Multiparametric Cardiovascular Magnetic Resonance Assessment of Pacemaker-Induced Alterations in Ventricular Activation and Function

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A 73-year-old woman with presyncope and frequent episodes of symptomatic 2:1 atrioventricular block underwent implantation of a dual-chamber MRI-conditional pacing system (Advisa MRI SureScan pacing system, Medtronic, Minneapolis, MN) to facilitate cardiovascular magnetic resonance (CMR) assessment of apparent isolated right ventricular (RV) hypertrophy seen on transthoracic echocardiography (Figure 1 and online-only Data Supplement Movies I and II). The ventricular lead was positioned in the outflow tract. This pacing system is approved, outside of the United States, for MRI without isocenter restriction, provided certain conditions are fulfilled, including a static magnetic field strength of 1.5 T, a maximum gradient slew rate ≤200 T/m per second, whole body average specific absorption rate levels ≤2.0 W/kg, and a minimum period of 6 weeks between implantation and scanning. Within the United States, the isocenter is presently required to be either superior to C1 or inferior to T12 vertebrae.

CMR assessment was performed in accordance with the stated conditions. The impact of pacing on the activation pattern and regional deformation of both ventricles, and aortic and pulmonic forward flow, were studied by imaging in unpaced and paced (VVO; 75 bpm) modes. On balanced steady-state free precession imaging marked susceptibility artifact led to almost nondiagnostic image quality (Figure 2A and online-only Data Supplement Movie III). Switching to a spoiled gradient echo sequence greatly improved image quality (Figure 2B and online-only Data Supplement Movie IV) and reduced the specific absorption rate.

Assessment of myocardial displacement, using spatial modulation of magnetization (tagging) images with sine wave–based analysis, demonstrated a synchronous pattern of left ventricular (LV) activation when imaging was performed during underlying sinus rhythm, ie, unpaced mode (Figure 3A and 3C and online-only Data Supplement Movie V), but a markedly dyssynchronous pattern during pacing (Figure 3B and 3D and online-only Data Supplement Movie VI). Simultaneous LV and RV myocardial deformation assessment with an endocardial feature-tracking algorithm, applied using spoiled gradient echo cines, revealed a detrimental effect of pacing on biventricular function and synchronicity (Figures 4 and 5). Speckle-tracking echocardiography of the LV revealed analogous findings (Figure 6). As a likely consequence, pacing was associated with a marked acute reduction in per-beat aortic and pulmonic forward-flow volume (Figure 1).

Figure 1. Parasternal long-axis (A) and short-axis (B) echocardiogram images showing apparent right ventricular wall thickening.
assessed using phase-contrast velocity mapping of the aorta and main pulmonary artery, respectively. Blood pressure changed from 136/84 during unpaced mode to 133/83 during pacing.

RV wall thickness was found to be normal; overlying epicardial fat (epicardial lipomatosis) was felt to have accounted for the echocardiographic findings. Pacemaker parameters were unaffected by scanning.

Figure 2. Marked susceptibility artifact from the right ventricular pacing lead is seen in the 3-chamber view acquired using balanced steady-state free precession imaging (A), resulting in almost non-diagnostic image quality. In comparison, minimal artifact is seen on the corresponding image acquired using spoiled gradient echo (B).

Figure 3. Longitudinal left ventricular myocardial displacement in unpaced mode (ie, during underlying sinus rhythm; A and C) and during pacing (B and D), assessed using sine wave-based analysis (inTag; CREATIS lab, France and Maastricht University, The Netherlands) of tagged 4-chamber images and displayed as displacement maps at end-systole (A and B; also see online-only Data Supplement Movies III and IV) and graphically (C and D); x axis, frame count; y axis, displacement. During underlying sinus rhythm, a normal pattern of left ventricular activation was observed, with regional peak displacement occurring simultaneously and corresponding septal and lateral wall segments having equivalent displacement magnitude. Basal segments showed greater displacement than apical segments, as expected. During pacing, ventricular activation was markedly dyssynchronous, with substantial heterogeneity in the timing and magnitude of regional displacement.
RV apical pacing adversely affects LV systolic function in patients with a bradyarrhythmic indication for pacing and normal baseline ejection fraction. Furthermore, in patients with impaired LV systolic function, RV pacing has a detrimental impact on heart failure and mortality. The negative effect appears to be related to the cumulative percentage of paced beats. The widely proposed underlying mechanism is that the abnormal pattern of LV electric activation...
associated with RV pacing leads to dyssynchronous ventricular contraction, as illustrated here, and subsequent cardiac remodeling, including asymmetrical hypertrophy, mitral regurgitation, increased left atrial size, and reduced ejection fraction.3

Echocardiographic parameters of LV dyssynchrony have proved to have only modest utility in cardiac resynchronization therapy patient selection and optimization, largely owing to low reproducibility.4 As is demonstrated by this case, CMR acquisition sequences and image analysis techniques allow simultaneous visualization and quantification of the activation pattern and regional function of both ventricles, thereby enabling a more comprehensive assessment of the impact of pacing. Because CMR-based quantification methods display generally higher reproducibility, it is possible that when MRI-compatible cardiac resynchronization therapy devices become available, these techniques, in conjunction with phase-contrast velocity mapping of aortic and pulmonic flow, may better guide cardiac resynchronization therapy patient selection and optimization.

![Figure 6](image6.png)

**Figure 6.** Left ventricular circumferential myocardial strain (\(\varepsilon_{cc}\)) assessed using speckle-tracking echocardiography during underlying sinus rhythm (A) and during pacing (B). Analogous to the CMR-based analysis (as displayed in Figure 4), during underlying sinus rhythm, peak global midventricular \(\varepsilon_{cc}\) was −21% (A; x axis, time (milliseconds); y axis, \(\varepsilon_{cc}\) (percent); colored lines correspond to myocardial segments as follows: light blue, anterior; yellow, anteroseptal; red, inferoseptal; dark blue, inferior; purple, inferolateral; green, anterolateral; dotted white, global), which fell to −14% during pacing (B). Also, in keeping with the CMR assessment, marked intraventricular dyssynchrony was seen during pacing, with a maximum intersegmental difference in time to peak \(\varepsilon_{cc}\) of 220 ms in comparison with 110 ms during underlying sinus rhythm. CMR indicates cardiovascular magnetic resonance.

![Figure 7](image7.png)

**Figure 7.** Aortic blood flow assessed using CMR phase-contrast velocity mapping (A and B) and corresponding echocardiographic aortic velocity-time integral (VTI) data (C and D). During underlying sinus rhythm (A and C), per-beat aortic forward-flow volume was 54 mL (A) and the corresponding aortic VTI was 21 cm (C). During pacing, per-beat aortic forward-flow volume fell to 44 mL (B) and the corresponding aortic VTI dropped to 17 cm. Per-beat pulmonic forward-flow volume, assessed by using CMR phase-contrast velocity mapping, also fell during pacing (from 68 mL during underlying sinus rhythm to 56 mL during pacing; not shown). CMR indicates cardiovascular magnetic resonance.
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References
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Movie Files

**Movie 1.** Parasternal long-axis echocardiogram. (View with Windows Media Player).

**Movie 2.** Parasternal short-axis echocardiogram. (View with Windows Media Player).

**Movie 3.** Balanced steady-state free precession three-chamber CMR cine. (View with QuickTime Player).

**Movie 4.** Spoiled gradient echo three-chamber CMR cine. (View with QuickTime Player).

**Movie 5.** Tagged four-chamber CMR cine, with a myocardial displacement map overlay, imaged during underlying sinus rhythm. (View with QuickTime Player).

**Movie 6.** Tagged four-chamber CMR cine, with a myocardial displacement map overlay, imaged during pacing. (View with QuickTime Player).