A Study of the 16-Segment Regional Wall Motion Scoring Index and Biplane Simpson’s Rule for the Calculation of Left Ventricular Ejection Fraction: A Comparison with Cardiac Magnetic Resonance Imaging

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Aims: Accurate calculation of left ventricular ejection fraction (LVEF) is important for diagnostic, prognostic and therapeutic reasons. Cardiac magnetic resonance (CMR) is the reference standard for LVEF calculation, followed by real time three-dimensional echocardiography (RT3DE). Limited availability of CMR and RT3DE leaves Simpson’s rule as the two-dimensional echocardiography (2DE) standard by which LVEF is calculated. We investigated the accuracy of the 16-Segment Regional Wall Motion Score Index (RWMSI) as an alternative method for calculating LVEF by 2DE and compared this to Simpson’s rule and CMR. Methods and Results: The 2D echocardiograms of 110 patients were studied (LVEF range: 7–74%); 57 of these underwent CMR. A RWMS was applied, based on the consensus opinion of two experienced cardiologists, to each of 16 American Heart Association myocardial segments (RWMSI: hyperkinesis = 3; normal regional contraction = 2; mild hypokinesis = 1.25; severe hypokinesis = 0.75; akinesis = 0; dyskinesis = –1). LVEF was calculated by: LVEF(%) = Σ(16segRWMS)/16 × 30. LVEF was calculated by Simpson’s rule and CMR using standard methods. Results were correlated against CMR. Intertechnique agreement was examined. A P value of <0.05 was considered significant. RWMSI-LVEF correlated strongly with Biplane Simpson’s rule (P < 0.001, r = 0.915). RWMSI-LVEF had a strong correlation to CMR (P < 0.001, r = 0.916); Simpson’s rule-LVEF had a moderate correlation to CMR (P < 0.001, r = 0.647). In patients with LV dysfunction (EF < 55%), on linear regression analysis, RWMSI-LVEF had a better correlation with CMR than Simpson’s rule. Further more Simpson’s rule overestimated LVEF compared to CMR (mean difference: –6.12 ± 16.44, P = 0.002) whereas RWMSI did not (mean difference: 2.58 ± 14.80, P = NS). Conclusion: RWMSI-LVEF correlates strongly with CMR with good intertechnique agreement. In centers where CMR and RT3DE are not readily available, the use by experienced individuals, of the RWMSI for calculating LVEF may be a more simple, accurate, and reliable alternative to Simpson’s rule. (Echocardiography 2011;28:597-604)

Key words: regional wall motion score, left ventricular systolic function, cardiac magnetic resonance, Simpson’s rule

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The quantification of left ventricular ejection fraction (LVEF) is important for therapeutic and prognostic reasons.1 The high spatial resolution of cardiac magnetic resonance (CMR) imaging makes it the reference standard for LVEF calculation.2 Real time three-dimensional echocardiography (RT3DE) is also an effective method for assessment of LVEF.3–5 However due to limited availability of CMR and RT3DE in many departments, two-dimensional echocardiography (2DE) remains the most widely utilized imaging modality for assessing global left ventricular (LV) systolic function. Currently, the joint
American Society of Echocardiography (ASE) and European Association of Echocardiography (EAE) guidelines recommend that Simpson’s biplane method of discs remains the preferred 2D method for calculating LVEF despite the recognized limitations of this technique.6

The same joint guidelines recommend the American Heart Association 16-segment model for the assessment of regional LV function.6 A regional wall score is applied to each myocardial segment classifying it as follows: 1 = normal contraction, 2 = hypokinetic (reduced contraction), 3 = akinetic (no contraction), and 4 = dyskinetic (paradoxical motion during systole). One limitation of this scoring system is that it does not differentiate between the contractile differences of mildly hypokinetic and severely hypokinetic myocardial segments.

Study Aims:
The aim of this study was to validate the accuracy of a simple novel 2DE technique to quantify global LV systolic function by using a modified regional wall motion scoring system and comparing it against the Biplane Simpson’s rule and also CMR as the reference standard.

Methods:
Study Design:
This study was approved by the Regional Ethics Committee and study subjects gave written informed consent.

One hundred ten patients exhibiting a broad spectrum of LVEF’s (range 7–74%) were recruited from outpatient clinics, elective echocardiography, and cardiac catheterization lists.

All study subjects underwent standard 2DE (GE Vivid 7, GE Medical Systems, Wauwatosa, WI, USA). Fifty-one of 110 successfully underwent CMR (LVEF range: 12–73%). LVEF was calculated by 2DE using Simpson’s rule and CMR in the standard way as described below. A regional wall motion score (RWMS) was applied to each of 16-American Heart Association (AHA) myocardial segments based on the consensus opinion of two cardiologists experienced in echocardiography and blinded to the other scan results.

The modified Regional Wall Motion Score Index (RWMSI) was then used to calculate a global LVEF as described below. The two echocardiographic methods for quantifying LV function were then compared against each other. LVEF calculated by using the RWMSI (RWMSI-LVEF) and by using Simpson’s rule (Simpson’s-LVEF) was then correlated against CMR as the reference standard for the subgroup of 51 patients who successfully underwent CMR. There was a broad range of LVEF (12–73%) assessed in this cohort. Subgroup analyses were performed to assess intertechnique agreement of both the RWMSI and Simpson’s rule compared to CMR in patients with normal (LVEF ≥ 55%) and impaired (LVEF < 55%) LV systolic function. Patients with normal LV systolic function, globally impaired LV systolic function and regional wall motion abnormalities were included in the study. Patients were excluded if they had a contraindication to CMR or had poor endocardial wall definition as defined by the inability to accurately visualize ≥2 AHA myocardial segments. Clinical characteristics of the study population are described in Table I.

Imaging Methods:
CMR and 2DE were performed consecutively, within 30 minutes of each other, to ensure similar cardiac loading conditions.

CMR imaging: All CMR studies were performed using a 1.5T MRI scanner (Siemens Sonata, Erlangen, Germany) and a phased array surface coil. Long axis reference views were used for positioning the perpendicular LV short axis slices from the level of the mitral annulus to the LV apex. Short axis images were obtained with prospectively ECG-gated TrueFISP (Fast Imaging with Steady-State Precision) sequences at 10-mm slice thickness. Acquisition time was 90% of the RR-interval, image matrix 256 × 150, field of view 380 mm, repetition time 52.05 ms, echo time 1.74 ms, flip angle 70°, and 12–17 heart phases were acquired per repetition time interval. All images were acquired during 8–10 second breathholds and stored digitally for offline analysis of LV function.

2D echocardiography imaging: 2DE imaging was performed from the parasternal and apical windows with the patient in the left lateral decubitus position using a Vivid 7 scanner, (GE Medical Systems). Depth and frame rate were

| TABLE I |
| Clinical Characteristics of Study Subjects Who Completed both CMR and 2D Echocardiography Protocols (n = 51) |
| Gender (M:F) | 29:22 |
| Mean age (years) | 59 |
| Clinical diagnosis | |
| Ischemic heart disease | 31 |
| Valvular heart disease | 3 |
| Dilated cardiomyopathy | 3 |
| Pulmonary hypertension | 3 |
| Restrictive cardiomyopathy | 1 |
| Atrial septal defect | 1 |
| Coronary artery spasm | 1 |
| No cardiac diagnosis | 8 |

F = female; M = male.

*Diagnosed either on coronary angiography, or clinical diagnosis of angina/previous myocardial infarction.
Figure 1. Calculating LVEF using the Regional Wall Motion Scoring Index A regional wall motion score (RWMS) is applied to each of the 16-American Heart Association myocardial segments. RWMS: hyperkinesis = 3; normal regional contraction = 2; mild-moderate hypokinesis = 1.25; moderate-severe hypokinesis = 0.75; akinesis = 0; dyskinesis = -1. LVEF is then calculated by: LVEF (%) = Σ(16segRWMS)/16 × 30. In this example, the RWMS = 18, therefore LVEF = 18/16 × 30 = 34%.

optimized and 2D images recorded of the parasternal long axis (PSLAX), parasternal short axis (PSSAX), apical four-chamber (A4C), apical two-chamber (A2C), and apical long axis (ALAX) views of the left ventricle and stored for subsequent LV analysis. Harmonic imaging was used consistently throughout each study. Echo contrast agents were not used.

Image Analysis:
CMR: LV analysis was performed off-line using a proprietary software program (Argus software, Siemens Medical Solutions, Germany). Short-axis LV endocardial and epicardial contours were manually traced in end-diastole (start of R-wave) and in end-systole (smallest cavity area). Papillary muscles and trabeculations were excluded from the ventricular volume and were included if contiguous with the myocardial mass. The basal slice was selected as the slice where the blood volume was surrounded by >50% of ventricular myocardium. The end-diastolic and end-systolic cavity surface areas were then summed and end-diastolic (EDV) and end-systolic (ESV) volumes calculated by multiplying with interslice intervals as per Simpson’s method of discs. LVEF was calculated as LVEF = ((EDV-ESV)/EDV) × 100%.2

2D echocardiography: Biplane Simpson’s rule: LVEF was calculated from the A4C and A2C views using Biplane Simpson’s rule as per ASE/EAE guidelines.6

RWMSI: A modified RWMS was applied to each of 16-AHA myocardial segments, based on the consensus opinion of two British Society of Echocardiography accredited cardiologists blinded to other scan results. The RWMS was applied as follows: hyperkinesis = 3; normal regional contraction = 2; mild-moderate hypokinesis = 1.25; moderate-severe hypokinesis = 0.75; akinesis = 0, dyskinesis = -1. This modified RWMS includes analysis of hyperkinetic and dyskinetic myocardial segments and differentiates between degrees of hypokinesis. Normal regional contraction was defined by the presence of normal wall thickening in the radial plane of the LV. In cases of partial segment contractility, when half a myocardial segment exhibited akinesis (0) and the other half normal contractility (2) the combined scores were averaged to give an overall score (1) for that segment. LVEF was then calculated by: LVEF(%) = Σ(16segRWMS)/16 × 30 (Fig. 1).

Reproducibility: Interobserver and intraobserver variability in Simpson’s-LVEF and RWMS-LVEF was assessed in 10 patients exhibiting a range of LVEFs (LVEF range: 12–68% by CMR analysis). LVEF was assessed using RWMSI and Biplane Simpson’s rule by two independent observers. These measurements were repeated by one observer 6 months later.

Statistical analysis: Values are expressed as mean ± standard deviation (SD). All data sets were tested for normality using the Shapiro–Wilk test when sample size was greater than fifty and the Kolmogorov–Smirnov test when it was not. Each echocardiographic technique was correlated against CMR-LVEF using a bivariate correlation (Pearson’s correlation coefficient for parametric data and Spearman correlation coefficient for nonparametric data). For parametric data, linear regression analysis was used to directly compare RWMSI-LVEF to Simpson’s-LVEF when indexed against CMR-LVEF as the reference standard. Subgroup analysis was performed to assess the accuracy of RWMSI-LVEF and Simpson’s-LVEF indexed against CMR-LVEF in patients with normal (LVEF ≥ 55%) and impaired (LVEF < 55%) LV systolic function. Bland–Altman analysis was used to determine the bias and limits of agreement between the corresponding measurements. Results are expressed as mean bias ± 1.96 SD. The significance of intertechnique biases was tested using the paired samples T-test for parametrically distributed data and Wilcoxon signed ranks test for nonparametrically distributed data. A value of P < 0.05 was considered significant.
Eight patients were excluded from the study due to poor endocardial wall definition and one patient failed to complete the CMR protocol due to claustrophobia. 102 patients successfully underwent 2DE and 51 of 102 completed the CMR protocol.

Correlation and Intertechnique Agreement of RWMSI-LVEF with Simpson’s-LVEF:
LVEF derived using the RWMSI was compared to LVEF calculated using 2D Simpson’s rule in 102 patients (EF range: 7–74%). RWMSI-LVEF correlated strongly with 2D Simpson’s rule (P < 0.001, \( r = 0.915 \)). Mean calculated LVEF was significantly lower using RWMSI compared to Simpson’s rule (mean bias: 4.06 ± 12.94; Z = -5.25, P < 0.001; Fig. 2).

Correlation and Intertechnique Agreement of RWMSI-LVEF and Simpson’s-LVEF with CMR-LVEF in Patients with Normal LV Systolic Function:
Twenty-seven patients who successfully underwent CMR had normal LV systolic function (LVEF ≥ 55%). Although a good correlation was noted between RWMSI-LVEF and CMR-LVEF (\( r = 0.785, P < 0.001 \)), RWMSI significantly underestimated LVEF in patients with normal LV systolic function (mean bias: 2.39 ± 7.41; Z = -3.20, P = 0.001). There was no significant difference in mean LVEF calculated using Simpson’s rule and CMR in patients with normal LV systolic function (mean bias; -1.10 ± 15.86 with 95%CI: -4.30 to 2.11, P = NS), however correlation between these two techniques in patients with normal LV function was surprisingly poor (\( r = 0.124, P = NS \); Fig. 4).

Correlation and Intertechnique Agreement of RWMSI-LVEF and Simpson’s-LVEF with CMR-LVEF in Patients with Impaired LV Systolic Function:
Twenty-four of the 51 patients who underwent CMR had impaired LV systolic function (LVEF < 55%). RWMSI-LVEF showed a good correlation with CMR-LVEF (\( r = 0.866, P < 0.001 \)) in patients with impaired LV systolic function, this being comparable to the correlation of Simpson’s-LVEF with CMR-LVEF (\( r = 0.826, P < 0.001 \)). On linear regression analysis, RWMSI-LVEF had a significantly stronger correlation with CMR-LVEF (\( T = 3.14, P = 0.005 \)) than Simpson’s-LVEF (\( T = 1.84, P = NS \)). In patients with impaired LV systolic function there was no significant difference between LVEF calculated using the RWMSI and using CMR (mean bias: 2.58 ± 14.80 with 95%CI: -0.60 to 5.77, P = NS). Simpson’s rule significantly overestimated LVEF compared to CMR with a mean difference of -6.12 ± 16.44 with 95%CI: -9.66 to -2.58 (P = 0.002; Fig. 5).

Reproducibility:
Results from Bland–Altman analyses for intraobserver and interobserver variability for RWMSI-LVEF and Simpson’s-LVEF are presented as mean, the difference between the means ± 1.96 SD.
Figure 3. Correlation of CMR-LVEF with A. RWMSI and B. Simpson’s rule in 51 subjects (LVEF range: 12–73%). C. Bland–Altman analysis between CMR and RWMSI; solid horizontal line denotes the mean difference between RWMSI and CMR measurements, broken horizontal lines represent the limits of agreement (2SD around the mean intertechnique difference). Bottom right of Bland–Altman plot: mean bias ± 1.96 SD, the mean bias is significant if P < 0.05. D. Bland–Altman analysis between CMR-LVEF and Simpson’s rule in the same format as in Figure 3C. LVEF = left ventricular ejection fraction; RWMSI = Regional Wall Motion Score Index; SD = standard deviation.

Intraobserver mean of RWMSI-LVEF was 40.42% with difference between the means of 1.68 ± 10.88%. Interobserver mean of RWMSI-LVEF was 40.48% with difference between the means of 1.64 ± 12.32%. Intraobserver mean of Simpson’s-LVEF was 51.20% with difference between the means of –0.34 ± 12.33%. Interobserver mean of Simpson’s-LVEF was 52.52% with...
difference between the means of $-2.91 \pm 9.86$. The intraclass correlation coefficient between two independent observers for CMR-LVEF calculation at our center has previously been reported as 0.82.²

Discussion:
CMR imaging has rapidly become the reference standard for assessing cardiac anatomy and function. The technique for quantifying LVEF by CMR is highly reproducible as previously reported by our research group.² However, there remain major limitations to its widespread use due to initial cost and inability of some individuals to enter an enclosed space. Furthermore, patients with severe LV dysfunction may be unable to lie flat for the duration of the investigation, or may be contraindicated from undergoing CMR due to the increasing prevalence of cardiac resynchronization therapy and internal cardioverter defibrillator devices in this cohort. RT3DE measurements compare favorably to CMR reference values,³⁻⁵,⁷ however as yet RT3DE is not widely available outside specialist centers. 2DE, on the other hand, is widely available, relatively inexpensive and well tolerated.

At present, the ASE/EAE recommend Simpson’s rule as the preferred 2DE method by which to calculate LVEF despite its recognized limitations.⁶ This technique requires both the presence of good endocardial definition and the absence of apical foreshortening during image acquisition. The technique is further limited by the fact it is biplane and does not therefore take into account regional wall motion abnormalities that may be present in the anteroseptum or inferolateral walls of the left ventricle. In echogenic subjects and with the introduction of second harmonic imaging in the absence of contrast enhancement, interobserver errors are still significant. Thomson et al. showed that the interobserver variability in calculating the left ventricular end diastolic volume (LV EDV), left ventricular end systolic volume (LV ESV) and LVEF are 13%, 17%, and 18%, respectively.⁸ Even with the use of both second harmonic imaging and contrast enhancement (which is neither practical or feasible for routine use in a busy technician-led echocardiography laboratory), interobserver variability for LV EDV, LV ESV, and LVEF are 8%, 15%, and 6%, respectively.⁸ Calculation of LVEF by the regional wall motion scoring index is a simple method for quantifying LV systolic function that encompasses information from all 16-AHA myocardial segments of the left ventricle. It has the potential therefore to be of value in quantifying global LV systolic function in patients with impaired LV function due to the presence of regional wall motion abnormalities in addition to patients with global cardiomyopathies. Furthermore, quantification using this method does not require the presence of specialist software, and therefore can be performed in any cardiac center.
on any 2D echocardiogram by an experienced operator.

In this study, RWMS-LVEF showed acceptable reproducibility, comparable to that of Biplane Simpson’s rule. Importantly, LVEF calculated using the RWMSI had a strong correlation to CMR (P < 0.001, R = 0.914). Biplane Simpson’s rule LVEF had a moderate correlation to CMR (P < 0.001, R = 0.647) when tested over a wide range of LVEFs (range 12–73%).

On subgroup analysis when compared to CMR, Simpson’s rule did not correlate with CMR in patients with normal LV systolic function. Although at first this result may seem surprising, on review of the literature, previous comparisons of Simpson’s Biplane method of discs performed by transthoracic echocardiography and volumetric assessment of LVEF performed by CMR have demonstrated large and systematic differences in absolute measurements; Gardner et al reported important differences in CMR volumes and LVEF and echocardiographic volumes and LVEF on indirect comparisons of normal volunteers9 and Chuang et al. have demonstrated that intermodality comparison of cardiac volumes and EF are significantly better between volumetric CMR analysis and volumetric echocardiography (3DE) than between volumetric CMR and biplane echocardiography (Simpson’s rule).10 They have also reported wide limits of agreement when comparing volumetric CMR with biplane echocardiography for calculating LVEF.10 These results suggest that LVEF measurements by the two techniques are not interchangeable. By comparison, the RWMSI had a significantly better correlation with CMR-LVEF in patients with normal LV systolic function compared to Simpson’s rule, despite a tendency to underestimate absolute LVEF in this cohort (mean RWMSI-LVEF vs. mean CMR-LVEF: 59.37% ± 2.99% vs. 61.75% ± 4.82, P = 0.001).

In patients with LV dysfunction, although both echocardiographic techniques correlated well with CMR-LVEF, RWMSI-LVEF had a significantly better correlation with CMR-LVEF than Simpson’s-LVEF on step-wise regression analysis. Importantly, RWMSI-LVEF had good intertechnique agreement with CMR in patients with impaired LV systolic function. Simpson’s rule significantly overestimated LVEF in the cohort of patients with LV systolic dysfunction. Bellenger et al.11 have previously studied LVEF and cardiac volumes calculated using CMR, 2DE Simpson’s rule and radionuclide ventriculography in patients with heart failure and also concluded that echocardiography tends to yield a higher ejection fraction than CMR; a similar finding to this study. This is a clinically important finding. A LVEF ≤ 35% is a prerequisite for heart failure patients to be considered for certain device therapies such as cardiac resynchronization therapy and internal cardiac defibrillators.12–14 If Simpson’s rule is significantly overestimating LVEF in patients with impaired LV function, patients who would benefit from these devices, may potentially be being excluded. RWMSI did not significantly overestimate or underestimate LVEF in this cohort.

The results of our study suggest that the novel RWMSI-LVEF may be a simple and reliable alternative to Biplane Simpson’s rule for quantifying LV systolic function. Furthermore, RWMSI-LVEF appears to have superior intertechnique agreement with CMR-LVEF than Biplane Simpson’s rule.

**Study Limitations:**
This pilot study was designed to examine the feasibility of using the RWMSI to calculate LVEF and to examine its accuracy compared to CMR and Biplane Simpson’s echocardiography. Subgroup analysis in patient subgroups with mild, moderate and severe LV dysfunction was not possible due to the small number of study patients and this warrants further investigation.

**Conclusion:**
We have compared the use of the 16-segment RWMSI to Biplane Simpson’s rule for the quantification of global LV systolic function in patients exhibiting a wide range of LVEF, when indexed against CMR as the reference standard. RWMSI-LVEF correlates strongly with CMR and has good intertechnique agreement. The RWMSI is a simple and widely available method for quantifying LV systolic function using 2DE. In centres where CMR and RT3DE are not readily available, the use by experienced individuals, of the RWMSI for calculation of LVEF may offer a more simple and reliable 2D echocardiographic alternative to Biplane Simpson’s rule.

**References**


