CLINICAL RESEARCH

Assessment of left ventricular ejection fraction using the wall motion score index in cardiac magnetic resonance imaging

Évaluation de la fraction d’éjection du ventricule gauche par le score de contractilité régionale (WMSI) en résonance magnétique cardiaque

Réal Lebeau, Karim Serri, Marie-Claude Morice, Thomas Hovasse, Thierry Unterseeh, Jean-François Piéchaud, Jérôme Garot

a Hôpital du Sacré-Cœur de Montréal, université de Montréal, 5400 Boulevard Gouin Ouest, Montréal, H4J 1C5, Canada
b Institut cardiovasculaire Paris Sud, 6, avenue du Noyer-Lambert, 91300 Massy, France

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KEYWORDS
Cardiac magnetic resonance imaging; Left ventricular ejection fraction; Wall motion score index

Summary
Background. — Left ventricular ejection fraction (LVEF) is an important indicator of left ventricular function and of the severity and prognosis of ischaemic heart disease. Assessment of regional function using the wall motion score index (WMSI) is an alternative means of evaluating left ventricular function.

Aim. — We attempted to evaluate LVEF by a method using the WMSI with cardiac magnetic resonance imaging (MRI).

Methods. — One hundred and twenty-two patients referred for evaluation of heart disease had rest WMSI evaluation by cardiac MRI. The WMSI was evaluated using the 16-segment model and score proposed by the American Society of Echocardiography. In our first group of 80 patients, a correlation between WMSI and cardiac MRI LVEF was established and a regression equation was derived. This regression equation was then used in 42 consecutive patients to compare WMSI LVEF with the gold standard MRI LVEF.

Results. — In the first 80 patients, MRI LVEF and WMSI correlated very well ($r = 0.93$). Similarly, in the second group of 42 patients, WMSI LVEF derived from the regression equation correlated very well with MRI LVEF ($r = 0.94$).

Abbreviations: ASE, American Society of Echocardiography; DCMR, Dobutamine Cardiac Magnetic Resonance; LGE, Late Gadolinium Enhancement; LV, Left Ventricular; LVEF, Left Ventricular Ejection Fraction; MRI, Magnetic Resonance Imaging; PCI, Percutaneous Coronary Intervention; RNA, Radionuclide Angiography; SSFP, Steady State Free Precession; TE, Echo Time; TR, Repetition Time; WMS, Wall Motion Score; WMSI, Wall Motion Score Index.

* Corresponding author. Fax: +1 514 338 2381.
E-mail address: real.lebeau@yahoo.ca (R. Lebeau).

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Conclusion. — An objective evaluation of LVEF can be easily made using the WMSI with cardiac MRI, which correlates very well with standard MRI planimetric methods. © 2012 Elsevier Masson SAS. All rights reserved.

Résumé
Contexte. — La fraction d’éjection du ventricule gauche (FEVG) est un important indicateur de la fonction ventriculaire gauche, de la sévérité et du pronostic de la maladie cardiaque ischémique. L’évaluation de la fonction régionale du VG en utilisant le score de contractilité régionale ou ‘‘wall motion score index’’ (WMSI) permet une évaluation alternative de la fonction du VG.
Objectif. — Évaluer la FEVG en utilisant le WMSI en résonance magnétique cardiaque (RMC).
Méthodes. — Cent vingt-deux patients références pour évaluation de cardiopathie ont eu une RMC de repos pour évaluer leur fonction VG. Le score de contractilité régionale (WMSI) a été évalué en utilisant le modèle de 16 segments proposé par l’American Society of Echocardiography. D’un premier groupe de 80 patients, une corrélation entre le WMSI et l’évaluation de la FEVG par planimétrie à la RMC a été effectuée. Une équation de régression en a été déduite et fut utilisée dans un second groupe de 42 patients consécutifs. Les résultats furent comparés au gold standard, soit le calcul de la FEVG par planimétrie en RMC.
Résultats. — Chez les 80 premier patients, la FEVG par RMC et le WMSI avaient une excellente corrélation ($r = 0.93$). Dans le second groupe de 42 patients, la FEVG dérivée de l’équation de régression était corrélée aussi très bien avec la FEVG par planimétrie à la RMC ($r = 0.94$).
Conclusion. — Une évaluation de la FEVG peut être facilement effectuée en utilisant le WMSI en RMC et corrèle très bien avec les méthodes de planimétrie en RMC.
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Background

LV systolic function is a major determinant of cardiac performance and LVEF is widely used as an index of systolic function in the management of cardiac patients. Echocardiography and RNA are the more commonly used techniques for estimation of LVEF. Echocardiographic analysis can be performed by simple visual assessment or more quantitative methods. One semi quantitative method separates grades different LV segments to obtain a global score of LV function or WMSI. The relationship between echocardiography-derived WMSI and LVEF has been studied previously. The objective of this study was to derive a similar WMSI LVEF using cardiac MRI and to compare its accuracy in determining LVEF.

Methods

Study population

From April to July 2009, 122 patients referred for cardiac MRI were enrolled in the study. Stress testing with dipyridamole was performed in 56 patients. Patients had to have sufficient image quality (i.e. good endocardial definition) to allow evaluation of LV function. Patients with significant valvular disease, hypertrophic cardiomyopathy or congenital heart disease were excluded from the study because of the unusual LV morphology, which is inappropriate for the classical geometric formula used in the planimetric method. To see if a difference between the WMSI and MRI LVEF would cause a change in classification (i.e. moderate LV dysfunction classified as severe, or normal LV function classified as mildly abnormal), patients were separated into the following subgroups according to LVEF: severely abnormal LV function with LVEF ≤ 30%; moderately abnormal LV function with LVEF 31–44%; mildly abnormal LV function with LVEF 45–54%; and normal LV function with LVEF ≥ 55%.

Cardiac MRI technique

For the assessment of LV function, images were acquired during multiple breath-holds using a 1.5-T whole-body magnet (Magnetom Espree, Siemens, Erlangen, Germany). Sixteen-channel anterior and posterior phased-array coils were used for signal acquisition. We used an electrocardiogram-triggered segmented K-space SSFP cine MRI pulse sequence. After scout images were completed, a stack of three base-to-apex short-axis cross-sectional SSFP cine MRI scans were performed, one at the base, one at the mid-ventricular level and one at the apex of the left ventricle. Each slice was acquired during one short breath-hold (7 to 12 seconds each, depending on heart rate). Scanner settings were as follows: field of view typically in the range of 300–360 mm; slice thickness, 6 mm; TR, 3.1 ms; TE, 1.6 ms; flip angle, 60 degrees; and image matrix $256 \times 160$. Temporal resolution was typically between 30 and 40 ms.

Cardiac MRI study

We used three standard short-axis views from the short-axis stack for analysis: basal (mitral level), mid-ventricular (papillary muscle) and apical, as used in the echocardiographic WMSI method. We then analyze the entire short-axis stack offline with the Siemens computer analysis system for calculations of LVEF, by tracing the endocardial outline
at end-systole and end-diastole. End-systole was defined as the frame with the smallest cavity area and end-diastole as the frame with the largest LV cavity area. Visual semi quantitative assessment of regional wall motion and thickening for WMSI was performed by an experienced cardiologist in a blinded fashion. We used the 16-segment model recommended by the ASE [1]. The 17-segment model, recommended for perfusion by the ASE and the European Society of Cardiology [2], was not used because the 16-segment model is more appropriate for evaluation of wall motion abnormalities as the tip of the normal apex (segment 17) does not move. At the basal and mid-ventricular levels, the left ventricle was divided into six segments and at the apical level it was divided into four segments (Fig. 1). The score for each segment was graded according to the following system: normal, 1; hypokinesia, 2; akinesia, 3; dyskinesia, 4. Adequate visualization of all 16-segments was required for assessment of WMSI. The total wall motion score (WMS) was obtained by adding the score for each segment. The WMSI was calculated by dividing the total wall motion score by 16, as shown in Fig. 1.

**Figure 1.** Wall motion score index calculation. If a patient has eight normal segments and eight akinetic segments the wall motion score would be calculated as 32 and the wall motion score index would be 32/16 = 2.

The study population was composed of 82 men and 40 women, with ages ranging from 38 to 89 years (mean 65 years). Most of the patients were referred for evaluation of chronic ischaemic heart disease (72%), evaluation of non-ischaemic cardiomyopathy (24%) or other pathologies (4%).

In the initial cohort of 80 subjects, we observed a linear correlation between WMSI and the MRI LVEF calculated offline. Using regression analysis, the correlation coefficient between cardiac MRI LVEF and WMSI was calculated to be $r = 0.93$. The formula derived from this regression equation (MRI $LVEF = 0.879 - [0.244 \times WMSI]$) was then validated in the second cohort of 42 patients. The correlation between the WMSI and MRI LVEF was excellent, with a correlation coefficient of 0.94.

The estimation of LVEF according to WMS and WMSI is shown in Table 1. Table 2 shows WMSI LVEF by MRI and WMSI LVEF from two echocardiography studies. Table 3 shows the

### Results

Data obtained for WMS and MRI LVEF were compared by linear regression analysis. Correlation was assessed using the Pearson correlation coefficient. Intraclass correlation was calculated to assess agreement between the two methods. The interobserver and intraobserver variabilities were assessed using linear regression analysis and by calculating average percentage differences.

**Statistical analysis**

The study population was composed of 82 men and 40 women, with ages ranging from 38 to 89 years (mean 65 years). Most of the patients were referred for evaluation of chronic ischaemic heart disease (72%), evaluation of non-ischaemic cardiomyopathy (24%) or other pathologies (4%).

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Table 1 Estimation of LVEF according to WMS and WMSI in the cohort of 122 patients.

<table>
<thead>
<tr>
<th>WMS (WMSI)</th>
<th>LVEF (%)</th>
<th>WMS (WMSI)</th>
<th>LVEF (%)</th>
<th>WMS (WMSI)</th>
<th>LVEF (%)</th>
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</thead>
<tbody>
<tr>
<td>16 (1.0)</td>
<td>64</td>
<td>27 (1.7)</td>
<td>46</td>
<td>38 (2.4)</td>
<td>28</td>
</tr>
<tr>
<td>17 (1.1)</td>
<td>62</td>
<td>28 (1.8)</td>
<td>45</td>
<td>39 (2.4)</td>
<td>27</td>
</tr>
<tr>
<td>18 (1.1)</td>
<td>61</td>
<td>29 (1.8)</td>
<td>43</td>
<td>40 (2.5)</td>
<td>25</td>
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<tr>
<td>19 (1.2)</td>
<td>59</td>
<td>30 (1.9)</td>
<td>41</td>
<td>41 (2.6)</td>
<td>23</td>
</tr>
<tr>
<td>20 (1.3)</td>
<td>58</td>
<td>31 (1.9)</td>
<td>40</td>
<td>42 (2.6)</td>
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<td>21 (1.3)</td>
<td>56</td>
<td>32 (2.0)</td>
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<td>22 (1.4)</td>
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<td>23 (1.4)</td>
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<td>24 (1.5)</td>
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<td>46 (2.9)</td>
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<td>25 (1.6)</td>
<td>49</td>
<td>36 (2.3)</td>
<td>31</td>
<td>47 (2.9)</td>
<td>14</td>
</tr>
<tr>
<td>26 (1.6)</td>
<td>48</td>
<td>37 (2.3)</td>
<td>30</td>
<td>48 (3.0)</td>
<td>12</td>
</tr>
</tbody>
</table>

LVEF: left ventricular ejection fraction; WMS: wall motion score; WMSI: wall motion score index. Regression equation for the 122 patients was MRI LVEF = 0.903 – (0.262 × WMSI).

correlation between MRI LVEF and WMSI LVEF according to LVEF classification (mild, moderate or severe LV dysfunction and normal LV function). The correlation between MRI LVEF and WMSI is shown in Fig. 2 and the Bland-Altman analysis is shown in Fig. 3.

In the 27 patients with MRI LVEF ≤ 30%, the WMSI LVEF overestimated LVEF in four patients with values of 32% (n = 2) and 37% (n = 2). In the 33 patients with moderate LV dysfunction (31–44%), the WMSI LVEF underestimated LVEF in five patients with values of 29% (n = 3), 27% (n = 1) and 24% (n = 1); overestimation occurred in two patients with values of 49%. In the 25 patients with mild LV dysfunction (45–54%), the WMSI LVEF underestimated MRI LVEF in five patients with values of 44% (n = 3) and 41% (n = 2). Overestimation occurred in nine patients with values of 56% (n = 6) and 61% (n = 3). In the 37 patients with MRI LVEF ≥ 55%, the WMSI LVEF underestimated MRI LVEF in six patients with values of 54% (n = 4) and 49% (n = 2) (Table 3). The mean difference between MRI LVEF and WMSI LVEF was ± 3.6% for LVEF ≤ 30%, ± 4.9% for LVEF 31–44%, ± 5.8% for LVEF 45–54% and ± 6.5% for LVEF ≥ 55%.

Assessment of the WMSI was fast. Scoring the 16-segments (LV short-axis views at the base, midventricle and apex) took less than 1 minute and adding the score less than 5 seconds. Manual drawing of the entire short-axis stack required 15 to 20 minutes. No long-axis or apical views were used.

Table 2 WMSI LVEF by two echo studies and MRI.

<table>
<thead>
<tr>
<th>WMSI</th>
<th>ECHO LVEF (Lebeau; n = 243)</th>
<th>ECHO LVEF (Moller; n = 767)</th>
<th>MRI LVEF (n = 122)</th>
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<td>1.0</td>
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<td>3.0</td>
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ECHO: echocardiography; LVEF: left ventricular ejection fraction; MRI: magnetic resonance imaging; WMS: wall motion score; WMSI: wall motion score index.
Table 3  Correlation between MRI LVEF and WMSI LVEF.

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<th>WMSI LVEF</th>
<th>MRI LVEF</th>
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<tr>
<td></td>
<td>≤ 30%</td>
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<td>≤ 30%</td>
<td>23</td>
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<td>31–44%</td>
<td>4</td>
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<tr>
<td>45–54%</td>
<td>0</td>
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<tr>
<td>≥ 55%</td>
<td>27 (22.1%)</td>
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Weighted kappa 0.802; standard error 0.032; 95% confidence interval 0.738 to 0.865. LVEF: left ventricular ejection fraction; MRI: magnetic resonance imaging; WMSI: wall motion score index.

Interobserver and intraobserver variability

Two cardiologists interpreted 30 different MRI examinations covering all the LVEF range. The intraobserver variability was r = 0.95 and the interobserver variability was r = 0.94. The intraclass correlation coefficient was 0.949 (95% confidence interval 0.896–0.975).

Discussion

Our study demonstrates that the WMSI can be used to accurately measure LVEF using MRI, which is considered the gold standard in evaluation of cardiac function. WMSI LVEF is a reliable method that can be used in routine examination to support the planimetric method (ten to 12 short-axis slices or three to ten long-axis apical views). It can confirm visual estimation and is an alternative to automatic border detection, which can often be erratic. As in echocardiography, the WMSI allows the analysis of all 16-segments by using only the apical views if the short-axis views are technically difficult. However, as opposed to apical planimetric views, which are thin sagittal cuts of the heart providing only a few degrees of evaluation, we believe that the classical short-axis views offer the only real three-dimensional analysis of cardiac dynamics because they provide a 360-degree evaluation.

WMSI and echocardiography

The WMSI has been previously validated in several echocardiographic studies and correlated well with LVEF. In 1990, Rifkin et al. [3] described the first correlation between WMSI and LVEF by RNA. They used a complex WMSI grading system (normokinesia, 100%; akinesia, 0%; and various degrees of hypokinesia, 0–100%) and obtained a good correlation between the two techniques (r = 0.91). In 1992, Berning et al. [4] reported a similar study using WMSI to estimate LVEF compared with RNA. They used a nine-segment model with scores ranging from −1 to +3 (dyskinesia to

![Figure 2](image-url)  Correlation between MRI LVEF and WMSI. LVEF: left ventricular ejection fraction; MRI: magnetic resonance imaging; R2: coefficient of determination; SEE: standard error of the estimate; WMSI: wall motion score index.

![Figure 3](image-url)  Bland-Altman analysis of the correlation between MRI LVEF and WMSI. LCL: lower confidence limit; MRI: magnetic resonance imaging; UCL: upper confidence limit; WMSI: wall motion score index.
hyperkinesia) and observed a very good correlation ($r = 0.93$). We published in 2003, an assessment of LVEF derived from WMSI in 243 patients [5] using the classical 16-segment model and score recommended by the ASE. We obtained an excellent correlation with RNA LVEF ($r = 0.92$). The regression equation derived was: $\text{RNA LVEF} = 92.8 - (25.8 \times \text{WMSI})$. More recently, Moller et al. [6] compared the WMSI with a semi qualitative interpretation of LVEF and demonstrated that WMSI is superior to LVEF for risk stratification after acute myocardial infarction. In their series of 767 patients, using the same standard ASE model and score, their equation was identical to ours: $\text{LVEF} = 0.90 - (0.26 \times \text{WMSI})$ (see Table 2). Klein et al. [7], in a group of 101 patients with advanced ischaemic heart failure, found that preoperative echocardiographic WMSI was the only significant predictor of poor outcome after surgical ventricular restoration (ventricular remodelling surgery combined with mitral valve surgery) compared with LV end-diastolic volume, LVEF and moderate to severe mitral insufficiency. Yao et al. [8] in 1500 stress studies compared resting LVEF and WMSI for risk stratification and prognosis. A follow-up of 2.7 ± 1 years confirmed that both were significant predictors of cardiac events (myocardial infarction and cardiac death). Rizello et al. [9] in a dobutamine stress study ($n = 128$) found that the best predictors of cardiac death in multivariate analysis were the presence of multivessel disease, the WMSI at low-dose and the presence of contractile reserve. The presence of ischaemia in this model did not provide additional predictive value. Rosenthal et al. [10] in a study of patients with acute myocardial infarction (ST-segment elevation myocardial infarction) and percutaneous coronary intervention (PCI) compared the WMSI with longitudinal strain to predict scar development as documented by MRI late gadolinium enhancement (LGE). Comparing pre- and post-PCI (4–8 weeks) in a receiver operating curve analysis, strain had 64% sensitivity and 80% specificity for the detection of scar with transmurality ≥ 50% compared with 90% sensitivity and 80% specificity for the WMSI. Longitudinal strain did not add any significant predictive value to that obtained with the WMSI in a logistic regression analysis. Finally, Duncan et al. [11] studied 110 patients and compared echocardiographic LVEF derived from the WMSI, echocardiographic LVEF using Simpson’s biplane method and LVEF obtained by cardiac MRI. They concluded that WMSI-derived LVEF had a stronger correlation with LVEF from MRI ($r = 0.95$) than with LVEF from Simpson’s biplane method ($r = 0.64$). WMSI LVEF seems to be a better technique for evaluating LVEF. More recently, the use of the WMSI as a semi quantitative evaluation of LV function has been shown to help the non-cardiologist (emergency physician or intensivist) in the assessment of heart function and LVEF. Based on these preliminary results, we believe that the WMSI could be a useful method for training physicians in focus or goal-directed echocardiography [12]. McGowan et al. reported the accuracy of the three major echocardiographic methods to evaluate LVEF (Simpson’s biplane method, WMSI and subjective visual assessment) compared with RNA and contrast ventriculography. The authors performed a systematic review of 43 published studies over a 22-year period (1979–2001) and concluded that the three methods were equivalent, as no method appears to systematically underestimate or overestimate LVEF [13].

WMSI and cardiac MRI

The WMSI is often used in echocardiography in the prognosis of coronary artery disease, heart failure, valvular disease, post cardiac surgery and during stress tests. There is, therefore, sufficient interest to include the WMSI in different clinical situations in routine cardiac MRI examinations.

In 2003, Sierra-Galan et al. [14] published a first study on the correlation between cardiac MRI LVEF and WMSI using the 16-segment model of the ASE. Their analysis was performed by a computer-assisted planimetric quantitative method using short-axis views. MRI LVEF was calculated from end-diastolic and end-systolic volumes, as in our present study. In the first part of the study, a linear correlation between WMSI and MRI LVEF was observed in 117 patients ($r = 0.85$). This result was then validated in 86 new patients with very good results ($r = 0.93$). The authors concluded that a qualitative reading of regional wall analysis can accurately predict LVEF. Kelle et al. [15] studied 177 patients with chronic myocardial infarction and compared infarct size using MRI LGE (LGE scar score) and contractile reserve by WMSI variations at rest and during low-dose DCMR. Infarct size evaluated by LGE was a stronger predictor of clinical outcome than LVEF and LV volume at rest. In patients with large myocardial scars, contractile reserve (WMSI variations) was more important for the prediction of events than scar tissue. Pittigore et al. [16] studied 93 patients with normal baseline LV function and compared MRI perfusion (first-pass gadolinium) and function (WMSI) during high-dose dipyridamole MRI stress for detection of coronary artery disease. The positivity criterion for wall motion was a segmental score increase of ≥ 1 grade in at least two segments. The perfusion reserve index was calculated as the ratio of dipyridamole to rest upslope. A perfusion reserve index value < 1.54 in two contiguous myocardial segments was considered a positive perfusion criterion. The authors concluded that perfusion and wall motion abnormalities have similar diagnostic accuracy, particularly in the detection of moderate stenoses, perfusion showing higher sensitivity and wall motion showing higher specificity. Dall’Armellina et al. [17] studied 200 patients with reduced LVEF ≤ 55% to assess the role of DCMR in predicting cardiac events. They assessed WMSI at rest and during low-dose and peak infusion DCMR. Patients were followed for an average of 5 years after DCMR for the occurrence of cardiac death, myocardial infarction, unstable angina or congestive heart failure. The authors concluded that in patients with moderate reductions in LVEF (40–55%), DCMR-induced increases in WMSI could better predict events than resting LVEF. In those with LVEF < 40%, there was no predictive difference between WMSI and LVEF. Klecha et al. [18] studied the effect of 6 months of training on LV in 55 patients with chronic heart failure (New York Heart Association class 2–3 or LVEF < 35%). At 6 months, the trained group versus the untrained group had a tendency toward improvement in LVEF ($p < 0.05$), end-diastolic volume ($p < 0.05$) and WMSI ($p < 0.01$), suggesting an anti-remodelling effect of training in patients with ischaemic chronic heart failure. Finally, Flynn et al. [19] studied 29 patients with grade ≥ 3 chronic functional mitral regurgitation using cardiac MRI. They compared the WMSI and the degree of LGE (scarring) with improvement in postoperative mitral regurgitation 6 months after coronary artery
bypass graft and mitral annuloplasty. They concluded that the severity of extensive scarring (LGE) and the severity of wall motion abnormalities (WMSI) in the postoperative papillary muscle region predict significant mitral regurgitation early after mitral surgery. Annuloplasty was found to be ineffective for severe scarring of the posterior papillary muscle as detected by preoperative cardiac MRI.

**Study limitations**

Because of protocol restrictions and time constraints, we used only three short-axis views (as in standard echocardiographic analysis). Patients with significant valvular disease or hypertrophic cardiomyopathy were excluded because many factors in these conditions can modify LV volumes and affect LVEF. In standard MRI studies, LVEF is calculated from 12–14 short-axis views, which is more accurate and provides information on stroke volume, cardiac output and LV mass. In MRI, 30–40 ms is a rather high value for temporal resolution; we cannot achieve the perfect systolic peak but it is the classical reference for MRI cine. We did not grade hyperkinesias (our maximal LVEF was 64%) where planimetric methods would be more appropriate. Our range of normal LVEF values is similar to previously published MRI studies (mean of 66 ± 6%) [20–24] as well as RNA studies (mean of 63 ± 6%) [25–28]. Finally, estimation of wall motion abnormalities is subjective and the WMSI results are dependent on expertise and image quality.

**Conclusion**

Our results suggest that LVEF evaluation using the echocardiographic WMSI method is accurate and correlates well with standard MRI planimetric assessment. Our method, based on analysis of three short-axis views (base, mid and apex) as used in echocardiography, is simple and fast. This technique could support visual estimation and offer additional prognostic information. Similar to other imaging methods, MRI-derived WMSI remains operator dependent and requires expertise.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

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