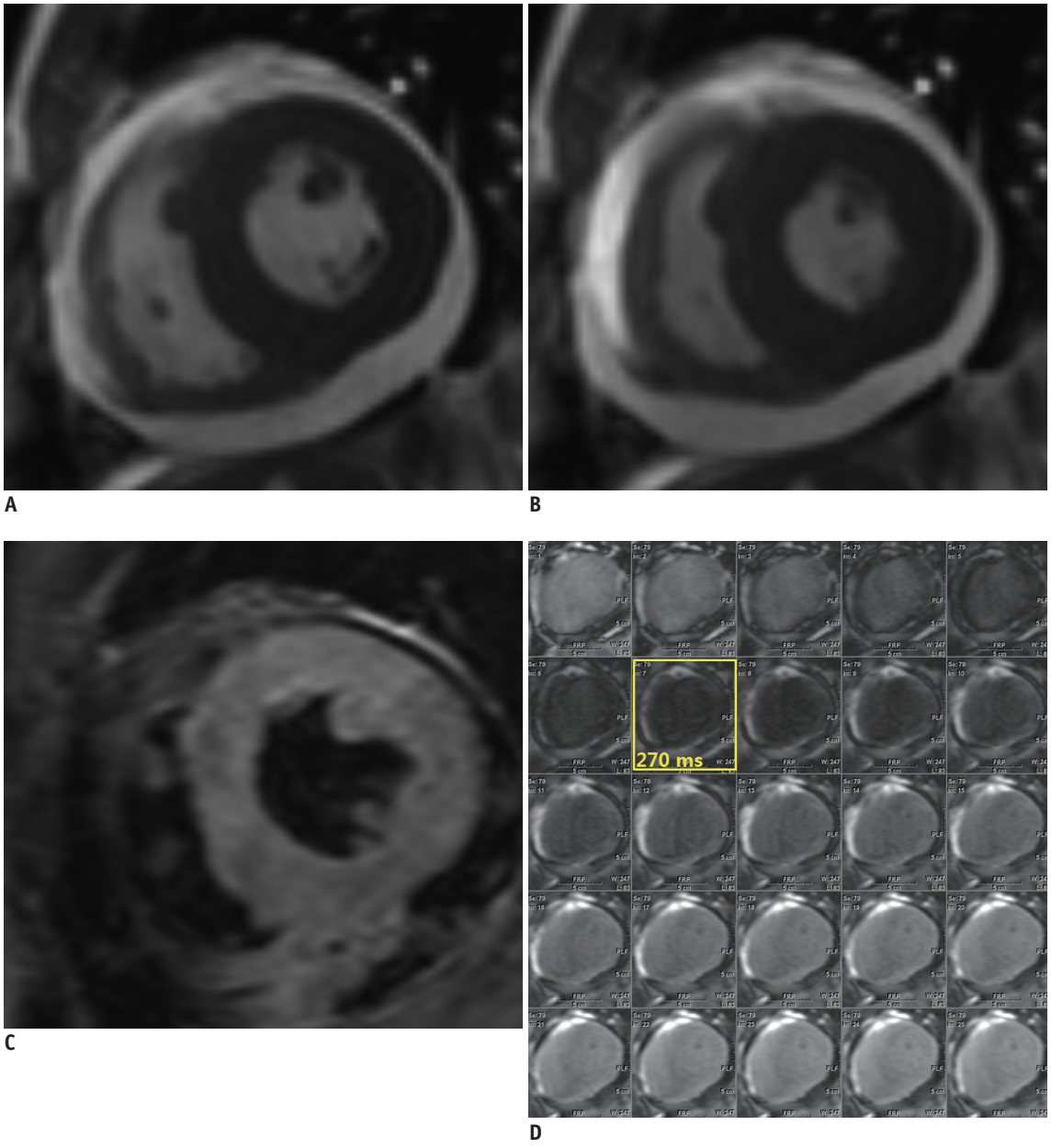

Fig. 1. Cardiac MR findings in acute global myocarditis.
Cine images during end-diastolic **(A)** and end-systolic **(B)** phases demonstrated global systolic dysfunction with EF of 30%. T2-Weighted images **(C)** revealed global edema with ratio of myocardium to skeletal muscle of > 2.0. On TI scout images, it was difficult to determine optimal nulling time for LV. We selected 270 ms as ideal nulling time in this study **(D)**. LV = left ventricle, SI = signal intensity, EF = ejection fraction

revealing improved global LV systolic function with an EF of 67%. CRP peaked on the fourth day of admission at 156.1 mg/L, but decreased thereafter and normalized to 1.1 mg/L on the fourteenth day of admission.

DISCUSSION

On cardiac MRI, myocarditis can be diagnosed by using three tissue markers including edema, hyperemia/capillary leak, and necrosis/fibrosis (2, 4, 9). Edema can be evaluated by using T2W images, and is defined as a signal intensity ratio of > 2.0 between the myocardium (myo) and skeletal muscle (skm) (edema ratio = SImyo / SIskm). Hyperemia or capillary leak can be evaluated on early enhancement images within 5 minutes of administration of contrast media. On early enhancement images, the signal intensity enhancement ratio between the myocardium and skeletal muscle represents the myocardial global relative enhancement ratio (REglobal) {REglobal = REmyo / REskm = ([postSImyo - preSImyo] / preSImyo) / ([postSIskm

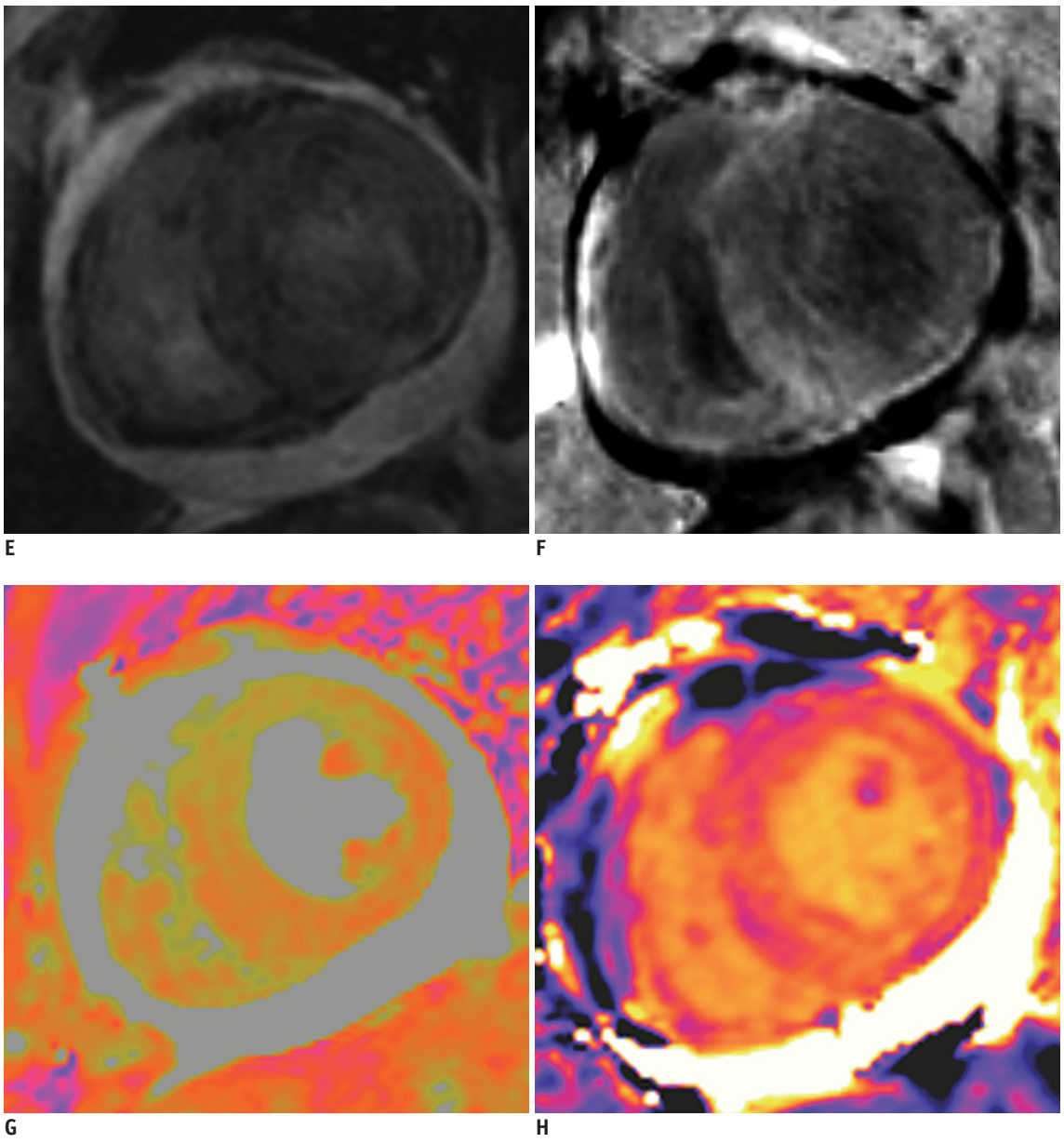

Fig. 1. Cardiac MR findings in acute global myocarditis.
On LGE images with magnitude and PSIR **(E, F)**, diffuse hyper SI of entire LV myocardium was likely but uncertain. T2 map images **(G)** and Pre-T1 map images **(H)** demonstrated diffuse myocardial edema with increased T2 and T1 values. LGE = late gadolinium enhancement, LV = left ventricle, PSIR = phase-sensitive inversion recovery

- preSIskm] / preSIskm)}. Hyperemia can be defined as a REglobal of more than 4.0, or an absolute myocardial enhancement of > 45%. Necrosis or fibrosis can be assessed on LGE images, and is defined as abnormal delayed myocardial enhancement without a vascular territory. When two or more of these criteria are positive, the accuracy of cardiac MR in diagnosing myocarditis is approximately 80% (2). The presence of a pericardial effusion and LV dysfunction are also suggestives of myocarditis (2, 9).

Cardiac MR has some limitations in diagnosing myocarditis, and the interpretation of these images can be particularly challenging when there is global myocardial involvement. Detecting edema on conventional T2WI could be limited by image quality and objective image interpretation (6), and global edema might be missed when the skeletal muscle is also inflamed. Global myocardial enhancement may also be confusing on LGE images due to incomplete myocardial nulling, or conversely, may be ignored due to diffuse myocardial nulling. Direct T1/T2 mapping can aid in the diagnosis of diffuse myocardial

Korean Journal of Radiology
KJR

abnormalities by providing quantitative T1 or T2 values. T2 maps can detect myocardial edema without the limitations of T2WI even in cases of global involvement since the T2 map is objective and less sensitive to motion artifact, surface coil inhomogeneity, and subendocardial blood flows (6, 10). Verhaert et al. (6) reported that a T2 value of 62 ms may serve as an appropriate cutoff for the diagnosis of edema on T2 mapping. Pre-contrast T1 mapping can also detect myocardial edema similar as seen with T2 mapping (11). Using post-contrast T1 mapping, increased myocardial gadolinium accumulation can be evaluated, even in the setting of global enhancement. After injection of the contrast media, the post-contrast T1 value of the myocardium abruptly decreases, and then, continuously increases due to gadolinium washout, with normal myocardium consistently showing a higher T1 value than the LV cavity (12). Myocardial post-contrast T1 values that are similar to or lower than the LV cavity are indicatives of abnormal accumulation of gadolinium in the myocardium (12). Furthermore, the ECV fraction, as calculated by the pre-and post-contrast T1 values and the patient's hematocrit, can provide information regarding the presence or absence of extracellular expansion of the myocardium (8).

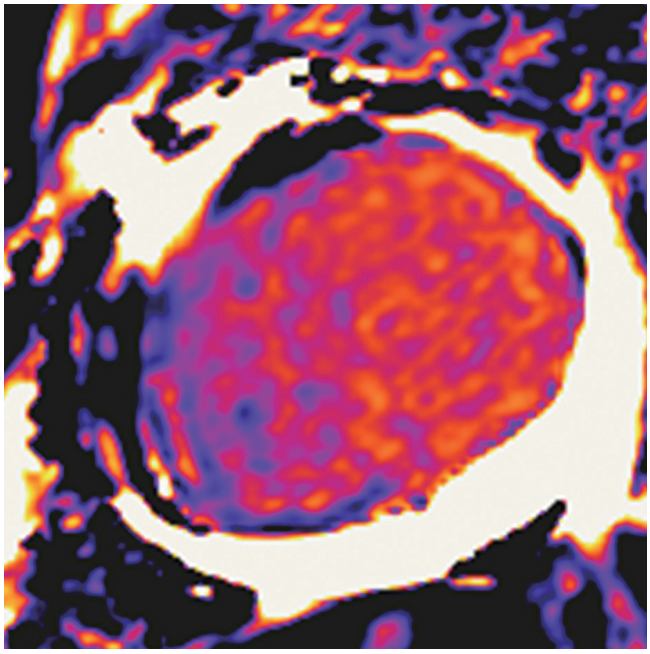

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Fig. 1. Cardiac MR findings in acute global myocarditis. On post-T1 mapping images **(I)**, mean myocardial T1 value was similar to T1 value for LV cavity. Mean ECV fraction of LV myocardium was 45.9 ± 1.9% (range: 43-49.7%). ECV = extracellular volume, LV = left ventricle

Table 1. T2, Pre-T1, and Post-T1 Values as Well as ECV Fractions According to American Heart Association Myocardial Segmentation

Segment	T2 Value (ms)	Pre T1 Value (ms)	Post T1 Value (ms)	ECV Fraction (%)
1	100.5	1232	641	43
2	93	1225	624	45.3
3	87.4	1272	661	41.8
4	79.9	1314	634	47
5	86.4	1250	619	47
6	84.7	1275	627	45.8
7	97.2	1235	620	45.2
8	98.2	1278	608	48.6
9	84.9	1297	614	48.3
10	93.9	1333	629	47.3
11	87.6	1241	619	45.6
12	97.9	1281	630	45.4
13	96	1305	623	45.9
14	88	1311	598	49.8
15	97	1296	630	44.6
16	89	1280	637	43.2
Mean ± SD	91.4 ± 6.1	1276.6 ± 32.4	625 ± 12.4	45.9 ± 1.9

Note.— ECV = extracellular volume, SD = standard deviation

In this case, myocarditis with global LV involvement was diagnosed by CMR using quantitative T1 and T2 mapping. Pre-contrast T1 and T2 maps demonstrated diffuse myocardial edema with prolonged T1 and T2 values. Post-contrast T1 mapping revealed increased myocardial gadolinium accumulation as compared to the LV cavity. Additionally, the calculated ECV fraction indicated an abnormally expanded myocardial extracellular volume. By using quantitative T1 and T2 mapping, the diagnosis of myocarditis can be more easily made, even in cases with global myocardial involvement.

REFERENCES

1. Blauwet LA, Cooper LT. Myocarditis. *Prog Cardiovasc Dis* 2010;52:274-288
2. Friedrich MG, Sechtem U, Schulz-Menger J, Holmvang G, Alakija P, Cooper LT, et al. Cardiovascular magnetic resonance in myocarditis: A JACC White Paper. *J Am Coll Cardiol* 2009;53:1475-1487
3. Feldman AM, McNamara D. Myocarditis. *N Engl J Med* 2000;343:1388-1398
4. Laissy JP, Messin B, Varenne O, Iung B, Karila-Cohen D, Schouman-Claeys E, et al. MRI of acute myocarditis: a comprehensive approach based on various imaging sequences. *Chest* 2002;122:1638-1648
5. Cerqueira MD, Weissman NJ, Dilsizian V, Jacobs AK, Kaul S, Laskey WK, et al. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart.

A statement for healthcare professionals from the Cardiac Imaging Committee of the Council on Clinical Cardiology of the American Heart Association. *Int J Cardiovasc Imaging* 2002;18:539-542
6. Verhaert D, Thavendiranathan P, Giri S, Mihai G, Rajagopalan S, Simonetti OP, et al. Direct T2 quantification of myocardial edema in acute ischemic injury. *JACC Cardiovasc Imaging* 2011;4:269-278
7. Nacif MS, Turkbey EB, Gai N, Nazarian S, van der Geest RJ, Noureldin RA, et al. Myocardial T1 mapping with MRI: comparison of look-locker and MOLLI sequences. *J Magn Reson Imaging* 2011;34:1367-1373
8. Ugander M, Oki AJ, Hsu LY, Kellman P, Greiser A, Aletras AH, et al. Extracellular volume imaging by magnetic resonance imaging provides insights into overt and sub-clinical myocardial pathology. *Eur Heart J* 2012;33:1268-1278
9. Gutberlet M, Spors B, Thoma T, Bertram H, Denecke T, Felix R, et al. Suspected chronic myocarditis at cardiac MR: diagnostic accuracy and association with immunohistologically detected inflammation and viral persistence. *Radiology* 2008;246:401-409
10. Giri S, Chung YC, Merchant A, Mihai G, Rajagopalan S, Raman SV, et al. T2 quantification for improved detection of myocardial edema. *J Cardiovasc Magn Reson* 2009;11:56
11. Ugander M, Bagi PS, Oki AJ, Chen B, Hsu LY, Aletras AH, et al. Myocardial edema as detected by pre-contrast T1 and T2 CMR delineates area at risk associated with acute myocardial infarction. *JACC Cardiovasc Imaging* 2012;5:596-603
12. Maceira AM, Joshi J, Prasad SK, Moon JC, Perugini E, Harding I, et al. Cardiovascular magnetic resonance in cardiac amyloidosis. *Circulation* 2005;111:186-193