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Comparison of Cardiac MRI Tissue Tracking and Myocardial Tagging for Assessment of Regional Ventricular Strain

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Abstract

This study sought to compare regional measures of ventricular strain by tissue tracking (TT) to those derived from myocardial tagging (MT) within cardiac MR (CMR), in normal subjects and patients with hypertrophic cardiomyopathy. CMR images from 13 normal subjects and 11 subjects with hypertrophic cardiomyopathy were retrospectively analyzed. For each subject, equivalent mid-papillary level short-axis cine steady-state free precession and MT slices from the same examination were evaluated. The time to peak circumferential strain and magnitude of the peak strain were calculated for 6 matched left ventricular segments. Data from 24 slices (n=144 segments) were compared. The mean difference between techniques in magnitude of peak strain and time to peak strain was $1\pm 9\%$ and 1 ± 58 ms, respectively. The mean difference in the standard deviation of time to peak strain within a slice was 0 ± 19 ms (mean cardiac cycle duration 1013 ± 204 ms). Bland-Altman analysis showed closer agreement in time to peak strain than peak strain magnitude. Measurements of segmental time to peak strain by TT and MT were in close agreement; agreement for the magnitude of peak segmental strain was more modest. The TT approach does not add to CMR examination time and may be a useful tool for the assessment of ventricular synchrony.

Keywords

cardiac magnetic resonance imaging; tissue tracking; feature tracking; myocardial tagging; speckle tracking; ventricular mechanics

Regional abnormalities in ventricular function have an important impact on clinical outcomes and functional capacity in a wide variety of populations. For example, in studies of patients undergoing resynchronization therapy, event-free survival is related to the degree of dyssynchrony prior to intervention [1]. As well, in patients with repaired tetralogy of Fallot, dyssynchrony is associated both with poor exercise capacity [2] and with death and ventricular tachycardia [3].

Regional function can be measured by echocardiography using tissue Doppler and 2D speckle tracking techniques. Suboptimal acoustic windows, however, may significantly degrade data quality. Cardiac magnetic resonance imaging (CMR) more consistently provides high-quality imaging with complete anatomic coverage of both ventricles. CMR techniques to analyze regional ventricular function include myocardial tagging (MT), phase contrast velocity imaging, displacement encoding (DENSE), and strain encoding (SENC) [4]. One drawback to all of these approaches is that they require acquisition of a specialized image dataset at the time of the examination, typically in addition to the standard cine CMR imaging of the ventricles. They thus require a priori planning, increase the duration of the examination, and cannot be applied retrospectively to existing CMR datasets. In addition, MT, the most widely used technique, may suffer from progressive attenuation of the tag signal during the cardiac cycle [5]. Such limitations have hindered the adoption of current CMR regional ventricular analysis techniques in both the clinical and research settings [6,7].

In this study we investigated the use of a method derived from speckle tracking echocardiography for analyzing regional ventricular function within CMR. This approach, which we refer to as tissue tracking (TT), can be used to derive regional myocardial strain from standard cine CMR images [3]. Consequently, this method does not increase examination time and can be applied retrospectively to existing CMR datasets. The aim of this study was to validate for the first time the TT technique for the assessment of regional ventricular mechanics. This was done by comparing TT-derived measurements of regional peak circumferential strain, time to peak circumferential strain, and ventricular synchrony with those measured by the MT method both in normal subjects and in patients with hypertrophic cardiomyopathy (HCM).

Methods

Subjects

CMR studies from subjects without structural heart disease and from patients with hypertrophic cardiomyopathy were identified retrospectively. The diagnosis of HCM was made by a left ventricular wall thickness measurement > 12 mm, in patients with no history of hypertension, coronary artery disease, or diabetes mellitus. CMR for the HCM patients was performed as part of their routine clinical study. The normal cohort consisted primarily of healthy volunteers but also included several patients with mild tricuspid regurgitation ($n=1$), history of supraventricular tachycardia ($n=1$), and a family history but no findings of hypertrophic cardiomyopathy ($n=3$). Permission to perform a retrospective data analysis was granted by the Institutional Review Board and the requirement for informed consent was waived.

CMR imaging

CMR imaging was performed using an Achieva 1.5 T whole body scanner (Philips Medical Systems, Best, the Netherlands) equipped with a 5-element cardiac synergy coil. Both standard cine CMR imaging for ventricular function assessment and MT were obtained in the same examination, typically within 10 minutes of each other.

Standard cine CMR imaging utilized a steady state free precession (SSFP) pulse sequence with retrospective vectorcardiogram-gating and breath holding. Images were acquired as a short-axis stack covering the entire left ventricle. Scan parameters included a field-of-view of 320 mm $\times$ 320 mm, matrix of 160 $\times$ 160, slice thickness of 8 mm, inter-slice gap of 2 mm, repetition time of 3.0 ms, echo time of 1.5 ms, flip angle of 60°, in-plane spatial resolution of 2 $\times$ 2 mm, and temporal resolution of 30-35 ms. MT used a complementary spatial modulation of magnetization (CSPAMM) pulse sequence [8], with prospective vectorcardiogram-gating and breath holding [9,10]. A single short-axis slice was obtained at the left ventricular mid-papillary muscle level. Scan parameters included a field-of-view of 320 mm $\times$ 320 mm, spiral readout with 8 interleaves, acquisition window of 9 ms, slice thickness of 10 mm, repetition time of 25 ms, echo time of 3.6 ms, flip angle of 25°, tag spacing of 5 mm, in-plane spatial resolution of 2.5 $\times$ 2.5 mm, and temporal resolution 25-35 ms.

Image analysis

For the MT strain analysis, a customized software program (Cardiotool [11]), written in MATLAB (MathWorks, Natick, MA), was used for analysis of Lagrangian circumferential strain of the mid-papillary level short-axis slice. The endocardium was drawn manually on the tagged images, and the right ventricular insertion sites were marked. The superior septal insertion point defined the border between the anteroseptal and anterior segment and the inferior right ventricular insertion point marked the boundary between the inferoseptum and the inferior segment. The septum was divided equally into anteroseptal and inferoseptal segments, and the rest of the LV wall was divided equally into anterior, anterolateral, inferolateral, and inferior segments (Figure 1). Tag tracking was completely automatic through identification of the phase of the tag line pattern. The software calculated the average endocardial circumferential strain for each of the segments as a function of time.

For TT analysis, the short-axis cine CMR image slice at the same level as the MT image was identified by cross-referencing locations on ventricular long-axis images. TT analysis was performed using Velocity Vector Imaging software (VVI v. 2.0, Siemens Medical Solutions USA Inc., Malvern, PA), a commercially available product commonly used for analyzing echocardiographic images. The DICOM header tags of the CMR images were modified using custom software to make them compatible with the VVI software. A series of 8-10 points were manually placed along the endocardial surface of the left ventricle, from which a splined curve was automatically constructed yielding 48 equidistant points along the endocardial surface. The VVI software, which performs automatic tracking of a user-specified region of interest, calculated Lagrangian endocardial circumferential strain at each of the 48 points throughout systole. The LV was divided into the same six short-axis segments described above for the MT analysis (Figure 1). Circumferential strain values for each of the 6 segments were calculated as a function of time by averaging the strain of the 8 points contained within the segment (Figure 1).

For both techniques, the magnitude of the peak circumferential strain for each of the 6 segments and the mean peak strain for the whole slice (all segments) were recorded. For convenience, strain values were multiplied by -1 so that shortening would yield positive

values. The time to peak circumferential strain from the time of the vectorcardiogram trigger, expressed in milliseconds and as a percentage of total cardiac cycle duration, was recorded for each of the 6 segments. Ventricular synchrony was assessed for each short-axis slice by recording (1) the difference in time to peak circumferential strain between the anteroseptal and inferolateral segments; (2) the maximum wall difference to peak circumferential strain (latest – earliest segment); and (3) the standard deviation of the time to peak circumferential strain for the 6 segments [1,12].

Three patient groups were analyzed; (1) normal; (2) HCM patients; and (3) combined, including normal and HCM patients. Comparisons between TT and MT parameters were made on a segment-by-segment basis (e.g., anteroseptal segment by TT vs. anteroseptal segment by MT), on a whole slice basis (average value of all 6 segments), and in a pooled fashion (all of the segmental data by TT compared to all of the segmental data by MT). Only high-quality image datasets were included for analysis in this study; if either the SSFP or tagged dataset were judged to be of inadequate quality, neither dataset was used for analysis.

Statistics

Demographic and baseline CMR data for the normal and HCM groups were compared using a two-sample unpaired t-test. Agreement between the two techniques was assessed by Bland-Altman analysis, rather than t-test (given the unclear clinical relevance of statistical differences in this setting). Mean differences with standard deviations of strain magnitude and time to peak strain were calculated for the two techniques. Unless otherwise noted, variables were summarized as mean $\pm$ standard deviation. P values < 0.05 were considered statistically significant. Analyses were performed using SAS 9.2 (SAS Institute Inc., Cary, NC)

Results

CMR datasets from 13 normal subjects and 11 patients with HCM were included, yielding a total of 144 mid-ventricular segments. Of the normal and HCM groups, 8/13 and 5/11 were male, respectively. Table 1 summarizes the subjects' age, body surface area, left ventricular mass, maximum diastolic wall thickness, ejection fraction, and cardiac cycle length. As expected, the HCM group had a significantly higher maximum diastolic wall thickness ($p < 0.001$) and LV mass ($p = 0.01$). The mean cardiac cycle length for the entire cohort was 1013 ± 204 ms, corresponding to a mean heart rate of 59 bpm.

Peak circumferential strain

Mean peak circumferential strain magnitudes measured by TT and MT for the combined, normal, and HCM groups are shown in Table 2 and Figure 2. Overall ($n = 144$ segments), the mean difference in the segmental peak strain magnitude measured by the two techniques (TT – MT) was $1 \pm 9\%$. For the whole slice comparison ($n = 24$), the mean difference was $1 \pm 5\%$. For the normal group, peak circumferential strain measured by TT was slightly greater than by MT in the anterolateral and inferior segments. For the HCM and combined groups, TT peak circumferential strain was greater than MT for the septal, anterolateral, and inferior segments. Overall, the trend was for an increase in the peak strain difference between the

two techniques as the mean peak strain magnitude increased. The mean peak strain values for the normal and HCM groups were $21 \pm 6\%$ and $27 \pm 9\%$ ($p < 0.001$), respectively, by TT; by MT, these values were $23 \pm 4\%$ and $23 \pm 5\%$ ($p = 0.73$).

Time to peak circumferential strain

Mean time to peak circumferential strain measured by TT and MT for the combined, normal, and HCM groups are shown in Table 3 and Figure 3. Overall ($n=144$ segments), the mean difference in the time to peak strain measured by the two techniques (TT-MT) was 1 ± 58 ms. For the whole slice mean time to peak strain, the mean difference between the methods was 1 ± 27 ms. In the normal and combined groups, time to peak strain was longer by TT than by MT in the septal and inferior segments. In the HCM group, the TT values were shorter than MT for the anterior and inferolateral segments. With time to peak segmental circumferential strain expressed as a percent of total cycle length, among all subjects there was close agreement between the two techniques with a mean difference of $0 \pm 6\%$. The mean times to peak strain for the normal and HCM groups were 319 ± 44 ms and 352 ± 81 ms ($p = 0.004$), respectively, by TT; by MT, these values were 320 ± 43 ms and 348 ± 83 ms ($p = 0.01$).

Left ventricular synchrony

A comparison of TT and MT indices of left ventricular synchrony for the combined, normal, and HCM groups is shown in Table 4. For all subjects combined, there was close agreement between the two techniques in the standard deviation of the time to peak circumferential strain (mean difference 0 ± 19 ms) (Figure 4A). There was also good agreement in the time difference to peak strain for the latest and earliest segments (mean difference 0 ± 52 ms), with the TT measurements being slightly shorter in the normal subjects but slightly longer for the HCM patients (Figure 4B). The extent of agreement between the two techniques was somewhat less for the difference in time to peak strain of the anteroseptal and inferolateral segments (mean difference -13 ± 57 ms), with the TT measurements tending to be slightly shorter for both the normal subjects and the HCM patients (Figure 4C).

Discussion

In this study, we compared the magnitude of the regional endocardial circumferential strain and the time to peak circumferential strain calculated by two CMR-based techniques. The first technique, TT, provides a novel means of assessing regional strain from standard, robust, cine SSFP images based on a method initially developed for use in echocardiography. The second, myocardial tagging, utilizes a specialized CMR imaging technique to apply markers to the myocardium for analysis. TT analysis, on average, could be accomplished in a fairly rapid fashion (1-2 minutes); MT typically took longer (12-15 mins). Care was taken to ensure that the myocardium analyzed was the same for the two techniques; cine SSFP and tagged MR data were taken from the same examination at the same location with matched short-axis segments. HCM patients as well as normals were included to enhance the variability of the ventricular mechanics of the study population. Prior studies that have compared TT and MT analysis of CMR images have been limited to whole-slice strain and have not compared peak strain on a segmental basis, or time to peak

strain, as was done here [13,14]. Differences between the normal and HCM group were noted by both techniques in the analysis of time to peak strain; for strain magnitude, however, the groups differed when analyzed by TT, but not MT.

In the analysis of the segmental time to peak circumferential strain, the bias (mean difference between the two techniques) was negligible (1 ms). When the segments were examined separately, the inferoseptum had the greatest overall bias (35 ms); this number, however, was small compared to the average cardiac cycle duration (1013 ms). As demonstrated by the Bland-Altman analysis, the agreement in the normal group was better than that in the HCM patients. In both groups, however, the 95% limits of agreement were small relative to the cardiac cycle duration.

With regard to whole slice peak endocardial circumferential strain magnitude, the bias was small (1%) with moderately close agreement (95% limits of agreement of -8 to 10%). This finding is in accordance with work by Hor et al [13] who, in a similar comparison of TT and MT of CMR images, found a whole slice peak endocardial strain bias of 0.3%. In our segmental analysis we found a relatively small bias ranging from -3 to 5% but overall only modest agreement. The agreement was better in normals than in the HCM group, and became worse in absolute terms with increasing values. The poorer agreement in strain parameters when calculated on a segmental basis rather than for the whole slice is expected as some of the segmental variability is averaged out with the whole slice calculation.

Multiple factors might contribute to the observed differences in the assessment of segmental peak strain and time to peak strain for the two techniques. These include true differences in physiological parameters that occurred between the time of the acquisition of the CMR MT and SSFP sequences, differences in the specific algorithms used to calculate endocardial circumferential strain, technical inadequacies of MT (e.g., loss of the tag signal from through-plane motion), and technical inadequacies of endocardial border tracking by the TT technique. The error introduced by the time of acquisition is likely to be small, due to the brief time delay between the two sequences. Error from differences in the algorithms used in each technique are not surprising; it has been shown within echocardiography that different speckle-tracking analysis software packages applied to the same dataset can yield different strain magnitudes [15,16]; this should not, however, impact the timing portion of the analysis. MT, while often considered to be the in vivo reference standard for strain analysis, clearly has a number of known technical limitations [5], and would be expected to introduce error accordingly.

The potential importance of TT border tracking errors is supported by the observed wider limits of agreement in the Bland-Altman plots for the HCM group compared with the normals. Indeed, we noticed early in our experience with TT that tracking of the midmyocardium in the HCM group performed poorly. This was likely a consequence of the homogeneous intensity of this region of the SSFP image. The TT technique, however, performed much better at the endocardial surface although it could still fail at peak systole in these patients, when there was nearly complete intracavitary obliteration and loss of endocardial contrast. Despite these observations we decided to specifically include patients with HCM in our comparison in order to objectively measure the impact of this challenging

scenario. TT border tracking performance may be improved in the future with the advent of newer, CMR-specific, TT tools.

The high degree of temporal concordance between the two techniques suggests a possible role for TT in the assessment of ventricular synchrony. Dyssynchronous contraction has been shown to predict both functional class improvement [17] and survival [1] following cardiac resynchronization therapy in adults, and has been associated with reduced right ventricular ejection fraction, exercise capacity, arrhythmia, and death in patients with repaired congenital heart disease [3,18]. The identification of a standard definition of synchronous contraction, however, has proven to be challenging [12]; efforts towards defining a clinically predictive electrophysiological or echocardiographic measure of synchrony are ongoing [7]. Proposed definitions based upon speckle tracking echocardiography, however, include anteroseptal to posterior wall delay (> 130 ms considered dyssynchronous), maximum delay (latest to earliest wall), and the standard deviation of the time to peak systolic strain [1,12]. Using each of these approaches, the differences between the MT and TT techniques in this study were small, relative to the cardiac cycle duration.

Limitations

The relatively low temporal resolution of CMR may compromise its ability to accurately assess peak systolic strain and may impact the determination of time to peak systolic strain. This limitation, however, holds equally true for both techniques as the cine SSFP and MT sequences used in this study have similar frame rates. No determination was made regarding the ability of either technique to discriminate dyssynchronous from synchronous contraction due to a lack of paired cine and tagged CMR datasets in patients with known dyssynchrony. Intra- and interobserver variability of the TT technique was not specifically addressed in this work; these measures have been reported in multiple prior reports, however, both CMR-based [13,19] and echocardiographic [20-22]. Finally, the strain parameter examined in this report was endocardial circumferential strain; further studies will be necessary to compare other parameters such as the radial and longitudinal components as well as epicardial and midwall strain.

Conclusions

TT-derived measures of time to segmental peak endocardial circumferential strain, ventricular synchrony, and whole slice peak strain agree well with those generated by MT. The magnitude of segmental peak endocardial circumferential strain as measured by the two techniques, however, shows more modest agreement. These findings support the judicious application of TT-based analysis to CMR cine SSFP images, particularly in investigations of regional time to peak contraction.

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Figure 1.

(A) Representative MT and cine SSFP short-axis images at the mid-papillary level from a normal subject. The myocardium was divided into 6 matching segments on the MT and SSFP images. (B) MT and TT analysis was performed to calculate the average endocardial circumferential strain within each segment at multiple time points throughout the cardiac cycle. MT = myocardial tagging, TT = tissue tracking.

Figure 2.

Bland-Altman plots of the magnitude of the peak endocardial circumferential strain for the TT and MT techniques: (A) whole slice; (B) segmental. The mean difference (bias) is shown as a solid line and the limits of agreement ($\pm 2SD$) as the dashed lines.

Figure 3.

Bland-Altman plots of the time to peak endocardial circumferential strain for the TT and MT techniques expressed as time in ms (A) and as a % of total cycle length (B).

Figure 4.

Bland-Altman plots of synchrony parameters for the TT and MT techniques. (A) Standard deviation of the time to peak endocardial circumferential strain for the 6 segments in the short axis; (B) time to peak endocardial circumferential strain, latest vs. earliest segment; and (C) time to peak endocardial circumferential strain, anteroseptal vs. inferolateral segment.

Table 1.
Demographic and CMR data for the normal and HCM groups (mean $\pm$ SD and range).

	Normal (n=13)	HCM (n=11)	<i>p</i>
Age (y)	32 $\pm$ 15 (18-53)	42 $\pm$ 17 (15-60)	0.13
BSA (m ²)	1.8 $\pm$ 0.2 (1.6-2.1)	1.9 $\pm$ 0.3 (1.4-2.2)	0.58
Maximum diastolic wall thickness (mm)	7.9 $\pm$ 1.7 (6-11)	19.6 $\pm$ 4.2 (14-27)	<0.001
LV ejection fraction (%)	61 $\pm$ 3 (55-65)	64 $\pm$ 6 (56-75)	0.17
LV mass (g)	95 $\pm$ 31 (63-183)	179 $\pm$ 88 (88-179)	0.01
Cycle length (ms)	976 $\pm$ 160 (760-1277)	1059 $\pm$ 246 (632-1364)	0.35

SD = standard deviation; BSA = body surface area; LV = left ventricular.

Table 2.

Endocardial circumferential strain magnitude (% strain, mean $\pm$ SD).

Location	Combined (n = 24)			Normal (n = 13)			HCM (n = 11)		
	TT	MT	Mean difference	TT	MT	Mean difference	TT	MT	Mean difference
Whole Slice	24 $\pm$ 4	23 $\pm$ 2	1 $\pm$ 5	21 $\pm$ 4	23 $\pm$ 2	-2 $\pm$ 3	27 $\pm$ 3	23 $\pm$ 2	4 $\pm$ 4
Anteroseptal	26 $\pm$ 12	21 $\pm$ 4	5 $\pm$ 11	19 $\pm$ 7	21 $\pm$ 3	-2 $\pm$ 6	34 $\pm$ 11	21 $\pm$ 4	13 $\pm$ 10
Anterior	24 $\pm$ 5	26 $\pm$ 4	-2 $\pm$ 6	24 $\pm$ 5	26 $\pm$ 3	-2 $\pm$ 6	23 $\pm$ 6	27 $\pm$ 5	-4 $\pm$ 7
Anterolateral	22 $\pm$ 6	21 $\pm$ 3	1 $\pm$ 6	21 $\pm$ 6	20 $\pm$ 4	1 $\pm$ 5	23 $\pm$ 6	22 $\pm$ 3	1 $\pm$ 7
Inferolateral	24 $\pm$ 11	27 $\pm$ 4	-3 $\pm$ 12	23 $\pm$ 10	27 $\pm$ 3	-4 $\pm$ 11	25 $\pm$ 12	26 $\pm$ 6	-1 $\pm$ 14
Inferior	23 $\pm$ 6	20 $\pm$ 3	3 $\pm$ 7	22 $\pm$ 4	21 $\pm$ 4	1 $\pm$ 5	25 $\pm$ 8	20 $\pm$ 1	5 $\pm$ 8
Inferoseptal	24 $\pm$ 8	23 $\pm$ 4	1 $\pm$ 9	19 $\pm$ 5	23 $\pm$ 4	-4 $\pm$ 5	31 $\pm$ 7	22 $\pm$ 4	9 $\pm$ 8

SD = standard deviation; TT = tissue tracking; MT = myocardial tagging.

Table 3.

Time to peak endocardial circumferential strain (ms, mean $\pm$ SD)

Location	Combined (n = 24)			Normal (n = 13)			HCM (n = 11)		
	TT	MT	Mean difference	TT	MT	Mean difference	TT	MT	Mean difference
Whole Slice	334 $\pm$ 53	333 $\pm$ 53	1 $\pm$ 27	319 $\pm$ 32	320 $\pm$ 29	-1 $\pm$ 30	352 $\pm$ 67	348 $\pm$ 71	4 $\pm$ 23
Anteroseptal	330 $\pm$ 74	310 $\pm$ 53	20 $\pm$ 51	310 $\pm$ 49	305 $\pm$ 32	5 $\pm$ 47	354 $\pm$ 93	316 $\pm$ 72	38 $\pm$ 53
Anterior	306 $\pm$ 71	332 $\pm$ 68	-26 $\pm$ 52	303 $\pm$ 49	310 $\pm$ 37	-7 $\pm$ 40	309 $\pm$ 92	358 $\pm$ 86	-49 $\pm$ 57
Anterolateral	344 $\pm$ 68	349 $\pm$ 67	-5 $\pm$ 49	319 $\pm$ 26	327 $\pm$ 55	-8 $\pm$ 53	375 $\pm$ 89	374 $\pm$ 73	1 $\pm$ 45
Inferolateral	340 $\pm$ 59	374 $\pm$ 68	-34 $\pm$ 65	336 $\pm$ 50	361 $\pm$ 43	-25 $\pm$ 66	345 $\pm$ 70	388 $\pm$ 89	-43 $\pm$ 65
Inferior	341 $\pm$ 55	328 $\pm$ 65	13 $\pm$ 53	317 $\pm$ 37	315 $\pm$ 37	2 $\pm$ 46	369 $\pm$ 61	344 $\pm$ 87	25 $\pm$ 60
Inferoseptal	342 $\pm$ 64	307 $\pm$ 53	35 $\pm$ 47	328 $\pm$ 49	304 $\pm$ 28	24 $\pm$ 44	360 $\pm$ 78	310 $\pm$ 75	50 $\pm$ 47

SD = standard deviation; TT = tissue tracking; MT = myocardial tagging.

Table 4.

Ventricular synchrony parameters (ms, mean $\pm$ SD).

Parameter	Combined (n = 24)			Normal (n = 13)			HCM (n = 11)		
	TT	MT	Mean difference	TT	MT	Mean difference	TT	MT	Mean difference
Standard deviation	41 $\pm$ 17	41 $\pm$ 15	0 $\pm$ 19	31 $\pm$ 12	35 $\pm$ 8	-4 $\pm$ 15	52 $\pm$ 15	47 $\pm$ 18	5 $\pm$ 22
Anteroseptal - inferolateral	50 $\pm$ 36	63 $\pm$ 41	-13 $\pm$ 57	40 $\pm$ 28	57 $\pm$ 33	-17 $\pm$ 50	61 $\pm$ 42	72 $\pm$ 48	-11 $\pm$ 66
Latest - earliest	108 $\pm$ 51	108 $\pm$ 38	0 $\pm$ 52	80 $\pm$ 33	97 $\pm$ 25	-17 $\pm$ 40	140 $\pm$ 51	122 $\pm$ 47	18 $\pm$ 60

SD = standard deviation; TT = tissue tracking; MT = myocardial tagging.