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Mapping-guided characterization of mechanical and electrical activation patterns in patients with normal systolic function using a sensor-based tracking technology

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Aims

In times of evolving cardiac resynchronization therapy, intra-procedural characterization of left ventricular (LV) mechanical activation patterns is desired but technically challenging with currently available technologies. In patients with normal systolic function, we evaluated the feasibility of characterizing LV wall motion using a novel sensor-based, real-time tracking technology.

Methods and results

Ten patients underwent simultaneous motion and electrical mapping of the LV endocardium during sinus rhythm using electroanatomical mapping and navigational systems (EnSite™ NavX™ and MediGuide™, SJM). Epicardial motion data were also collected simultaneously at corresponding locations from accessible coronary sinus branches. Displacements at each mapping point and times of electrical and mechanical activation were combined over each of the six standard LV wall segments. Mechanical activation timing was compared with that from electrical activation and preoperative 2D speckle tracking echocardiography (echo). MediGuide-based displacement data were further analysed to estimate LV chamber volumes that were compared with echo and magnetic resonance imaging (MRI). The lateral and septal walls exhibited the largest (12.5 [11.6–15.0] mm) and smallest (10.2 [9.0–11.3] mm) displacement, respectively. Radial displacement was significantly larger endocardially than epicardially (endo: 6.7 [5.0–9.1] mm; epi: 3.8 [2.4–5.6] mm), while longitudinal displacement was significantly larger epicardially (endo: 8.0 [5.0–10.6] mm; epi: 10.3 [7.4–13.8] mm). Most often, the anteroseptal/anterior and lateral walls showed the earliest and latest mechanical activations, respectively. 9/10 patients had concordant or adjacent wall segments of latest mechanical and electrical activation, and 6/10 patients had concordant or adjacent wall segments of latest mechanical activation as measured by MediGuide and echo. MediGuide’s LV chamber volumes were significantly correlated with MRI ($R^2 = 0.73$, $P < 0.01$) and echo ($R^2 = 0.75$, $P < 0.001$).

Conclusion

The feasibility of mapping-guided intra-procedural characterization of LV wall motion was established.

Clinical trial registration

http://www.clinicaltrials.gov; Unique identifier: CT01629160.

Keywords

Electromagnetic navigation • MediGuide • Speckle tracking echocardiography • Magnetic resonance imaging
What’s new?

- A novel method to intra-operatively characterize left ventricular (LV) wall motion and mechanical activation patterns is presented which uses electromagnetic mapping and cardiac navigation systems to track a magnetic sensor while in contact with the LV endocardium or within branches of the coronary sinus.
- Three-dimensional localized cardiac motion trajectories were measured, showing a gradual increase in displacement from the septum to the lateral wall and from the apex to the base.
- Triangular area-based strain waveforms were shown to be physiological and allowed for determination of the local time of mechanical activation.

Introduction

Cardiac disease frequently has a degenerative effect on cardiac pump function and regional myocardial contraction. An accurate assessment of regional wall motion in the form of myocardial tissue strain is, therefore, a measure of the extent and severity of the disease. Further, characterization of the regional timing of contraction provides insight into pathophysiology and treatment, with late-contracting sites suggested as targets for therapy and metrics of dysynchrony having potential value in patient selection and therapy targeting. Techniques to assess the extent and timing of regional myocardial contraction have traditionally been limited to echocardiography (echo), magnetic resonance imaging (MRI), and computed tomography (CT), each of which suffers from certain limitations. Echocardiography has a limited field of view and its interpretation encompasses inter- and intra-observer variability, MRI has had limited clinical application due to its expensive hardware and complex scan protocols, and CT exposes patients to considerable ionizing radiation. Importantly, none of these techniques can be easily used intra-operatively to evaluate regional myocardial contraction.

One opportunity for characterizing myocardial activation patterns intra-operatively comes from electroanatomical mapping systems that have been widely adopted to facilitate cardiac mapping and ablation of complex arrhythmias. These systems use impedance and/or magnetic information to enable creation of real-time, three-dimensional cardiac geometry and activation maps or to aid in cardiac navigation. One example is the MediGuide system (St. Jude Medical, St Paul, MN, USA) that tracks the real-time position of the moving phantom imitating cardiac and respiratory motions. For this study, we characterized LV wall motion by tracking the 3D location of MediGuide sensors when a MediGuide-enabled tool was placed in contact with the LV wall.

Methods

Patients

Patients older than 18 years of age indicated for a left-heart ablation procedure for atrial fibrillation (AF) or frequent premature ventricular contractions (PVCs) who were in sinus rhythm were prospectively enrolled for this pilot study at the University of Leipzig—Heart Center, Leipzig, Germany between July 2012 and November 2013. Patients with permanent AF and history of heart disease were excluded. All patients provided informed consent.

Echocardiography

Prior to the ablation procedure, all patients underwent a resting transthoracic 2D speckle tracking echo (GE Vivid 7TM, GE Healthcare, Milwaukee, WI, USA). The echo was performed during sinus rhythm in three standard apical views at a sampling frequency of 65–85 Hz and analysed with EchoPAC software (GE Healthcare). Longitudinal strain waveforms from the basal, mid-ventricular, and apical regions of each of the six standard anatomical LV wall segments (anteroseptal, anterior, lateral, posterior, inferior, and septum) were averaged using Matlab (Mathworks, Natick, MA, USA) to obtain an overall strain waveform for each wall segment. The time of mechanical activation was calculated as the time from the body surface QRS complex to 90% of the minimum average strain. An LV dyssynchrony index was defined as the standard deviation of times of mechanical activation among the six LV wall segments.

MediGuideTM technology

The MediGuide system has been described previously. Briefly, it generates an alternating electromagnetic field around the patient’s chest and projects the real-time position and orientation of tools embedded with MediGuide sensors onto live fluoroscopic or pre-recorded cine loops. A patient reference sensor attached to the patient’s chest allows automatic compensation of the sensor projections for patient movement and variations in respiration. In addition, surface ECG gating compensates for changes in heart rate. Previous studies have demonstrated that the MediGuide system is reliable and accurate in sensor tracking and projection with <0.5 mm positional error and <1° orientation error in a moving phantom mimicking cardiac and respiratory motions. For this study, we characterized LV wall motion by tracking the 3D location of MediGuide sensors when a MediGuide-enabled tool was placed in contact with the LV wall.

Mapping and ablation procedure

Patient setup and the clinically indicated ablation procedure were performed per clinical routine. MediGuide-based motion mapping of the LV endocardium was performed in all patients and of accessible coronary sinus (CS) branches in a subset of patients.

Endocardial MediGuide motion mapping

Two MediGuide sensor-equipped diagnostic catheters (LivewireTM, MediGuide EnabledTM, SJM) were placed per clinical routine in the CS and at the right ventricular apex as reference signals. After a trans-atrial septal puncture, contrast-filled ventriculograms in two views (RAO 20–30° and LAO 50–60°) were recorded for MediGuide’s dynamic background during LV mapping. A MediGuide sensor-equipped diagnostic catheter (LivewireTM, MediGuide-enabled) or ablation catheter (TherapyTM CoolPathTM Duo, MediGuide-EnabledTM, or SaphireTM Duo, MediGuide-EnabledTM, SJM) was used with a steerable transcatheter sheath (AgilisTM, SJM) for LV mapping. Twelve-lead surface ECG and bipolar intracardiac electrograms (IEGMs) from all catheters were recorded using an electroanatomical mapping system (EnSiteTM NavXTM, SJM) in communication with MediGuide.

Left ventricular motion mapping was conducted non-fluoroscopically during sinus rhythm by placing the roving MediGuide-enabled catheter in continuous contact with the endocardial surface for 15–20 s at multiple locations. Catheter contact was ensured via consistent...
peak-to-peak amplitude on the bipolar IEGM signal from the roving catheter. Similarly, extensive back pressure on the catheter was avoided by checking for elevation of the ST segment on the unipolar IEGM signal from the roving catheter. A homogenous distribution of mapped points throughout the LV was planned and monitored for each case. However, the specific number of map points collected differed among patients due to variance in LV size.

**Epicardial MediGuide motion mapping in CS tributaries**

Depending on the CS anatomy, a MediGuide-enabled diagnostic catheter, ablation catheter, or 0.014″ guidewire (CPS Excel® MediGuide-Enabled™, SJM) was used to perform motion mapping within CS tributaries. At each map point, the roving catheter in the LV endocardium was also placed in contact with the same location on the opposing endocardial surface as determined using fluoroscopy and the electroanatomical mapping system. Wall motion was recorded simultaneously from both endo- and epicardial surfaces.

**Data preprocessing**

Raw MediGuide 3D positional data were up-sampled offline from a native sampling frequency of 30–101 Hz to synchronize with electrical signals and band-stop filtered to remove effects of respiration. At each map point, beats were manually selected for analysis based on consistency of the following electrical and motion characteristics: (i) waveform morphology on at least two surface ECG leads, (ii) peak-to-peak voltage amplitude on roving catheter bipolar IEGM signals, (iii) cycle length, (iv) atrial and ventricular activation depicted on the CS catheter with consistent atrioventricular delays, and (v) MediGuide sensor positional data along all three dimensions. In the case of extra-systolic beats, the beats preceding and following the premature contractions were excluded from the analysis. Beat selection, as the only manual process of the analysis, was performed by a single observer to avoid inter-observer variability. Map points with <3 acceptable beats were excluded from further analysis.

Motion and electrical data from the selected beats were ensemble-averaged in Matlab to obtain representative motion and electrical waveforms per map point, using onset of the body surface QRS complex as the temporal reference. Time of electrical activation at each map point was defined as the time to the first peak of the roving catheter’s rectified and ensemble-averaged bipolar IEGM signal above twice the signal’s standard deviation. An electrical index of dyssynchrony was defined as the standard deviation of the times of electrical activation among the six LV wall segments.

**Motion analysis**

Three types of LV wall motion characterizations were performed: (i) point-based displacement, (ii) wall segment-based strain, and (iii) global LV chamber volume. For the first two characterizations, the LV endocardial surface was divided into the six standard circumferential wall segments, defining a construct in which each wall segment had two neighbouring wall segments (Figure 1A). The anatomical boundaries of these wall segments were defined using patient-specific anatomical landmarks, including the centroid of the mitral annulus, the LV apex, and LV outflow tract. Each map point was assigned to at least one wall segment, with map points at segmental boundaries being assigned to both neighbouring wall segments.

![Figure 1](https://academic.oup.com/europace/article/19/10/1700/2194470)

Figure 1 (A) A bulls’ eye view of motion map points divided into six standard anatomical wall segments shown in different colours with the schematic on the left and patient data on the right. (B) 3D Motion loops for one patient with an illustration of the displacement vector, along with its radial and longitudinal components (left). Black circles indicate location of each map point at the peak of the R wave with the surrounding loop delineating its corresponding 3D trajectory. The triangulation technique with corresponding strain waveform shown for each triangle is also illustrated (right). The excluded and included triangular strain waveforms are denoted in different colours. (C) An example of MediGuide point cloud (left) showing all motion loops used to create a high-definition 3D shell (right).
Displacement
To assess displacement of the LV wall at each map point, ensemble-averaged motion data were used to delineate a 3D trajectory loop (Figure 1B). A displacement vector was defined connecting the two samples within the 3D loop with the longest scalar distance between them. Displacement from all map points within a given wall segment was averaged and compared with other wall segments. Similar comparisons were made among the basal, mid-ventricular, and apical regions of the LV. Lastly, displacement vectors were decomposed using a patient-specific cardiac co-ordinate system into radial and longitudinal components (Figure 1B) to enable a comparison between epicardial and endocardial displacements.

Strain and mechanical activation time
To calculate strain, we filtered the ensemble-averaged motion data using singular value decomposition and then performed Delaunay triangulation to arrange all motion points within a segment and its two neighbours into non-overlapping triangles. A time-varying area of each triangle, $A_{AT}(t)$, was calculated and converted into time-varying triangular area strain, $e_{AT}(t)$, using the following formula:

$$e_{AT}(t) = \frac{A_{AT}(t) - A_{T0}}{A_{T0}} \times 100\%$$

where $A_{T0}$ is the area of the triangle at the time of body surface QRS onset. The time-varying area strain waveforms were used to exclude triangles from further analysis if they met at least one of the following criteria: (i) minimum strain did not reach at least $−10\%$, indicating the absence of substantial active contraction and, therefore, irrelevancy of timing annotation, (ii) peak-to-peak voltage $<0.5$ V on at least one but not all of the three triangle vertices, suggesting the presence of an electrical border zone that may lead to motion inhomogeneity within the triangle, (iii) $<300$ ms difference in cycle lengths among the three vertices, (iv) the presence of noise or artefact, or (v) other unusual morphologies, such as a large positive area under the $e_{AT}(t)$ waveforms (Figure 1B). The remaining $A_{T}(t)$ waveforms with at least one motion point within the given wall were aligned at the QRS onset and summed to calculate a time-varying wall area waveform, $A_{AV}(t)$, which was converted to the time-varying wall area strain, $e_{AV}(t)$, waveform using a similar formula as above.

The time of mechanical activation for each LV wall segment was defined as the time from the QRS onset to 90% of the peak $e_{AV}(t)$ minimum. In the case of multiple wall segments exhibiting the same time of mechanical activation to the nearest millisecond, multiple earliest and/or latest walls of activation are reported. An index of LV dysynchrony was defined as the standard deviation of the times of mechanical activation among the six anatomical LV wall segments.

Left ventricular chamber volume
To assess a global measure of LV chamber volume, a 3D shell of the LV endocardial surface was reconstructed from the point cloud of all MediGuide samples recorded throughout the intra-operative procedure (Figure 1C). The LV chamber volume enclosed by the dynamic geometry was calculated to obtain end-systolic volume (ESV) defined as the smallest volume, end-diastolic volume (EDV), defined as the largest volume, and by calculation, the LV ejection fraction (EF). These measurements were compared with measurements for each patient obtained using transthoracic echo and, when available, MRI. An example of a representative LV endocardial shell contracting over a single cardiac cycle can be found in Supplementary material online, Video S1.

Statistics
Continuous variables are reported as mean ± standard deviation. In the case of non-normally distributed measurements, data are summarized as median [inter-quartile range]. Analysis of variance (ANOVA) was performed to compare displacement of endocardial and epicardial surfaces. $P$-values $<0.05$ were considered significant.

Results
The study consisted of 10 patients (5 males) with a median age of 60 years, EF of 63%, and QRS duration of 88 ms. None of the patients had a history of cardiomyopathy, myocardial infarction, or prior revascularization. Nine patients were indicated for AF ablation and one patient for ablation of frequent PVCs. Electrical and mechanical mapping was successfully completed in all patients, with an average of $65 \pm 11$ endocardial map points and $5 \pm 4$ epicardial map points (Table 1). Of the 699 total endocardial and epicardial map points recorded, 157 (22.5%) had $<3$ acceptable beats and were excluded from further analysis.

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Gender</th>
<th>Age (years)</th>
<th>EF (%)</th>
<th>QRS width (ms)</th>
<th>Number of endocardial map points</th>
<th>Number of epicardial map points</th>
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<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>51</td>
<td>56</td>
<td>85</td>
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</tr>
<tr>
<td>2</td>
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<td>59</td>
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<td>80</td>
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<tr>
<td>3</td>
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<td>69</td>
<td>97</td>
<td>44</td>
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<tr>
<td>4</td>
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<tr>
<td>7</td>
<td>F</td>
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<td>90</td>
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<tr>
<td>8</td>
<td>M</td>
<td>60</td>
<td>60</td>
<td>82</td>
<td>79</td>
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<td>67</td>
<td>64</td>
<td>90</td>
<td>79</td>
<td>0</td>
</tr>
</tbody>
</table>

Median – 60 63 88 | Number of endocardial map points | Number of epicardial map points |

EF, ejection fraction; F, female; M, male.
Displacement
The largest displacement was seen in the lateral wall (12.5 [11.6–15.0] mm) and the smallest in the septal wall (10.2 [9.0–11.3] mm) (Figure 2A). Motion points in the basal segments of the LV exhibited the largest displacement (12.5 [11.8–13.5] mm) and the apical segments exhibited the smallest displacement (10.6 [9.3–11.3] mm) (Figure 2B).

Endocardial vs. epicardial motion
In 8 out of 10 patients, MediGuide motion mapping in CS tributaries was successfully performed. Three-dimensional displacement was not significantly different between endocardial (10.9 [9.4–13.4] mm) and epicardial (12.0 [10.2–15.0] mm) surfaces ($P = 0.4$), with an absolute difference in 3D displacement of 1.9 (0.9–3.8) mm between each endo–epi pair (Figure 3A). Radial displacement was significantly larger on the endocardial surface (endo: 6.7 [5.0–9.1] mm; epi: 3.8 [2.4–5.6] mm), but longitudinal displacement was significantly larger on the epicardial surface (endo: 8.0 [5.0–10.6] mm; epi: 10.3 [7.4–13.8] mm; Figure 3B and C).

Strain
In all patients, aggregate strain waveforms were successfully calculated for all LV wall segments. 23.7 ± 18.2% of the enclosed triangular area per wall was excluded as per the aforementioned exclusion criteria. Qualitatively, all resulting strain waveforms exhibited a morphology that included an initial plateau or a limited initial relaxation, followed by a sharp decrease, indicative of systolic contraction, followed by a more gradual increase, indicative of diastolic relaxation. All walls exhibited substantial active contraction of $-36.2 \pm 7.4\%$ (range $-18.8$ to $-56.0\%$) minimum area strain. The set of aggregate strain waveforms from a representative patient is shown in Figure 4.

An analysis of the time of mechanical activation based on MediGuide strain waveforms revealed the earliest site of mechanical activation to be the anteroseptal wall in three patients, the anterior wall in three patients, the septal wall in two patients, and the...
posterior and inferior walls in one patient each. The site of latest mechanical activation was the lateral wall in six patients, the anterior wall in two patients, and the anteroseptal and inferior walls in one patient each.

The delay between the earliest and latest times of mechanical activation based on MediGuide was 89 (69–118) ms.

**Comparison with two-dimensional speckle tracking echocardiography**

Two-dimensional speckle tracking echo was completed successfully in 9 out of 10 patients, with a bigeminy arrhythmia precluding acquisition in one patient. Echocardiography-based site of earliest mechanical activation was the inferior and anteroseptal walls in two patients each and the lateral and posterior walls in one patient each. In three patients, multiple walls had the same time of activation and were jointly labelled as the site of earliest mechanical activation. Relative to MediGuide-based strain analysis, echo-based site of earliest mechanical activation was concordant in three patients, adjacent in three patients, and remote in three patients (Figure 5C).

Similarly, echo identified the latest site of mechanical activation at the lateral wall in four patients, the septal wall in three patients, and the inferior wall in one patient. In two patients, both the anteroseptal and the septal walls exhibited the same latest activation. The sites of latest mechanical activation identified by MediGuide and the sites of latest electrical activation were concordant in four patients, adjacent in five patients, and remote in one patient (Figure 5D).

The delay between the earliest and the latest electrical activation was 16 (11–20) ms.

**Mechanical and electrical dyssynchrony**

The dyssynchrony index was similar when measured by MediGuide (41 [25–46] ms) and echo (32 [15–49] ms, P = 0.4). The electrical dyssynchrony index was considerably smaller at 6.3 (4.3–7.9) ms compared with mechanical activation.

**Left ventricular volume measurements**

MediGuide-based ESV and EDV measurements were significantly correlated with MRI-based ($R^2 = 0.73$, $P < 0.01$) and echo-based
chamber volumes \( (R^2 = 0.75, P < 0.001) \) (Table 2). The linear fit of the MRI vs. MediGuide data showed a slope closer to unity \( (m = 0.81) \) compared with 2D echo vs. MediGuide \( (m = 0.49) \), though there was considerable variability among the three modalities, with echo-based measurements underestimating chamber volumes relative to MediGuide and MRI (Figure 6).

**Discussion**

We demonstrated the feasibility of using the MediGuide non-fluoroscopic system to characterize LV wall motion. This represents a significant advance compared with existing imaging-based modalities of mechanical assessment of ventricular function which are challenging to apply/measure/integrate intra-operatively within the conventional electrophysiological clinical environment. MediGuide-based cardiac motion assessment can be achieved relatively easily intra-operatively using the same sensor-based devices that are otherwise used as interventional tools.

MediGuide motion mapping in patients with normal systolic function showed a gradual increase in displacement from the septum to the lateral wall, in accord with previously published results using both MRI and echo. Using MRI tagging, Maier et al.\(^\text{12}\) observed radial displacement to be minimal in the septal and inferior walls in healthy subjects. Similarly, using echo in healthy subjects, Mondillo et al.\(^\text{13}\) found less displacement of the atrioventricular plane in the septal and anterior regions than in the lateral and inferior regions. Also, the decrease in 3D displacement from the LV base to the apex that we observed is in agreement with the gradient that Maffessanti et al.\(^\text{14}\) reported using 3D echo techniques in healthy subjects.

The current study also demonstrated MediGuide-based strain waveform morphologies that were physiological and allowed for clear elucidation of the time of mechanical activation. In a majority...
of patients, the lateral wall was identified as the site of latest mechanical activation, consistent with previous findings using MR tagging techniques. Interestingly, in one patient with known left anterior hemiblock, motion mapping identified the anterior wall as the latest activating wall segment, as expected. We also showed that the sites of latest mechanical activation as determined by MediGuide were concordant or adjacent with the sites of latest electrical activation in 9/10 patients, but matched mechanical activation results from echo in only 6/9 patients. There are several possible explanations for this discrepancy, such as the known variability in echo-based characterization of dyssynchrony and the low number of patients included in the study. Additionally, it is likely that choosing a patient population with higher levels of dyssynchrony, such as those undergoing ablation for ventricular tachycardias or implantation for cardiac resynchronization therapy (CRT), would yield more concordancy across the different modalities. Therefore, a

Table 2 Chamber volume measurements

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>ESV (mL)</th>
<th>EDV (mL)</th>
<th>EF (%)</th>
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<td>Echo</td>
<td>MRI</td>
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<tr>
<td>Median</td>
<td>82</td>
<td>39</td>
<td>60</td>
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</table>

ESV, end-systolic volume; EDV, end-diastolic volume; EF, ejection fraction.

Figure 6 Magnetic resonance imaging and echo-based ESV and EDV measurements of the LV against those obtained from MediGuide (left panel). Volume measurements using MediGuide were significantly correlated with both MRI ($R^2 = 0.73, P < 0.01$) and echo-based volumes ($R^2 = 0.75, P < 0.001$). Bland–Altman plots of MediGuide vs. MRI (top right panel) and echo (bottom right panel) show how the different methods to calculate chamber volume compare. Dashed lines indicate the mean difference ± 2 standard deviations.
comparison in a larger cohort of patients with various underlying conditions is warranted.

In this cohort of patients with normal systolic function, the variance of mechanical activation times as an indirect measure of LV dysynchrony was relatively small and found to be similar to results obtained using echo and MRI. Using speckle tracking echo, De Boeck et al. reported a narrow range of activation times in healthy subjects with peak activation times of 39.6 ± 10.3 ms, comparable to our finding of 39.5 ± 26.0 ms. Similarly, using an MRI tagging protocol, Fonseca et al. showed LV dysynchrony values of 37.5 ± 7.0 ms for young (age 19–26 years) and 46.8 ± 11.5 ms for elderly (age 60–74 years) healthy volunteers. It is interesting that electrical dysynchrony was found to be significantly lower than mechanical dysynchrony as measured by both MediGuide and echo, which may reflect electromechanical dysynchrony and that mechanical discoordination encompasses both electrical dysynchrony and non-electrical factors such as regional contractile heterogeneity.

The results of the current study showed significant correlations between MediGuide-based chamber volume measurements and those from MRI and echo, though there was some variability in measurements across the different modalities. In particular, the echo data underestimated the chamber volumes compared with MediGuide and MRI in all patients, which matches results by Klein et al. showing that 3D speckle tracking echo underestimated LV volumes compared with MRI. Other studies have also demonstrated a mixed concordancy between cardiac measurements taken from MRI and various echo methods, with MRI generally viewed as the more accurate of the two modalities. However, given the limited number of patients included in the current study, it is difficult to conclude the accuracy of the MediGuide-based chamber volumes.

Limitations
This was a single-centre proof of principle study with a limited number of patients with normal systolic function to show feasibility of a new technique. While ideally the strain analysis would be completed on the standard 16-segment heart model, the lack of points taken in some segments due to procedural time constraints led us to condense the apical, mid, and basal regions together into the standard six-wall model. This catheter-based motion mapping technique may be limited by catheter reach and/or changes in heart rate during point-by-point mapping in a similar way as conventional electrical mapping techniques. The comparison of our technique based on 3D motions with 2D echo may have reduced the apparent concordance with an existing modality, and MRI chamber volumes were only available in half of the patients in this study. Therefore, further study of MediGuide motion assessment compared against other modalities or directly against physiologic or clinical outcomes is of interest. Finally, more detailed mapping of the CS and its tributaries will be useful to further establish the utility of this technique in the context of CRT implant.

Conclusion
MediGuide motion mapping can successfully characterize LV wall motion, including measurements of displacement and strain and identification of mechanical activation patterns. Application of this technique to patients with various cardiac diseases, such as candidates for CRT, has the potential to overcome many challenges with existing intra-operative imaging modalities while guiding patient-specific intra-operative optimization of therapy based on cardiac motion. For example, the point of latest mechanical activation, as identified using this technique, can be targeted for LV lead implantation, and the location of ventricular fibrosis can potentially also be elucidated based on ventricular motion patterns in patients with ischaemic cardiomyopathy and avoided during implantation. Further work needs to be completed to evaluate the technology in patients with abnormal systolic function and to perform motion analysis online for integration into the clinical workflow.

Supplementary material
Supplementary material is available at Europace online.

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Conflict of interest:
P.C. has received modest lecture honoraria from St Jude Medical, Biotronik, Medtronic, Boehringer Ingelheim, and Biosense Webster, is a member of the St Jude Medical, Siemens, and Biosense Webster advisory boards, and has received research support from St Jude Medical, Biotronik, Imricon, and Philips. O.A.B. has received modest lecture honoraria from St Jude Medical, Biotronik, Medtronic, and GE Healthcare. H.R., Y.N., S.R., C.M., E.O., and K.R. are employed by St Jude Medical with ownership interests. S.R. and S.R. have received modest lecture honoraria from St Jude Medical, Biotronik, and Boehringer Ingelheim. T.G. has received modest lecture honoraria from St Jude Medical, Biotronik, Boehringer Ingelheim, Daichi Sankyo, and Medtronic. F.W.P. serves as a consultant for St Jude Medical and has received research grants from Medtronic, Boston Scientific, EBR Systems, Biological Delivery System Cordis, MSD, and Proteus Biomedical. G.H. has received modest lecture honoraria from St Jude Medical, Inc., Biotronik, Medtronic, and Biosense Webster and is a member of the St Jude Medical and Biosense Webster advisory board. The other authors have no conflicts of interest to disclose. P.S. received modest lecture honoraria from St Jude Medical, Biotronik, Siemens, and Boehringer Ingelheim and is a member of the St Jude Medical and Boehringer Ingelheim advisory boards.

References
Septally located left atrial hematoma as a consequence of a steam pop

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The patient underwent point-by-point isolation of pulmonary veins (PV) with an irrigated, 3.5-mm-tip catheter (ThermoCool® SF NAV, Biosense Webster Inc., Diamond Bar, CA, USA) using an irrigation rate of 15 mL/min in power-controlled mode (30 W). During the isolation of right superior PV at the anterior-septal aspect an audible steam pop occurred. Two-dimensional transesophageal echocardiography (2D-TEE) revealed septally located hematoma with dimensions of 19.2 x 10.2 mm (A; white arrow). Five months after the index procedure the left atrial surface appeared completely (B; white arrow). In comparison with other left atrial hematomas reported as a complication of PV isolation (mostly located in the posterior wall), in our case the hematoma was located septally and was a consequence of a steam pop.

The full-length version of this report can be viewed at: http://www.escardio.org/Guidelines-&-Education/E-learning/Clinical-cases/Electrophysiology/EP-Case-Reports.