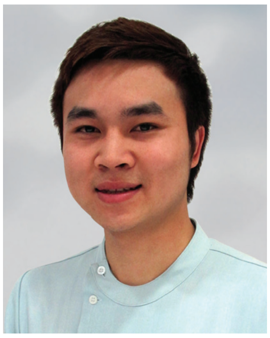
Original Article

Impaired Regional Myocardial Function Detection Using the Standard Inter-Segmental Integration SINE Wave Curve On Magnetic Resonance Imaging



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Keywords:
MRI, Gradient echo CINE MRI, Standard SINE wave curve, Standard cutoff point curve (mean- 2SD)

OBJECTIVE. 1. To quantify the value of myocardial regional wall motion and to study the inter-segmental integration pattern of the circumferential regional wall motion of the left ventricle using Magnetic Resonance Imaging (MRI) in patients with normal global and regional left ventricular systolic function (LVEF ≥ 55%) and compare results to groups with impaired left ventricular systolic function (LVEF ≤ 55%).

2. To prove that the inter-segmental integration pattern of normal myocardial regional wall motion is consistent and can be used effectively as a complimentary tool with visual estimation method to detect the impaired myocardial regional wall motion.

MATERIALS AND METHODS. A total of 60 adult patients (above the age of 15 years old) who underwent cardiac MRI during January to October, 2011 were recruited. Thirty-six patients had normal ejection fraction (LVEF ≥ 55%, Mean = 64%) and normal myocardial regional wall motion, 12 patients had moderate systolic dysfunction (LVEF ≥ 35%, < 55%, Mean = 49.3%) and 12 patients had severe systolic dysfunction (LVEF < 35%, Mean = 22.8%). We retrospectively analyzed and measured the left ventricular ejection fraction and regional wall motion by computerized program in the Brilliance work station of 3 Tesla (3T) MRI. The myocardial wall was divided into 3 parts, the basal (the myocardial level above papillary muscle), the mid (the myocardial level at the papillary muscle) and the apical part (the myocardial level below the papillary muscle). Myocardial wall in each part was segmented into 6 segments for regional wall motion assessment, which was modified from the American Heart Association (AHA) recommendation. The regional wall motion in each ejection fraction group was measured in millimeters and averaged. The average value of each myocardial segment of each systolic function group was plotted in line curve from segments 1-18 (basal to apical part) to form the qualitative standard curve **(Standard inter-segmental integration curve or Standard SINE wave curve)** of normal regional wall motion. The myocardial segment specific standard deviation (SD) value of the normal cardiac function group was also calculated. We created the **standard cutoff point curve** by plotting the resulting value of the average regional wall motion value of each myocardial segment (1-18) minus the segment specific 2-SD of the average value of regional wall motion of the normal cardiac function in line curve. The standard cutoff point curve was a double functional tool because it both displayed SINE wave curve character and provided quantitative cutoff point value. We used the standard cutoff point curve in combination with the standard SINE wave curve to detect impaired myocardial regional wall motion. The impaired regional wall motion myocardial segment was considered as a distortion or deviation point from SINE wave and/or the point of curve that stood below the cutoff point value. The accuracy of these tools in detecting impaired myocardial regional wall motion were compared to visual estimation in terms of sensitivity, specificity, positive predictive value and negative predictive value.

RESULTS. By comparison to the visual estimation method, the sensitivity, specificity, the positive predictive value and the negative predictive value of the standard SINE wave curve in impaired myocardial regional wall motion detection were of 67.8%, 74.6%, 90.5% and 32.2% respectively. By **combining the standard SINE wave curve with the standard cutoff point (mean value - < 2-SD) curve** to detect impaired myocardial regional wall motion, the sensitivity, the positive predictive value and the negative predictive value were increased to 90.9%, 90.4% and 66.7% respectively, compared to the visual estimation method.

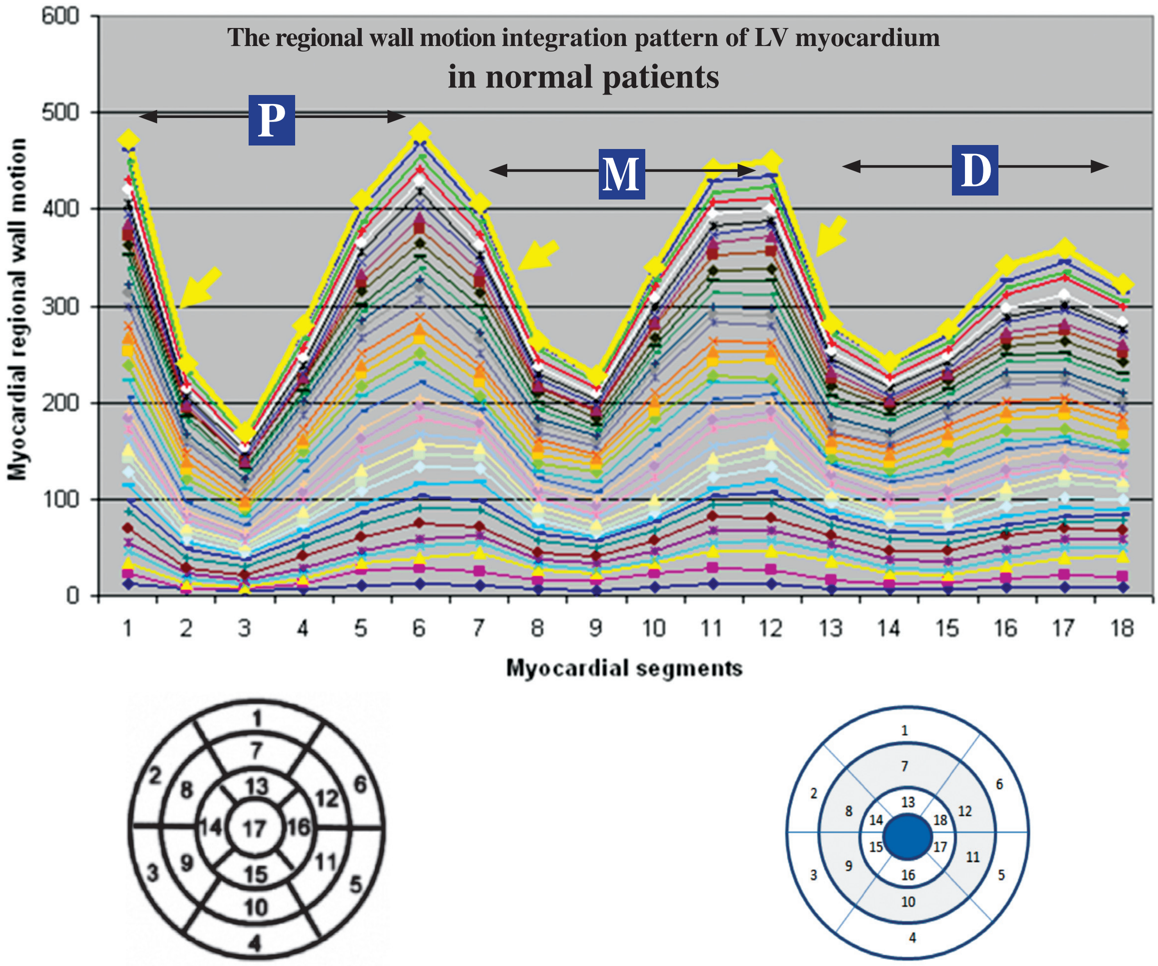
CONCLUSION. The circumferential regional wall motion integration pattern of the left ventricle in normal LVEF with normal regional wall motion patients is consistent; if characterized as a SINE wave curve, it can be used in combination with the standard cutoff point curve which displays the SINE wave character with a quantitative cutoff point, thus providing us with an additional support tool, to the visual estimation method, to detect impaired myocardial regional wall motion with acceptable high accuracy.

Magnetic resonance imaging (MRI) provides three-dimensional analysis of global cardiac function with high accuracy and reproducibility. MRI using CINE gradient technique and slice summation method is considered a gold standard tool for evaluation of the global ventricular function and is also used to evaluate regional myocardial function.[1] The left ventricular regional myocardial function is often assessed and scored by visual estimation as normal, hypokinesia (decreased wall motion), akinesia (absent wall motion), dyskinesia (wall motion in the opposite direction) and hyperkinesia (increased wall motion). However, assessment of myocardial regional wall motion by visual estimation method may be inaccurate because of inter-observer variation. The parameters which are used to express the regional myocardial function of the left ventricle are myocardial wall thickness, systolic myocardial wall thickening, circumferential and longitudinal myocardial wall motion or shortening.[2] In our study, we selected wall motion to be a qualitative and quantitative studied parameter to express the normal and impaired myocardial regional function. The aim of this study were to analyze the inter-segmental myocardial regional wall motion integration pattern and to prove that the integration pattern of normal myocardial regional wall motion can be used as a supporting tool with visual estimation method to depict the impaired regional wall motion myocardial segment.

Materials and Methods

A total 60 adult patients (over the age of 15 years old) of mixed gender who came to the hospital for cardiac MRI examination during January to October in the year of 2011 were recruited. CINE gradient echo MRI with slice summation method for left ventricular function analysis was performed for every patient. Thirty-six patients were classified as having normal global and regional left ventricular systolic function (LVEF ≥ 55%), 12 patients had moderate systolic dysfunction (LVEF ≥ 35%, < 55%) and 12 patients were severe systolic dysfunction (LVEF < 35%).We analyzed the left ventricular ejection fraction and regional wall motion by computerized program in the Brilliance work station of 3T MRI scanner (Achieva, Philips company, Netherlands). The myocardial wall was divided into the basal part (above papillary muscle), the mid part (at the papillary muscle) and the apical part (below the papillary muscle). To analyze myocardial regional wall motion, myocardial wall of three levels of the left ventricle were segmented into 6 segments including the apex, which was modified from the AHA recommendation criteria.[3] Of the total 18 myocardial segments, they were referred to as anterior segments (segments 1, 7, 13), antero-septal segments (segments 2, 8, 14) , infero-septal segments (segments 3, 9, 15), inferior segments (segments 4, 10, 16), infero-lateral segments (segments 5, 11, 17), antero-lateral wall segments (segments 6, 12, 18) and the apex . Segments 1-6 were of the basal part, segments 7-12 were of the mid part and the segments 13-18 were of the apical part. The apex is the most apical segment of the left ventricle (LV). Normally, the LV apical myocardium part was divided into 5 segments by AHA recommendation, in our study however, we divided the apical myocardium into 6 segments and the apex, for more convenience in comparative analysis, as is shown in **Figure 1**.

The apex segment was excluded from the analysis process. The regional wall motion of each segment of normal left ventricular global and regional function was measured in millimeter(s) and was plotted as a line curve from the basal to the apical part respectively, in order to study inter- segmental integration pattern of the left ventricular regional wall motion. The regional wall motion of each myocardial segment in the group with normal cardiac function was averaged and was plotted as a line curve to be used as a qualitative standard SINE wave curve tool, which would depict the impaired regional wall motion myocardial segment. The 2-SD (standard deviation) value of each myocardium was calculated. The standard cutoff point curve was created by the plotting of the result value of myocardial segment specific mean-2SD. We used the standard SINE wave curve and the standard cutoff point curve in order to compare these standard curves with the curve of the regional wall motion of the case we wished to examine. The verified,



AHA recommendation for myocardial segmentation

Basal (or proximal (P)) level; Segments 1-6, **Mid** (M) level; Segments 7-12, **Apical** (or distal (D)) level; Segments 13-16, **Apex** level; Segment 17 **Segments 1,7,13** = anterior, **Segments 2,8** = antero-septal, **Segments 3,9** = infero-septal **Segments 4,10,15** = inferior, **Segments 5,11** = infero-lateral, **Segments 6,12** = antero-lateral, **Segment 14** = septal, **Segment 16** = lateral, **Segment 17** = apex

Studied design : Modified AHA recommendation map of myocardial segmentation

Basal (or proximal (P)) level; Segments 1-6, **Mid** (M) level; Segments 7-12, **Apical** (or distal (D)) level Segments 13-16, **Apex** level; Segment 17 **Segments 1,7,13** = anterior, **Segments 2,8,14** = antero-septal, **Segments 3,9,15** = infero-septal, **Segments 4,10,16** = inferior, **Segments 5,11,17** = infero-lateral, **Segments 6,12,18** = antero-lateral

Figure 1: *Demonstration of the inter-segmental integration pattern of the normal regional wall motion of the left ventricular myocardium characterized a consistent SINE wave pattern with substantial base to apex decline of the amplitude. The left ventricular myocardium was segmented into 18 segments (modified from the American Heart Association (AHA) criteria). Myocardial segments 1-6 were of basal or proximal part (P), segments 7-12 were of mid part (M), segments 13-18 were of apical or distal part (D).*

impaired myocardial segment was the segment showing distortion in comparison to the standard SINE wave curve and the segment point that stood below the standard cutoff point curve.

Statistic analysis

We compared the accuracy of using the studied tool i.e., the standard SINE wave (of normal regional wall motion) curve, the standard cutoff point curve with the visual estimation method, for detection of impaired myocardial regional wall motion in terms of sensitivity, specificity, and positive and negative predictive value.

Cardiac function assessment by MRI

Cardiac function assessment was performed on 3T MRI (Achieva, Philips, Netherlands) scanner, using Gradient echo CINE MRI technique with electrocardiogram (ECG) gating for every patient who had no contraindication for MRI examination (i.e., no metallic implants in the body, no claustrophobia etc). Short axis view of CINE image was required. The number of short axis slice was adjusted to cover the whole length of the left ventricle (from the basal through the apical part) in diastole (with no gap between each slice). The slice thickness should not be beyond 10 mm to avoid

Table 1: Value of left ventricular myocardial wall motion in normal systolic function (LVEF > 55%), moderately imapired systolic function (LVEF > 35% , < 55%) and severely impaired systolic function (LVEF < 35%)

Segment	Location	LVEF ≥ 55% Wall Motion (mm) (mean±SD)	LVEF ≥ 55% Wall Motion (mm) (mean-2SD)	LVEF ≥ 35%, < 55% Wall Motion (mm) (mean± SD)	LVEF < 35% Wall Motion (mm) (mean±SD)
1	Basal anterior	12.75±2.36	8.03	9.97+3.48	6.25+4.20
2	Basal antero-septal	6.51±2.34	1.81	3.28+3.24	2.25+2.08
3	Basal infero-septal	4.58±1.80	0.96	2.25+2.37	1.91±1.77
4	Basal inferior	7.56±2.35	2.85	5.20+3.20	4.2±2.49
5	Basal infero-lateral	11.05±2.86	5.33	9.24+3.01	5.97±3.45
6	Basal antero-lateral	12.94±1.91	9.13	12.09+2.90	6.80±3.99
7	Mid anterior	10.99±3.64	3.72	7.91+3.97	4.18±3.65
8	Mid antero-septal	7.14±2.13	2.87	3.81+2.57	3.08±1.88
9	Mid infero-septal	6.14±2.31	1.51	3.62+1.71	2.83±1.64
10	Mid inferior	9.17±3.02	3.13	6.86+2.78	3.55±2.11
11	Mid infero-lateral	11.9±3.18	5.58	9.20+2.45	4.86±2.77
12	Mid antero-lateral	12.2±3.66	4.83	9.70+4.11	4.36±3.10
13	Apical anterior	7.62±3.01	1.59	4.28+3.18	2.35±2.11
14	Apical septum	6.53±2.43	1.66	4.53+2.39	2.70±1.78
15	Apical infero-septal	7.45±3.76	2.85	5.43+2.50	2.26±2.06
16	Apical inferior	9.25±3.03	3.19	6.61+2.54	3.52±2.32
17	Apical infero-lateral	9.72±3.76	2.19	6.72+2.78	3.42±2.15
18	Apical antero lateral	8.72±3.47	1.78	5.51+3.55	2.13±1.74

the partial volume effect. MRI scanning for cardiac function assessment was done without gadolinium contrast injection. The global cardiac function (LVEF (%)), the left ventricular end diastolic volume (ml), the left ventricular end systolic volume (ml), stroke volume (ml) and cardiac output (L/min) were obtained by delineation of endocardial and epicardial contours on short axis view of CINE images. The circumferential regional wall motion of each myocardial segment was measured automatically by computerized program on the 3T Brilliance work-station after preparation by endocardial and epicardial contouring.

Results

Total 60 patients were classified into three groups according to global cardiac systolic function (left ventricular ejection fraction, LVEF). Thirty-six patients had normal cardiac systolic function, 12 patients had moderately impaired systolic function and 12 patients had severely impaired cardiac systolic function. The average ejection fraction of the normal group was of 64.8 % (55.7%-78.4%), of the moderate LV systolic dysfunction group, 49.3% (37.0%-54.8%) and of the severe LV systolic dysfunction group 19.6% (11.7%-33.6%). The regional wall motion of each myocardial segment of each cardiac function group was quantified and averaged (**Table 1**).

The average value of each myocardial segment (segments 1-18) of each cardiac function group was plotted as a line curve, in order of segment 1 to segment 18, resulting in a SINE wave form curve with amplitude declining from the basal to apical in normal global and regional cardiac function group (**Figure 1**). The average regional wall motion distance value of the anterior and of the antero-lateral wall (segments 6, 12, 18), were at the peak of the positive amplitude and of the infero-septal wall (segment 3, 9, 15) were at the trough of the negative amplitude. For the impaired cardiac systolic function groups, the regional wall motion inter-myocardial segmental integration patterns were not consistent and were distorted from SINE wave (**Figure 2**). Therefore, the line curve with consistent patterns of circumferential regional wall motion inter-myocardial segmental integration of the normal cardiac function group was proposed to be used as a standard SINE wave curve tool, against which the impaired regional wall motion line curve, in case of interest, could be detected by comparison.

In our study, 270 myocardial segments of 15 patients with impaired cardiac systolic function and impaired regional wall motion (average LVEF = 24.84%; range 11.7-40.7%) were used to test the accuracy of the standard SINE wave curve in defining the impaired myocardial regional wall motion segment compared to the visual estimation method. The impaired myocardial segment will be shown as point of distortion from SINE wave curve as shown in **Figure 2, 3**. Two hundred and eleven of 270 myocardial segments were documented as impaired regional wall motion by visual estimation. Fifty-nine myocardial segments were normal. By using the SINE wave referent curve tool to detect impaired regional wall motion myocardial segment, 143 myocardial segments of total 211 were called impaired (143/211= 67.8%, true positive);15 segments of total 211 segments (7.1%, false positive) were considered impaired regional wall motion using standard SINE wave curve but were considered normal by visual estimation. By comparing with the visual estimation method, the sensitivity, specificity, the positive predictive value, the negative predictive value of standard SINE wave curve alone in impaired myocardial regional wall motion detection were of 67.8%, 74.6%, 90.5% and 32.2% respectively (Table 2). In addition, we can observe that the SINE wave pattern was also obtained in impaired systolic function with LV global hypokinesia. However, using only qualitative SINE wave form character of regional wall motion may not be adequate to be a single tool for detection of impaired myocardial regional wall motion. Hence we considered the quantitative cutoff point to be two standard deviation values subtracted from the average segment specific value of normal regional wall motion (**Table 1**). The average-2SD value of each myocardial segment of normal cardiac function group was plotted in line curve to form the standard cutoff point curve of normal myocardial regional wall motion. This cutoff point curve also displayed SINE wave form character that ran parallel to the standard SINE wave form curve (**Figure 4**). By using this tool combined with standard SINE wave form curve, a greater number of impaired myocardial regional wall motion

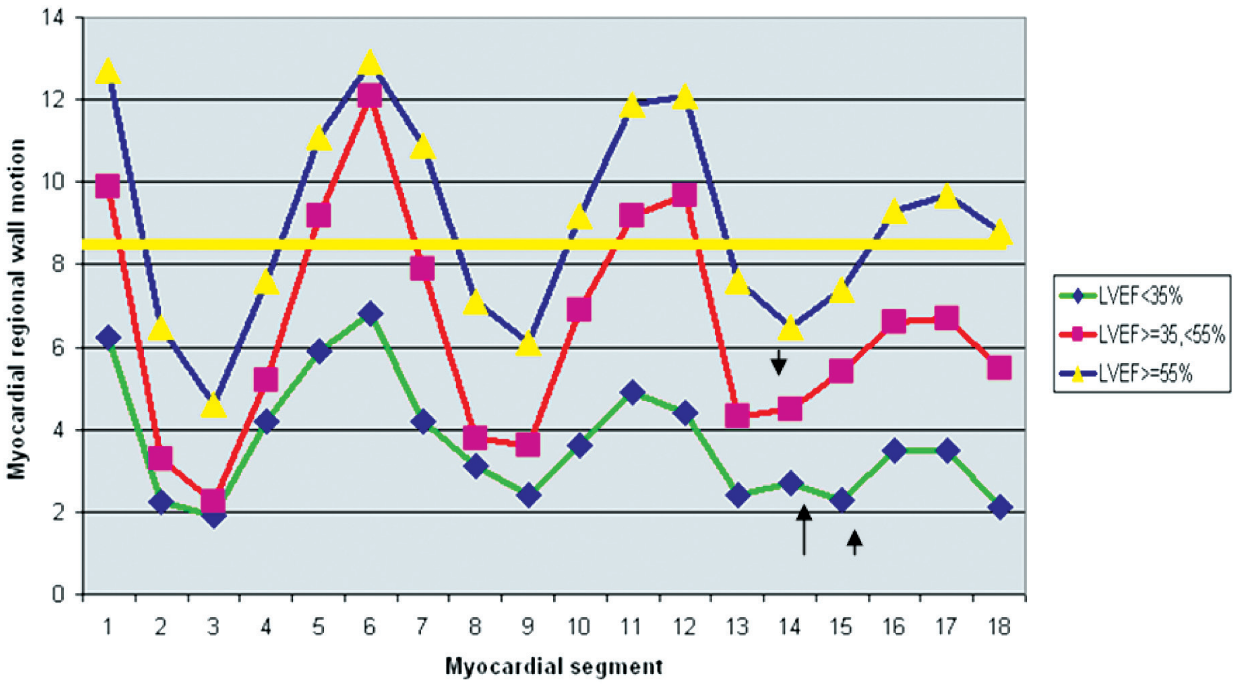


Figure 2: *Demonstration of the comparison of the inter-segmental integration pattern of the left ventricle between normal group (LVEF> 55%) and the impaired myocardial function group (Moderately impaired : LVEF >35, <55% , Severely impaired : LVEF<35%). Black arrow pointed the distortion points from SINE wave which indicated impaired myocardial regional wall motion segments.*

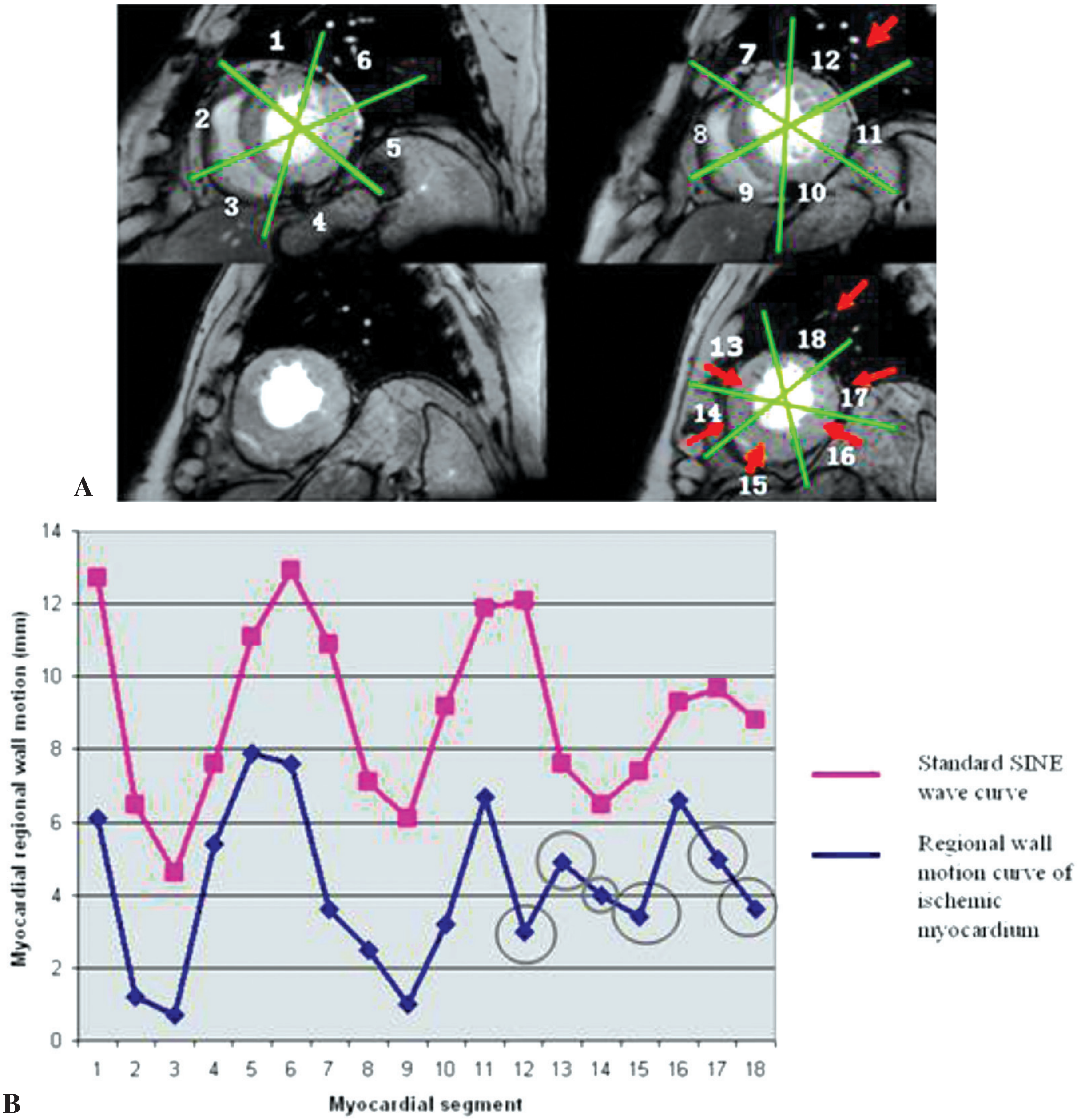


Figure 3A-B: *Demonstration of the application of the standard SINE curve as a tool for impaired regional wall motion detection by parallel comparing to the curve of regional wall motion of the interest case. The distortion point segment point from SINE wave curve was considered an impaired myocardial regional wall motion segment as shown in circle.*

Table 2: Correlative documentation of impaired myocardial segments between the visual estimation method and standard SINE wave form curve. The total studied myocardial segments were of 270 segments of 15 adult patients. The sensitivity, the specificity, the PPV and the NPV were of **60.8%** (143/211), **74.6%** (44/59), **90.5%** (143/168) and **32.2%** (44/112) respectively.

Myocardial segments	Visual estimation (+)	Visual estimation (-)
Standard SINE wave curve +	143	15
Standard SINE wave curve -	68	44

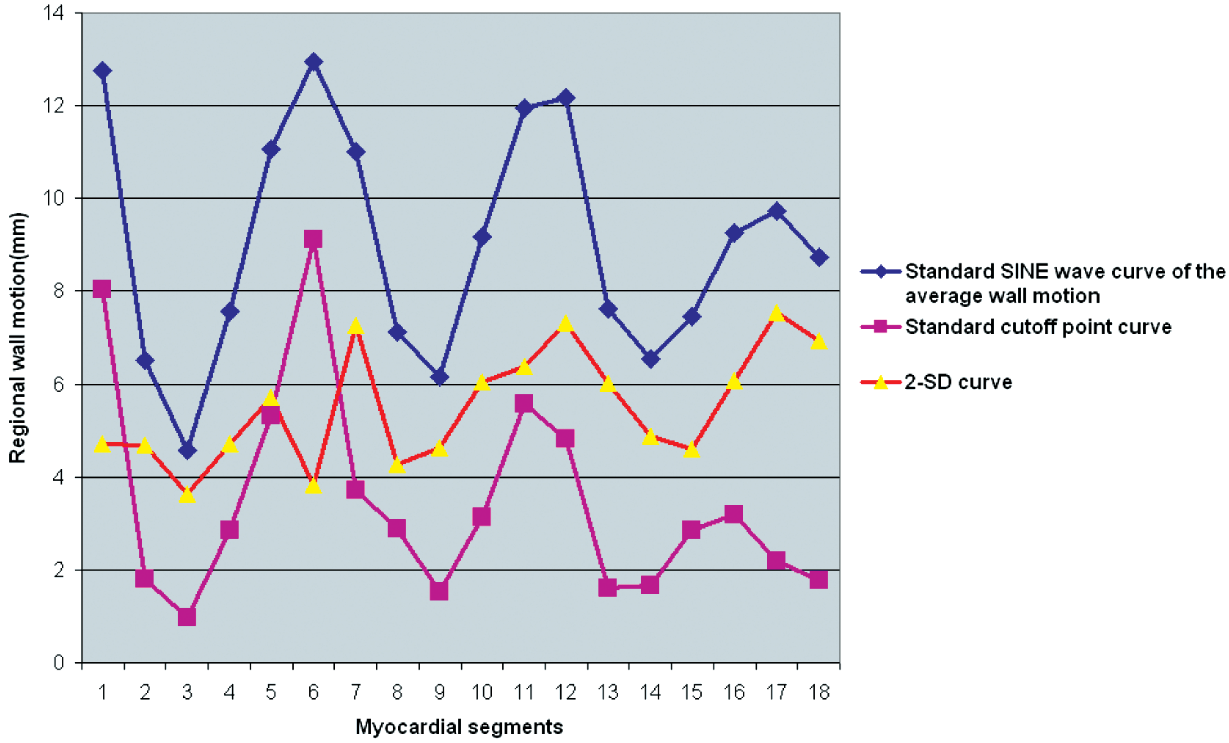


Figure 4: *Demonstration of strandard SINE wave curve, myocardial segment specific 2-SD curve and standard cutoff point curves (mean-2SD) of normal regional wall motion. Standard SINE wave curve was a qualitative tool, which was used to depict impaired myocardial regional wall motion segment by depicting the point of distortion from SINE wave. The standard cutoff point curve (segment specific mean-2SD curve) provided the segment-specific quantitative cutoff point value. Myocardial segment that has regional wall motion < segment specific mean-2SD of the average referent point is counted as for impaired regional systolic function myocardium. The standard cutoff point curve was a double function tool, which provides both qualitative and quantitative properties.*

Table 3: Correlative documentation of impaired myocardial segments between the visual estimation method and combination method (using standard SINE wave curve plus standard cutoff point curve. The sensitivity, the specificity, the PPV and the NPV were of **90.9%** (192/211), **64.4%** (38/59), **90.1%** (192/213) and **66.7%** (38/59) respectively.

Myocardial segments	Visual estimation (+)	Visual estimation (-)
Combination method +	192	21
Combination method -	19	38

segments were documented compared to using the standard SINE wave curve alone (**Figure 5**). Because the impaired regional wall motion myocardial segments were considered when they displayed a distortion from SINE wave and/or stood below the line of standard cutoff point curve. Comparing with the visual estimation method, 192 myocardial segments (90.9%, true positive) were called impaired by visual estimation and by use in combination with the standard SINE wave and standard cutoff point curve, 21 myocardial segments of 211 segments (9.9%) were detected as impaired myocardium by the combined standard curves but were specified as normal by visual estimation method. The sensitivity, specificity, the positive predictive value, the negative predictive value of the regional wall motion detection by using the combination of standard cutoff point compared to the visual estimation were **90.9%, 64.40%, 90.1%** and **66.7%** respectively (**Table 3**).

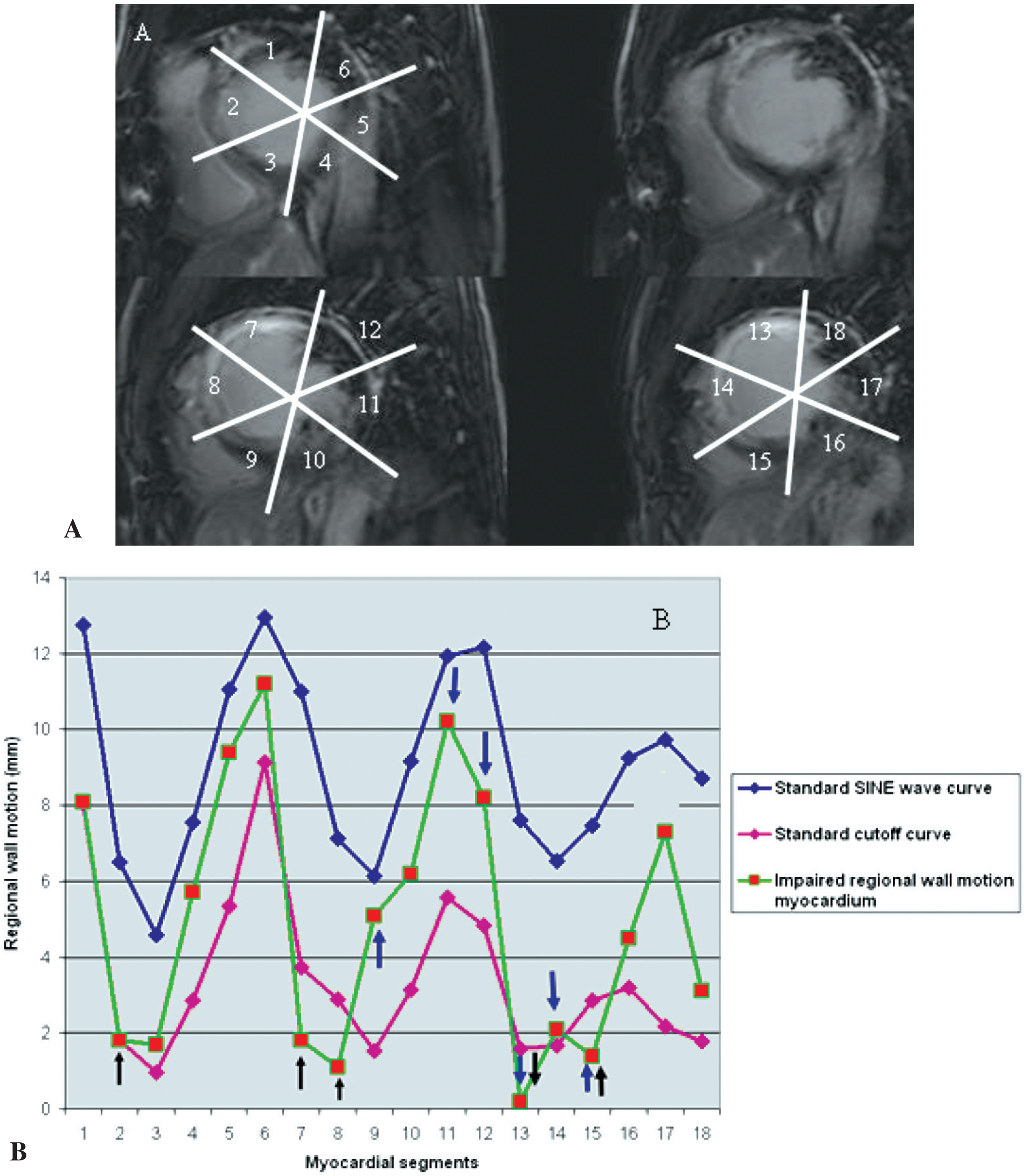


Figure 5A-B: *Demonstration of the application of the standard SINE curve tool plus the standard cutoff point curve to detect the impaired myocardial segment in validated prior myocardial infarction case. A: Delayed contrast enhancement study images showed myocardial contrast enhancement (bright signal) of myocardial infarction area corresponding to the impaired myocardial regional wall motion. B: Demonstration of using standard SINE wave curve combined with the standard cutoff point curve as tool to define impaired myocardial regional wall motion segment. Blue arrow indicated impaired myocardial regional wall motion depicted using standard SINE curve alone. The impaired myocardial regional wall motion segment was shown as a distortion point from the SINE wave. Black arrow indicates the impaired myocardial regional wall motion depicted by the standard cutoff point alone and the impaired myocardial regional wall motion segment was the point that stood below the standard cutoff point curve. The total impaired regional wall motion myocardial segments were all myocardial segments which distorted from SINE wave curve and/or the segments that stood below the stand cutoff point curve.*

Discussion

We demonstrated that the regional wall motion of normal function myocardium displayed the consistent pattern of inter-myocardial segmental integration on line curve and was characterized as a SINE wave form curve with substantial basal to apex amplitude decline. This consistent character can be used as a standard curve tool to depict the impaired myocardial regional wall motion by comparing it with the wave form of the interest case. The standard cutoff point curve is a tool which has both quantitative and qualitative properties by providing the character of SINE wave and lower limit threshold value of myocardial segment specific regional wall motion. Combined use of two standard curve methods can overcome the limitation of using standard SINE wave curve alone, in the case of global hypokinesia, which also showed a consistent SINE wave form as normal case.

In 2001, Sharir et al[4] used 2-3 SD as the cutoff point to define impaired myocardial regional wall motion on Gated myocardial perfusion Single-photon emission computed tomography (SPECT) images; this reflects the fact that detection of myocardial dysfunction is more complex in some segments. Our study used fixed 2-SD for every segment to create the standard cutoff point curve, but Sharir demonstrated that the suitable value for a better cutoff point for some myocardial segments may sometimes need more or less than 2-SD. This should be considered in future studies in order to improve the sensitivity and specificity of our studied tool.

Conclusion

Inter-myocardial segmental integration pattern of normal regional myocardial motion is characterized by a consistent SINE wave with substantial apex-to base amplitude decline. The application of standard segment-specific cutoff value curve in combination with standard SINE wave curve for defining the impaired regional wall motion myocardial segment provided reasonably accurate identification and grading of impaired regional myocardial function. It is thus suitable for use as a supportive diagnostic tool together with the visual estimation method.

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