Combined preoperative information using a bullseye plot from speckle tracking echocardiography, cardiac CT scan, and MRI scan: targeted left ventricular lead implantation in patients receiving cardiac resynchronization therapy

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Aims
To evaluate the feasibility and incremental value of using an integrated bullseye model for presenting data from cardiac computed tomography (CT) and magnetic resonance imaging (MRI) in combination with echocardiography evaluation of segmental mechanical delay for guiding optimal left ventricular lead placement in cardiac resynchronization therapy (CRT).

Methods and results
Thirty-nine patients (69 ± 9.7 years, 77% male, 82% with LBBB, 54% with ischaemic cardiomyopathy, 82% New York Heart Association classification of heart failure III) eligible for CRT were included. The left ventricular segment with the latest mechanical activation was determined by echocardiography with speckle tracking radial strain. Cardiac CT scan was used for anatomical evaluation of the coronary sinus and its branches. Cardiac MRI was used for evaluation of viability. A composite bullseye plot was constructed, indicating the most appropriate site for left ventricle (LV) lead placement. The latest mechanical delay was in the basal-anterior (3%), basal-inferior (3%), basal-inferolateral (13%), basal-anterolateral (21%), mid-anterior (8%), mid-inferior (3%), mid-inferolateral (34%), and mid-anterolateral (16%) segment. There were on average 2.5 ± 0.8 veins of suitable sizes (≥ 1.5 mm in diameter). A preoperative combined bullseye plot indicated that in 53% of the patients, there was a matching vein in the segment with the latest mechanical delay. If immediately adjacent segments were included, an optimal placement was possible in 95% of the patients. At 6 months, there was a statistically significant reduction in the left ventricular end systolic volume and the left ventricular ejection fraction was improved (P < 0.01).

Conclusion
Presenting data from echocardiography, cardiac CT, and MRI in a combined bullseye plot is both feasible and convenient for indicating the most appropriate site for LV lead placement. An optimal electrode position can be suggested in almost all patients.

Keywords
cardiac resynchronization therapy • heart failure • radial strain • echocardiography • cardiac CT

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Introduction

Cardiac resynchronization therapy (CRT) is a highly validated treatment for reducing mortality and morbidity in heart failure that is refractory to medical therapy, along with a wide QRS complex.\(^1\)–\(^4\) However, ~25–40% of patients do not seem to benefit from the treatment, reducing its cost-effectiveness and also exposing them to adverse side-effects without any advantage. Non-response to the device therapy seems to be multifactorial, although there is increasing data about how the left ventricular lead positioning can play a crucial role, it has been shown that an apical lead placement is inferior to one in the basal or mid-segments of the heart.\(^5\)–\(^8\) Judged from the typical electro-anatomical activation in the left bundle branch block, it has been proposed that optimal placement is in the mid- or basal inferolateral segments. However, there is considerable individual variation in the latest mechanically activated segment in CRT recipients, and some segments are unsuitable due to transmural scar.\(^9\) The most reliable, and the only prospectively validated method so far, has been radial strain analysis of the segment with latest mechanical delay, using echocardiography evaluation by speckle tracking.\(^10\) Underlying heart failure aetiology does not seem to affect the quantity and distribution of coronary veins available for left ventricle (LV) lead placement; however, in the individual patient, limitations of venous anatomy may restrict LV lead placement to a single vein, with little scope for site selection in almost half of all patients.\(^11\)

Multidetector cardiac computed tomography (CT) has the ability to provide detailed anatomical information preoperatively for the coronary sinus and its branches, and has emerged as a promising preoperative imaging modality.\(^12\)–\(^14\)

Cardiac magnetic resonance imaging (MRI) is the gold standard for assessing viability with late gadolinium enhancement (LGE) to visualize non-viable segments with transmural infarction or fibrosis.\(^15\)–\(^18\)

By combining these three modalities, one might preoperatively decide in which branch the LV electrode should be placed, or whether there is no suitable branch for optimal placement. In order to take advantage of the added information from different modalities, it is imperative to present it in a clinically relevant and useful way. We investigated the feasibility and impact of combining these modalities in a standard 17-segment bullseye plot, and whether this strategy yields comparable preoperative results for patients with both ischaemic and dilated cardiomyopathy, and for both men and women.

Methods

Consecutive patients eligible for CRT (QRS duration for more than 120 ms, left ventricular ejection fraction ≤35%, and New York Heart Association classification of heart failure (NYHA II–IV) despite optimal medical treatment) were invited to be part of the study, according to recent international recommendations.\(^19\) The only major contraindications were severe renal failure (eGFR ≤30 mL/min) and chronic atrial fibrillation. The study was approved by the local ethics committee and informed consent was signed by all patients.

Population characteristics

Thirty-nine patients were recruited from Skane University Hospital in Lund, a tertiary referral centre in Sweden. All patients fulfilled the criteria for CRT therapy according to the current guidelines.\(^20\) Relevant clinical data were collected from the regional medical database. All patients had optimal medical therapy with the highest tolerable dosage of angiotensin-converting enzyme inhibitor or angiotensin receptor blocker, beta blocker, and aldosterone blockade. Additional cardiovascular medication was used at the discretion of the treating physician.

Echocardiography

Data acquisition

All patients had a comprehensive preoperative echocardiographic assessment, and the echocardiographic studies were performed with a standard imaging system (Vivid E9, GE Medical, Horten, Norway) by experienced echocardiographers. Offline analysis was performed on a PC workstation with Echopac software (Echopac BT12, GE Medical, Horten, Norway).

Data analysis

Standard echocardiography measures of left ventricular volume was performed using the recommended Simpson’s biplane method.\(^21\) Mitral regurgitation (MR) severity was graded 1–3 according to the current guidelines.\(^20\) Intraventricular dyssynchrony was defined using radial speckle tracking analysis of the anteroseptal and inferolateral mid-LV segments, with a cut-off of >130 ms as previously described.\(^22\) Intraventricular dyssynchrony was defined as a difference in time >40 ms from QRS onset of the continuous Doppler recordings in the aortic and pulmonary outflow tracts. Analysis of segmental mechanical delay was performed from short-axis parasternal views of the basal and mid-LV segments, assessing the peak radial strain (time to peak) derived from speckle tracking data (Figure 1). All collected data were analysed three times, and the mean values were used for the final decision. The latest segment with a peak radial strain >9.5% was defined as the optimal segment for LV lead placement, based on observations from previous studies.\(^20\)\(^23\) If more than one segment had the same (latest) time-to-peak radial strain, both segments were defined as optimal for lead placement, but preference was given to the segment with the highest peak radial strain value. Segments immediately bordering the selected optimal segment were defined as ‘adjacent to the optimal segment,’ and all other segments were defined as ‘remote to the optimal segment.’ The optimal segment was presented in a bullseye plot with a standard 17-segment model. In accordance with previous study results, the apical segments (i.e. segments 13–17) were not considered as possible targets for lead placement, and therefore, not included in the model.\(^23\) Strain analysis was performed by two experienced echocardiographers simultaneously, and the result was only accepted in case of agreement between observers, thus interobserver variability was not relevant. Intraobserver variability was expressed as mean difference in percent between two paired measurements.

Cardiac CT scan

Data acquisition

The CT protocol was weight and frequency based, and tailored for each individual patient. The standard tube voltage was 100 kV at 350 mAs; for patients with BMI <25, 80 kV at 150 mAs, and for BMI >30, 120 kV 400 mAs. Patients with normal or low BMI (but large breasts or prominent pectoral muscles) were assigned a CT protocol for higher BMI. During the course of the study, our CT machinery was updated with three different machines being used: 128-detector row ICT (Philips Healthcare, Eindhoven, The Netherlands), 256-detector row iCT (Philips Healthcare, Eindhoven, The Netherlands), or 256-detector row Siemens Definition Flash (Siemens Medical Systems, Erlangen, Germany). ECG-dependent dose modulation was used for all patients. Region of interest for bolus tracking was chosen in the ascending or descending aorta, with the
threshold set to 140 HU. The contrast agent was either Omnipaque 350 mg/mL (GE Health Care) or Iomeron 400 mg/mL (Bracco Altana Pharma GmbH, Konstanz, Germany). The contrast protocol was partially bolus triggered and partially fixed, in that it triggered contrast bolus in the ascending aorta and added 15 (for example $9 + 15$) s, which in most patients resulted in good venous contrast phase. Intravenous beta blocker, Metoprolol Succinate 1 mg/mL (2.5–10 mL) (Astra Zeneca, Södertälje, Sweden), was used for frequency regulation in some patients, when necessary. Nitroglycerine was not given.

**Data analysis**

From the cardiac CT scan, the number and anatomical course of the coronary sinus branches were delineated, and manually transferred to a bullseye plot similar to the plot used for presentation of echocardiography data. A multiplanar reformatting (MPR) reconstruction was made, such that the images corresponded to the standard echocardiographic short-axis view. Segmentation and alignment of the images from different modalities was done manually: On the short-axis slice representing the basal segments, the commissures of the mitral valve were used as reference points (see Figure 2). At the mid-segment level, the papillary muscles were used as reference points. This allowed for precise identification of the corresponding segments for all used imaging modalities. The coronary sinus was followed from the ostium in the right atrium, while all branches were recorded and the course of the veins were noted in the 17-segment model. An appropriate vein was defined as a branch with $\geq 1.5$ mm diameter, a length of $\geq 2$ cm, and an angle $<150^\circ$ from the great cardiac vein. Coronary vein anatomy was described as the number of vein branches originating from the main coronary sinus in between the middle cardiac vein (MCV, running in the inferior interventricular sulcus) and the great cardiac vein (GCV, running in the anterior interventricular sulcus; see Figure 3). Standard nomenclature for the branches was used, including the posterior vein, the inferolateral vein, and the LV. If there was a sufficiently large diameter branch originating from the MCV, it was designated as a marginal inferolateral vein; conversely an anterolateral branch originating from the GCV was called a diagonal anterolateral vein.

**Cardiac MRI scan**

**Data acquisition**

A 1.5-T and 3-T MRI scanner (Philips Achieva, Philips Healthcare, Best, Netherlands) were used to acquire LGE images during end-expiratory apnoea and ECG gating. Parallel short-axis images were acquired, covering the heart from base to apex as well as four-chamber, two-chamber, and three-chamber long-axis images. LGE images were acquired $\sim 10–15$ min after intravenous administration of 0.2 mmol/kg gadolinium-based contrast agent (gadoteric acid, Gd-DOTA, Guerbet, Gothia Medical AB, Bilddal, Sweden) with an inversion-recovery sequence. Inversion time was adjusted to nullify the signal from viable myocardium.

**Figure 1** Radial strain evaluation by echocardiography. Radial strain curves derived from speckle tracking in a parasternal short-axis view. The tracking shows the latest activation (white arrow), in this case it is in the mid-inferior segment (purple) with a time-to-peak radial strain value of 768 ms. To the upper left is a colour-coded image of maximal strain values. To the upper right is the strain value over time, showing a typical ‘septal flash’ pattern in the inferoseptal (red) segment (red arrow). To the lower left is the time of peak strain in each segment, and to the lower right is a picture showing colour-coded radial strain over time in each segment.
Typical voxel size was $1.5 \times 1.5 \times 8$ mm with a slice gap of 0 mm, while typical image parameters were repetition time of 3.1 ms, echo time of 1.6 ms, and flip angle of 15°.

**Data analysis**
Segmental analysis of the viability of the LV was performed according to the 17-segment model and established methods.24 – 26 Viability of each segment was visually graded by the degree of transmural infarction or fibrosis (0: no infarction/fibrosis, 1: 1–25% infarction/fibrosis, 2: 26–50% infarction/fibrosis, 3: 51–75% infarction/fibrosis, and 4: 76–100% infarction/fibrosis). Segments with transmural scar (>50%) were defined as not being suitable for LV lead placement in accordance with previous studies.17,27–29 Total scar burden was calculated as the summed score of infarction divided by 68, which is the maximum score of the myocardium.16 Results were presented in a standard 17-segment bullseye plot. All images were evaluated by two experienced physicians.

**Data integration**
Results from the different examinations were manually transferred to a standard 17-segment ‘bullseye’ plot, which was then used for data integration and clinical decision-making (see Figure 4). A similar projection and alignment of the papillary muscles (mid-segment), the mitral valve commissures (basal segment), and the right ventricular attachment to the LV (basal and mid-segments) was then used for MRI and CT 2D views, thus making sure that the segments were labelled in the same way for all modalities, before interpretation and representation in the final common bullseye plot. A 3D reconstruction of the coronary sinus was also available for the operating room implanters, and the appropriate vein was indicated based on the decision from the image integration bullseye plot.

**Electrocardiography**
All patients had a QRS duration $>$120 ms. Left bundle branch block (LBBB) was defined as a broad, notched, or slurred R-wave with absent q-waves in the lateral leads. Right bundle branch block (RBBB) was defined as an rSR’ morphology in lead V1 or V2, and an S-wave $>$40 ms or R-wave duration in lead I and V6. Left anterior hemiblock was diagnosed if the electrical axis was $-45^\circ$ to $-90^\circ$ and there was a qR pattern in combination with RBBB. Left posterior hemiblock was diagnosed if the electrical axis was $90^\circ$–$180^\circ$ with an rS pattern in leads I and aVL or a qR pattern in lead III and aVF.

**Statistical analyses**
SPSS was used for data analysis (IBM, SPSS version 21, 2012). Continuous variables are expressed as mean ($\pm$ SD) or median ($\pm$ interquartile range). Categorical variables are presented as frequencies and
percentages. Differences were assessed using paired and unpaired Student’s t-tests for continuous variables, the χ² test for trend for ordinal variables, or the Fisher exact test for unordered categorical variables as appropriate. A two-sided P-value < 0.05 was considered statistically significant.

**Results**

A total of 39 consecutive patients were included, with baseline clinical data corresponding well to a ‘standard’ CRT patient population; the majority of patients were in NYHA class III, had LBBB and ischaemic cardiomyopathy (see Table 1).

**Echocardiography data**

The mean EF was 23% and the mean EDV was 223 mL. Interventricular dyssynchrony was present in 51% of all patients. The mean delay in activation between the anteroseptal and inferolateral (ASPWD) mid-LV segments was 183 ± 149 ms, and in those patients who had an anteroseptal to inferolateral delay > 130 ms (i.e. positive finding for dyssynchrony, n = 21) the mean value was 290 ± 121 ms. Patients with ischaemic cardiomyopathy had borderline significantly longer intraventricular delay, 198 ± 170 ms compared with the non-ischaemic group, 167 ± 129 ms (P = 0.053). There was no significant difference between men and women (177 ± 156 vs. 199 ± 130 ms; P = 0.7) or in patients with or without LBBB.

**Figure 3** Coronary sinus anatomy. Schematic representation of the coronary sinus anatomy of the heart on a 17-segment model of the LV. The basal and mid-segments are highlighted and the vein-branches from the main coronary sinus are depicted in blue, showing the MCV (5) running in the inferior intraventricular groove with a short marginal branch, a long posterior branch, (4), a short posterior branch ending in the mid-lateral segment (3), and a lateral branch bifurcation in the mid-lateral segment (2). Superiorly is the GCV, ending in the anterior intraventricular groove (1).

**Figure 4** Schematic representation of how the appropriate target segment was selected (the pictures from the different modalities are only for illustration). Four bullseye plots together with colour coding. Plot (A) shows echocardiography data, the segment with latest mechanical activation is red, neighbouring segments with late activation are yellow and remote segments are grey. Plot (B) shows CT data, segments with one or more suitable vein branches are highlighted. Plot (C) shows MRI data, viable segments are grey, segments with non-transmural infarction (< 50%) are yellow, and segments with transmural infarction (≥ 50%) are red. The final plot (D) shows the optimal segment (green), acceptable adjacent segments (yellow) and non-suitable or remote segments (grey). MRI, magnetic resonance imaging; CT, computed tomography.
indications and in 1 case image quality was not satisfactory due to MRI data being not available for 3 cases (2 cases had contraindications, 1 case due to motion artefacts). On average, 9% (patients with ischaemic disease) or 2% (non-ischaemic disease) of segments were defined as not suitable because of transmural scar—but only in one case did the echocardiography evaluation indicate a segment with transmural scar as a target segment. None of the patients with dilated cardiomyopathy had transmural scar in the proposed target segments. Overall, subendocardial scar was present in 1/3 of the target segments, and these patients were more likely to have ischaemic disease (78%). The presence of subendocardial scar, however, did not influence the selection of the target segment. Total scar burden was on average 9.4% of the left ventricular volume.

### Image integration data

The majority of patients (35/39) had one optimal segment identified, but in 4 patients, 2 segments were defined as equally optimal. In the end, 38/39 patients received a successful CRT implantation. Optimal segments were usually, but not always, in the lateral regions of the LV (see Figure 5). In 21 (53%) patients, there was a suitable vein traversing the optimal segment. In those patients with no vein in the optimal segment, there was a suitable vein in an immediately adjacent segment in 88% of cases (n = 16). The inferior and inferolateral parts were generally well supplied by suitable veins, so that the percentage of ‘perfect match’ between latest activation and good vein was the highest in these segments (Figure 5). There was no statistically significant difference between patients with ischaemic and dilated aetiology, or between men and women, when the distribution of latest segments and percentages of ‘perfect match’ were compared (all P > 0.05). There was no difference between the groups with classical LBBB on ECG vs. the non-LBBB group (P > 0.05).

### Follow-up data (echocardiography)

Baseline echocardiography characteristics were compared with the 6 month results. The left ventricular ejection fraction increased from 22 ± 7 to 32 ± 9% (P = 0.01), meanwhile the LV mass diminished from 377 ± 115 to 289 ± 99 g (P = 0.0001). The end-systolic volume decreased significantly from 184 ± 79 to 138 ± 60 mL (P = 0.001) and the end diastolic volume also showed a trend to decrease from 224 ± 78 to 208 ± 77 mL (P = 0.16). Likewise, the left atrial volume was significantly smaller at 6 months follow-up—81 ± 27 vs. 58 ± 43 mL—(P = 0.0001). These results harmonize with the previous studies showing reverse remodelling in successful CRT therapy.

### Discussion

Our data suggest that identifying and presenting a target segment for LV lead implantation in CRT is feasible preoperatively, using a bullseye plot with combined data from CT, MRI, and echocardiography. In 95% of cases, a suitable vein was identified in the optimal segment or in an immediately adjacent segment, showing that planning the procedure in advance has a high success rate for identifying a feasible target segment. Image acquisition and sufficient data analysis were possible in the vast majority of patients, and the strategy worked well regardless of the aetiology of heart failure and sex; there were no significant differences in the number of suitable veins and distribution of the latest mechanical segments between the groups. The clinical baseline data of our patient material correlates well with other published

### Table 1 Baseline clinical data and left ventricular dimensions assessed by echocardiography

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
<th>SD</th>
</tr>
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<tbody>
<tr>
<td>Sex; female/male (%)</td>
<td>9 (23/30 (78)</td>
<td></td>
</tr>
<tr>
<td>Age (years/SD)</td>
<td>69.1 ± 9.7</td>
<td></td>
</tr>
<tr>
<td>Diabetes, n (%)</td>
<td>4 (10)</td>
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<tr>
<td>Ischaemic cardiomyopathy, n (%)</td>
<td>21 (54)</td>
<td></td>
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<tr>
<td>LVEF (%)</td>
<td>50 ± 15</td>
<td></td>
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<tr>
<td>LVESV (mL)</td>
<td>184 ± 79</td>
<td></td>
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<tr>
<td>LVEDV (mL)</td>
<td>224 ± 78</td>
<td></td>
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<tr>
<td>Blood pressure (systolic/diastolic)</td>
<td>123/76</td>
<td></td>
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<tr>
<td>LV Mass (mL)</td>
<td>370 ± 122</td>
<td></td>
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<tr>
<td>Atrial fibrillation (paroxysmal)</td>
<td>21%</td>
<td></td>
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<tr>
<td>Medication (%)</td>
<td>9%</td>
<td></td>
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<tr>
<td>Beta blockers</td>
<td>91%</td>
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<td>ACEi/ARB</td>
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<tr>
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<td>Aldosterone blockage</td>
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<tr>
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<td>Anti-platelet therapy</td>
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<td>NYHA class, n (%)</td>
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<tr>
<td>Class III</td>
<td>32 (82)</td>
<td></td>
</tr>
<tr>
<td>Class IV</td>
<td>1 (3)</td>
<td></td>
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<tr>
<td>ECG pattern (LBBB/non-LBBB) (%)</td>
<td>82/18</td>
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</tbody>
</table>

#### CRT, cardiac resynchronization therapy; LV, left ventricle; MRI, magnetic resonance imaging; CT, computed tomography; LVEF, left ventricular ejection fraction; LVESV, left ventricular end systolic volume; LVESV, left ventricular end systolic volume; NYHA, New York Heart Association classification of heart failure; eGFR, estimated glomerular filtration rate; MR, mitral regurgitation; MCV, middle cardiac vein; GCV, great cardiac vein; CS, coronary sinus; LGE, late gadolinium enhancement; MADIT-CRT, Multicenter Automatic Defibrillator Implantation Trial-Cardiac Resynchronization Therapy trial; CARE-HF, Cardiac Resynchronization-Heart Failure trial; TARGET, Targeted Left Ventricular Lead Placement to Guide Cardiac Resynchronization Therapy study.

#### aLeft ventricular ejection fraction.

#### bLeft ventricular end systolic volume.

#### cLeft ventricular end diastolic volume.

#### dLeft ventricular mass.

#### eElectrocardiography.

#### fLeft bundle branch block.

(185 ± 144 vs. 174 ± 171 ms P = 0.5). Strain evaluation was possible in 97% of all mid- and basal segments. The mean intra-individual variability was 4.1%. The septum was not the latest activated segment in any patient. One or two optimal segments for an LV lead position were identified in all patients (see below).
studies, e.g. MADIT-CRT and CARE-HF: therefore, our results are likely to be representative of the average CRT population, despite that this was a study on a smaller patient group.\textsuperscript{3,30}

It was previously shown in the TARGET study that targeted LV lead implantation, using the same echocardiographic technique as that in our study, improved the composite clinical outcome at 6 months follow-up.\textsuperscript{10} In an earlier study by Delgado \textit{et al}.\textsuperscript{31} it was shown that patients who had received the LV lead placed in segments without transmural scar, but with late mechanical activation, had the best long-term prognostic results. The present study takes the concept of targeted LV lead placement one-step further by including a preoperative evaluation of coronary sinus anatomy. This strategy has several potential advantages. First, it is possible for preoperative planning of the LV lead placement strategy, including selection of appropriate tools for difficult angles from the CS main trunk to the appropriate side branches. Secondly, and perhaps most important, it may be possible before the intervention to identify the patients in whom there are no suitable CS side branches traversing viable left ventricular segments (in our study, \textasciitilde 5\% of patients). These patients can then avoid a prolonged transvenously attempted implantation procedure, and instead be referred for epicardial LV lead placement, as soon as the RA and RV leads are placed transvenously.

Several different concepts of image integration have been tried recently, including MRI-based integration or a combination with preoperative CT scan and fluoroscopy pictures.\textsuperscript{32,33} However, a functional, easy-to-operate automated integration of cardiac MRI, cardiac CT, and echocardiography has not yet been examined in a larger study. The combined bullseye plot presents a new perspective by clearly visualizing the latest mechanical segment with viable myocardium and the corresponding vein traversing the same segment. It also provides the opportunity to present the necessary information to the implanter, who can plan the procedure in advance. The segmental position of each vein is known from the image interpretation off-line, so all the implanter must do is perform a cine contrast venography of the CS and identify each vein (i.e. count from the ostium and select the appropriate numbered branch for implantation of the lead). The segmental position of the vein is given by the previous interpretation of CT images, and the implanter can then choose between the basal and mid-segment of that vein, based on which is the target segment.

Other techniques for strain imaging and automated image integration have been proposed and tried.\textsuperscript{10,34–36} One of the most visually elegant methods was presented by Doring \textit{et al}.\textsuperscript{37} using 3D transoesophageal echocardiography strain fused with CS rotational angiography preoperatively. Compared with that study, our technique is based on 2D strain with superior time resolution (frame rate 70–90/s) rather than 3D strain imaging (typically 20–30/s), allowing for a more precise definition of the latest activated segment. In addition, compared with transoesophageal echocardiography, the trans-thoracic approach allows for a better chance of correctly capturing all left ventricular segments in the large dilated heart. Doing the offline analysis before implantation creates time to optimize image quality and also makes multiple measurements to compensate for variability in strain results. To our knowledge, this is the first prospective study to use all imaging modalities in an integrated fashion, including echocardiography, cardiac CT, and cardiac MRI.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{bullseye_plot.jpg}
\caption{Bullseye plots showing the presence of a suitable vein in each segment (A), latest activated segment (B), and ‘perfect match’ between the two (C). On the top of the picture is a classical bullseye plot represented with the respective anatomical segment name on the right side. On the bottom of the figure three bullseye plots appear. Bullseye plot (A) represents the percentage of patients who had a vein suitable for electrode placement in each represented left ventricular segment; Bullseye plot (B) shows the distribution of where the latest mechanically activated segment was (i.e. the target segment); and bullseye plot (C) shows the availability of the ideal segments in per cent, in the respective patients, where a suitable vein was also available (‘perfect match’ in the respective target segments).}
\end{figure}
Limitations

This report is only intended to demonstrate the feasibility of a novel concept in presenting integrated imaging data with regard to a CRT implantation procedure; thus, a limitation will be lack of follow-up data regarding electrode placement and lack of clinical follow-up. However, the material was not powered to detect any differences in the clinical outcome, and the cohort was too small to draw any definite conclusions regarding long-term results using this technique, even though the results suggested a significant improvement in ejection fraction, end-systolic volume and left atrial volume. The image integration was done manually and so there is a risk of small measurement mistakes when designating the left ventricular segments in exactly the same way for all three modalities. However, care was taken to avoid this, and all interpretations were done by at least two independent physicians. Interpretation of coronary CT scans can be difficult, because if the contrast phase is sub-optimally timed, there is a risk of missing or underestimating the size of small vein branches. One way of avoiding this is by increasing the radiation dosage, but we aimed to keep the radiation dose as low as possible while maintaining acceptable image quality for meaningful interpretation of venous anatomy. The study did not include patients with persistent or chronic atrial fibrillation. In patients with atrial fibrillation it is necessary to average the radial strain values from beats with approximately the same RR interval, and it may also be necessary to include more beats than three in order to get reliable results. However, the method as such will certainly also be feasible in patients with atrial fibrillation, provided they have a controlled ventricular rate (i.e. <60/min ideal and <100/min acceptable).

Conclusions

Using cardiac CT, MRL, and echocardiography in combination before CRT implant was seen to be feasible in a standardized fashion. Presenting the information in a standard 17-segment bullseye view gives a comprehensive overview of the possible optimal or acceptable LV electrode positions. Prospective studies with clinical follow-up will have to confirm if this approach is prognostically beneficial for CRT patients.

Conflict of interest: None declared.

References

13. McMurray JJ, Adamopoulos S, Anker SD, Auricchio A, Bohm M, Dickstein K et al. ESC guidelines for the diagnosis and treatment of acute and chronic heart failure 2012. The Task Force for the Diagnosis and Treatment of Acute and Chronic Heart Failure 2012 of the European Society of Cardiology. Developed in collaboration with the Heart Failure Association (HFA) of the ESC. Eur J Heart Fail 2012;14:803–69.
Symptomatic pericardial cyst in the presence of partial congenital absence of the pericardium

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A 38-year-old male was admitted with exertional syncope, atypical chest pain, sinus bradycardia (46 bpm), and non-orthostatic hypotension (90/45 mmHg). Chest X-ray (Panel A) showed cardiac levoposition, flattening, and elongation of the left heart border, opacity at the left costophrenic angle, and lucency between the pulmonary artery and aorta. Transthoracic echocardiography (Panel B) confirmed a cystic anterior structure and leftward rotation of the right ventricle. Cardiac magnetic resonance imaging (Panels C and D) documented the pericardial cyst (8.6 × 3.5 cm) and insinuation of lung tissue between the aorta and pulmonary artery. Cine sequences (Supplementary data online, Video S1) confirmed paradoxical ventricular septal motion consistent with the congenital absence of the left pericardium. Exercise testing excluded chronotropic incompetence as the cause of his syncope; however, he was unable to appropriately increase his blood pressure with exercise (110/76 mmHg at rest and 116/75 mmHg at maximum stress).

Surgical inspection of his left-sided pericardial absence showed no signs of ability for herniation. The cyst was excised (Panel E), revealing a benign mesothelial-lined membrane consistent with a pericardial cyst. His postoperative course was uneventful, and follow-up chest X-ray (Panel F) showed resolution of the previous opacity at the left costophrenic angle. To our knowledge, no previous case has reported both congenital anomalies occurring in the same patient.

Supplementary data are available at European Heart Journal — Cardiovascular Imaging online.