Clinical Experience with the BioMatrix Beat Sensor: Cardiac MRI Exams Without ECG Leads

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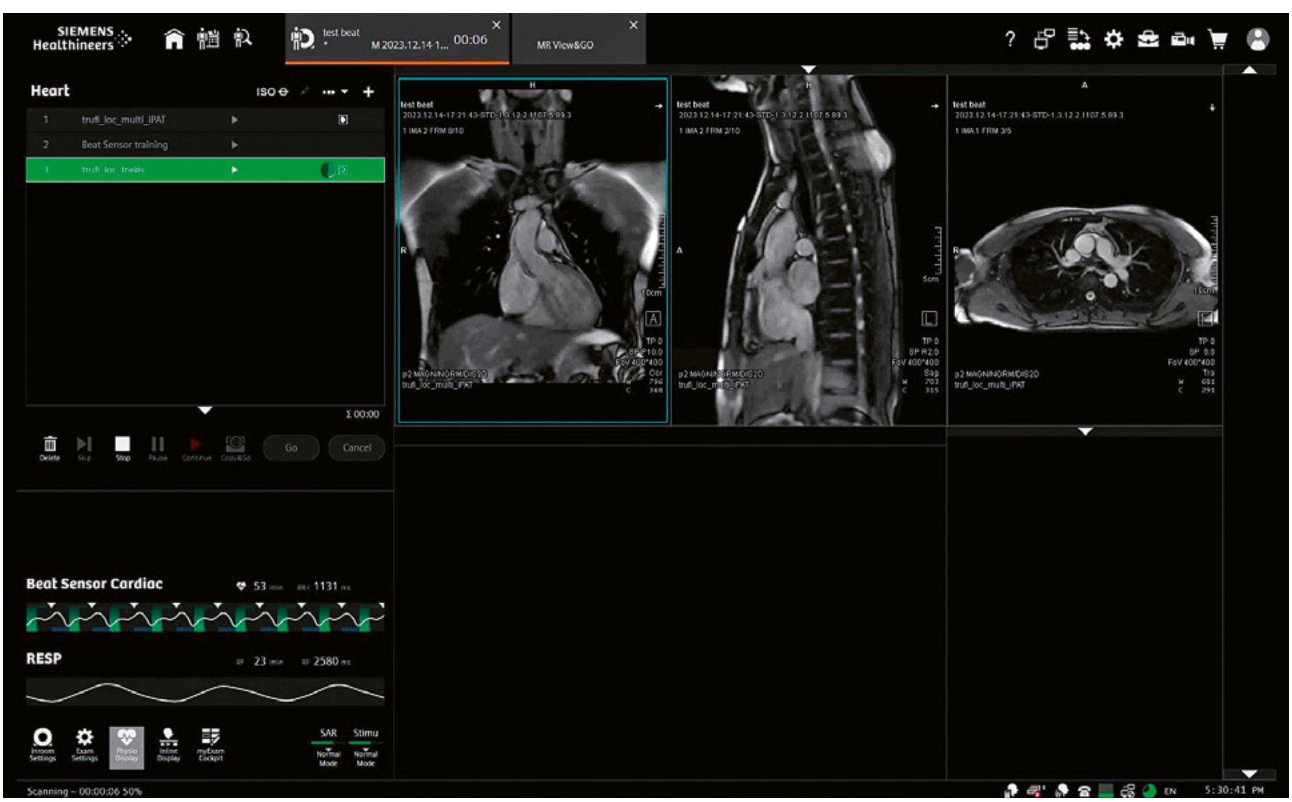
Introduction

ECG gating is essential for performing cardiac MRI examinations. However, the accuracy of cardiac synchronization with ECG gating is significantly influenced by the patient's condition and characteristics, such as their body size, chest hair, cardiac location, motion, and arrhythmia. ECG gating aims to detect the variations in the electric potential of the heart, but it is often difficult to obtain the original ECG waveform due to radio frequency (RF) pulses or magnetic field interference. The BioMatrix Beat Sensor, which was recently launched by Siemens Healthineers, is an innovative technology that can acquire biological information including cardiac activity and diaphragmatic motion without placing ECG leads or respiratory belts. Therefore, this technique is expected to simplify patient preparation and reduce examination time in cardiac MRI examinations and improve the patient experience during the scan.

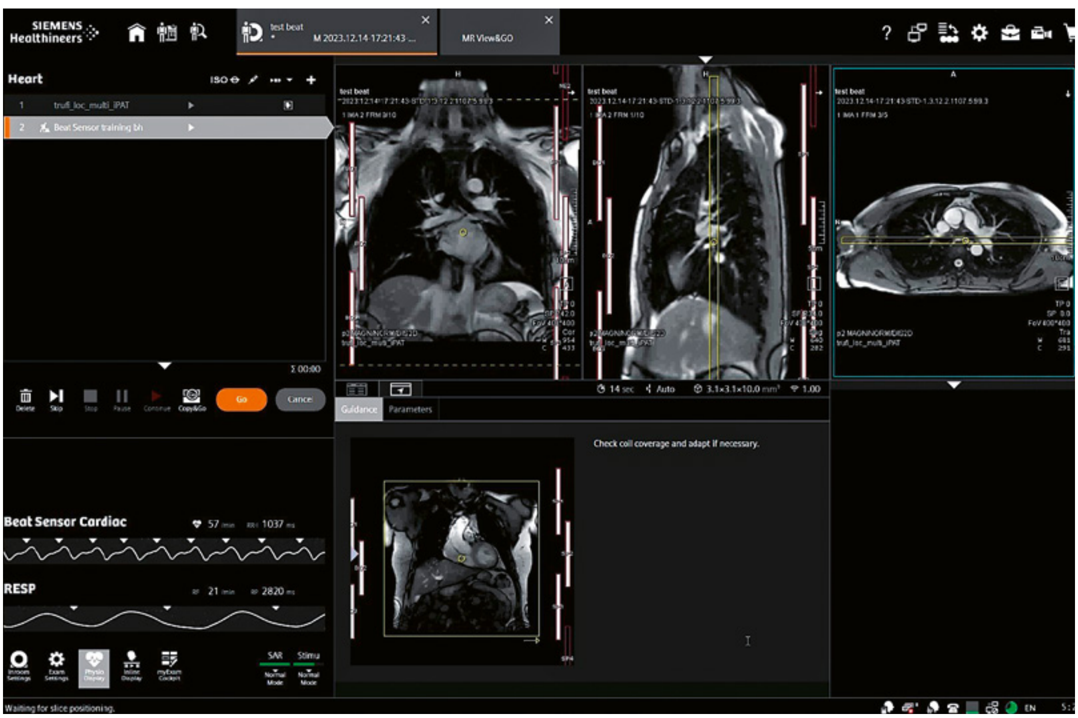
In this article, we introduce our experience with clinical patients and healthy volunteers who underwent cardiac MRI with the BioMatrix Beat Sensor on a 1.5T MAGNETOM Sola with BioMatrix Body 12-channel and Spine 32-channel coils.



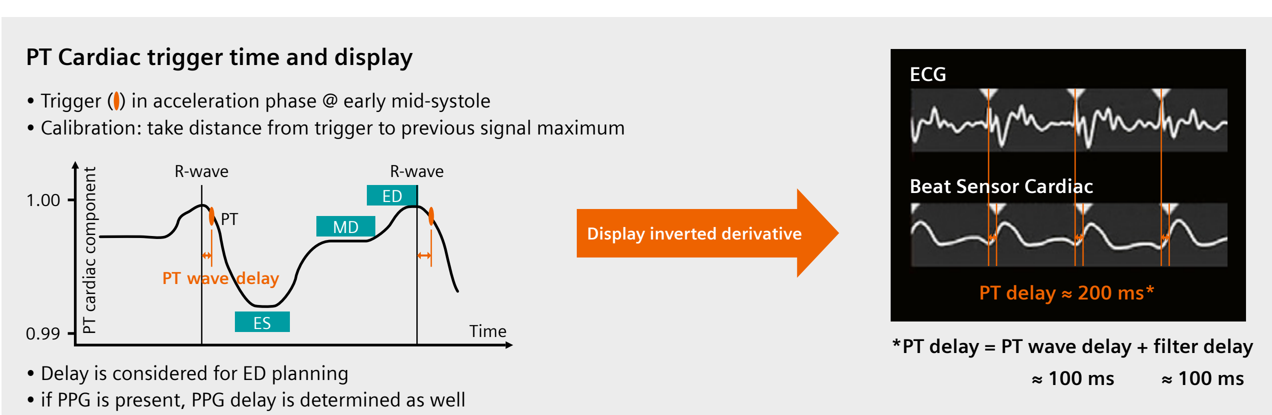
1 BioMatrix Beat Sensor interface for a cardiac MRI scan.

BioMatrix Beat Sensor

Pilot Tone (PT), which was developed based on the principle that a constant RF signal can be modulated by physiological, especially cardiac motion, enables the detection of cardiac motion when the BioMatrix Body coil (Fig. 1) is used. As mentioned earlier, since the Beat Sensor does not require ECG leads placed on chest walls, or respiratory belts, it is expected to improve the clinical workflow of MRI examinations by avoiding preparations involving direct skin contact. This is especially helpful for patients with chest hair. Before imaging with the BioMatrix Beat Sensor, a training scan ("learning") has to be performed to confirm the position of the heart, the appropriate type of coil, and to perform training of the signal processing for isolation of the cardiac signal component und suppression of RF artifacts. After the training scan, the trigger source Beat Sensor can be applied to all imaging protocols including cine, T2-weighted, myocardial mapping, and late gadolinium enhancement (Fig. 2). For comparison, in general, a vectorcardiography-based QRS detection algorithm is used for ECG gating, which aims to detect the R-wave at its peak by recognizing the R-wave's rising edge. However, the timing of cardiac triggers detected by the Beat Sensor is about 200 milliseconds delayed with respect to the R-wave, which is detected by ECG triggering. Triggering with the Beat Sensor in the acceleration phase of the cardiac contraction and subsequent low pass filter processing both contribute to this delay [1] (Fig. 3).



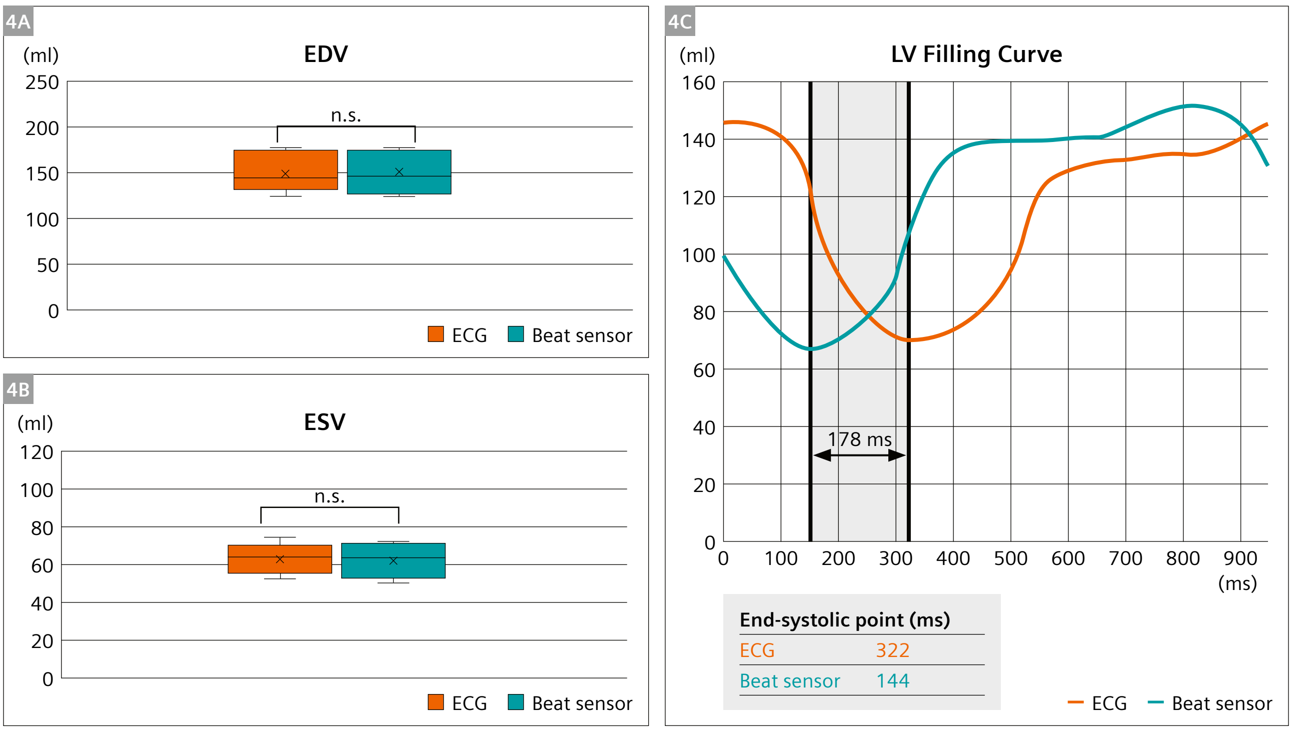
2 BioMatrix Beat Sensor interface for a training scan.



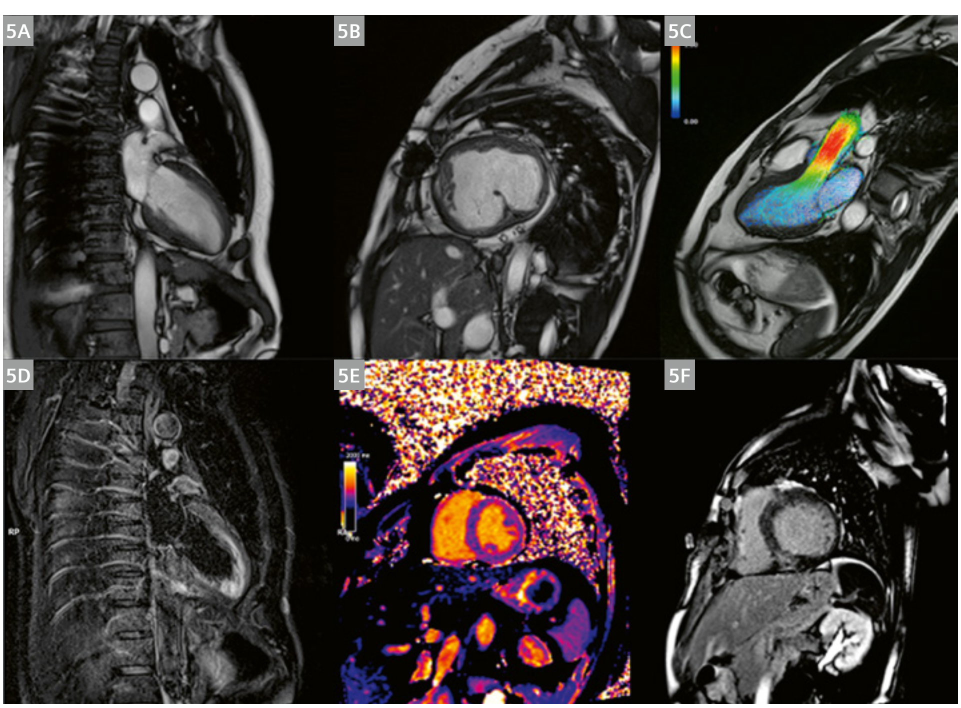
3 PT signal characteristics and trigger time point [1].

Left ventricular functional analysis in healthy volunteers

In 8 healthy volunteers, we compared left ventricular (LV) volumes derived by the Beat Sensor to those derived by ECG gating. We found that there were no significant differences in end-diastolic (EDV) and end-systolic volumes (ESV) between the two groups (not shown). The beginning of the LV volume filling curves recorded by the Beat Sensor was delayed by approx. 200 milliseconds as previously estimated [1] (Fig. 4). These characteristics of the Beat



4 LV volume and filling curves in healthy volunteers undergoing cine cardiac MRI with Beat-Sensor and ECG gating. **(4A)** EDV, **(4B)** ESV, and **(4C)** example of LV filling curves. EDV = end-diastolic volume, ESV = end-systolic volume.



5 Example images of cardiac MRI with the BioMatrix Beat Sensor. Cine imaging, 4D-flow imaging, and T1 mapping using the Beat Sensor in a healthy volunteer are shown in Figures **5A**, **5C**, and **5D**, respectively. Figure **5B** shows cine imaging in a case with a single ventricle, and **5F** shows MOCO PSIR for the hypertrophic cardiomyopathy patient.

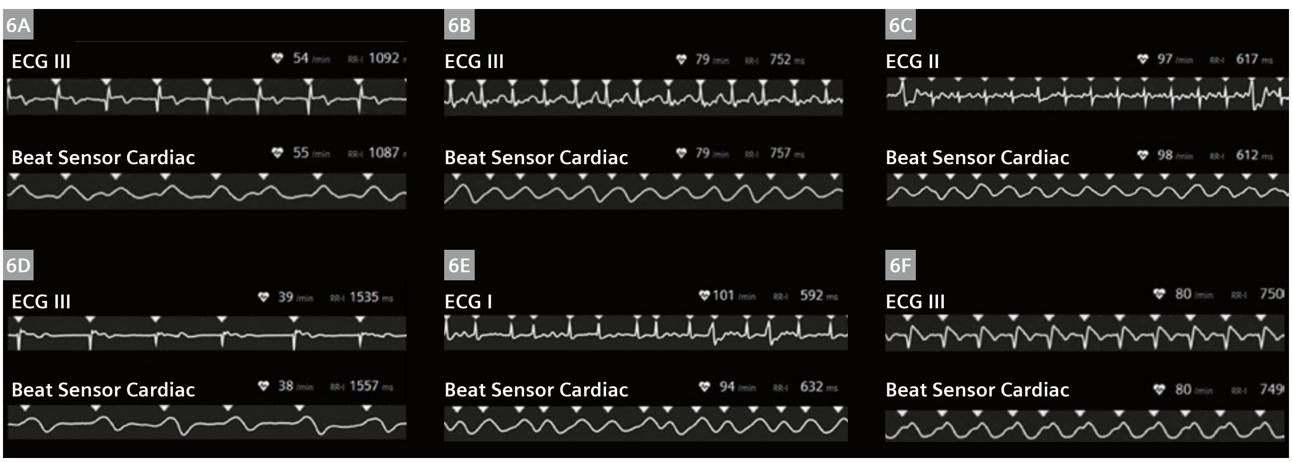
Sensor should be kept in mind, especially when scanning still-imaging protocols such as T2-weighted and myocardial mapping, and late-gadolinium enhancement with manual positioning of the scan window, which are often scanned in diastole.

Clinical patients

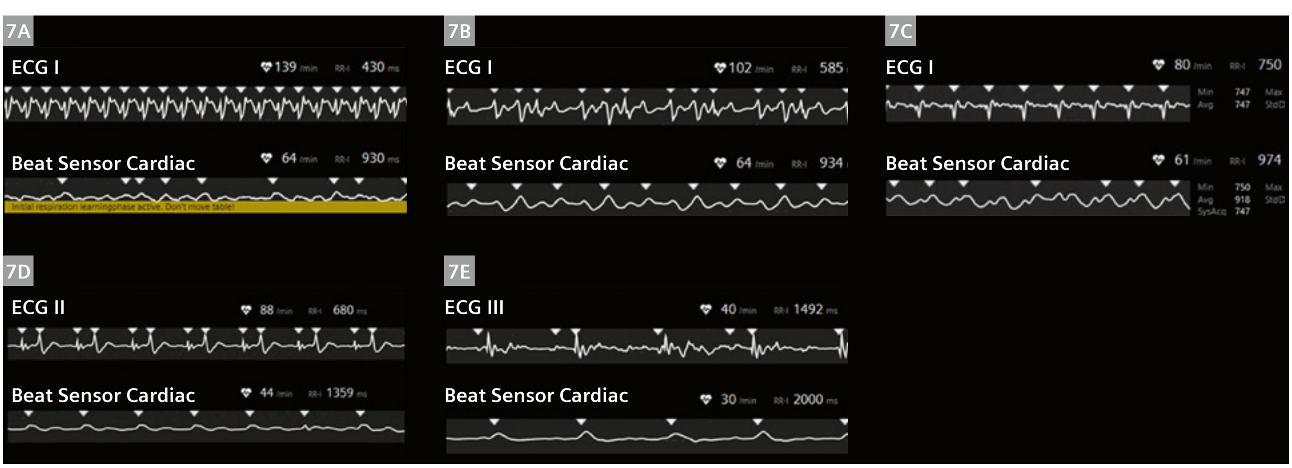
In our experience, reading physicians could adeptly evaluate cardiac motion through cine imaging and could conduct tissue characterization via myocardial mapping and late gadolinium enhancement, thereby effectively addressing the majority of clinical cases. Notably, the Beat Sensor has reliably achieved cardiac synchronization in a wide spectrum of cases, including patients with hypertrophic cardiomyopathy, complex congenital heart disease, and reduced ejection fraction (Fig. 5). Our observations extend published results of successful cardiac synchronization [2, 3] also to patients with arrhythmias, high heart rates, and pacing rhythms (Fig. 6). In an overweight patient [4] the Beat Sensor signal was more easily disturbed by other contributions, e.g., patient motion, but trigger time points corresponded very well to ECG (Fig. 7C).

In a newborn[1] the Beat Sensor training failed, resulting in unreliable triggering (Fig. 7A), likely due to the high heart rate and large size of coil elements of the BioMatrix Body 12. Figure 7 also shows results in patients with Wolff-Parkinson-White syndrome, bigeminy, and complete atrioventricular (AV) block.

[1]Siemens Healthineers disclaimer: MR scanning has not been established as safe for imaging fetuses and infants less than two years of age. The responsible physician must evaluate the benefits of the MR examination compared to those of other imaging procedures. Note: This disclaimer does not represent the opinion of the author.



6 ECG waveform during cardiac MRI with ECG gating and the BioMatrix Beat Sensor. ECG waveform in patients with hypertrophic cardiomyopathy **(6A)**, a single ventricle **(6B)**, a reduced LV ejection fraction **(6C)**, atrial fibrillation with low heart rates **(6D)**, atrial fibrillation with high heart rates **(6E)**, and pacing rhythm (DDD implantation) **(6F)**.



7 ECG waveform during cardiac MRI with ECG gating and the BioMatrix Beat Sensor. ECG waveform during cardiac MRI with ECG gating and the Beat Sensor in a newborn[1] with high heart rate **(7A)**, and in patients with Wolff-Parkinson-White syndrome **(7B)**, overweight **(7C)**, bigeminy **(7D)**, and complete AV block **(7E)** are shown.

The advantages of the BioMatrix Beat Sensor

Using the BioMatrix Beat Sensor provides a crucial advantage, in that it enables cardiac MRI scans even in challenging scenarios, such as with arrhythmias or difficulties in breath-holding, which are difficult conditions for ECG gating. Further, by conducting a preparatory training scan, the Beat Sensor facilitates imaging with both breath-holding and free breathing. Additionally, after the training, the operator can simply switch between ECG and Beat Sensor gating, eliminating the need for extra settings or preparation.

Cardiac MRI examinations do not aim to detect waveforms that detect the electrical potential difference of the heart. Rather, they aim to assess cardiac motion and perform tissue characterization. In our experience cardiac synchronization with the Beat Sensor is sufficient for these exams. ECG gating may not only acquire cardiac signals from heart motion, but also subtle electrical signals generated by muscles or arrhythmias, which can often cause reduced imaging quality. Since the Beat Sensor directly detects the heartbeat, it enables scanning at the cardiac phase without cardiac motion, especially for still cardiac imaging.

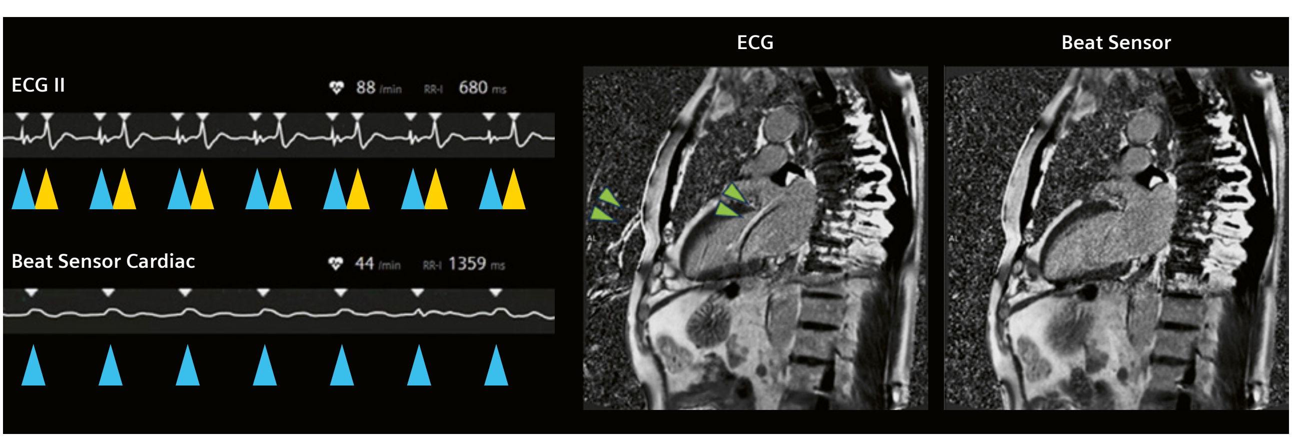
In the following section, we present clinical cases with bigeminy and complete atrioventricular block, for which the Beat Sensor provided efficient cardiac MRI scanning.

1. Bigeminy

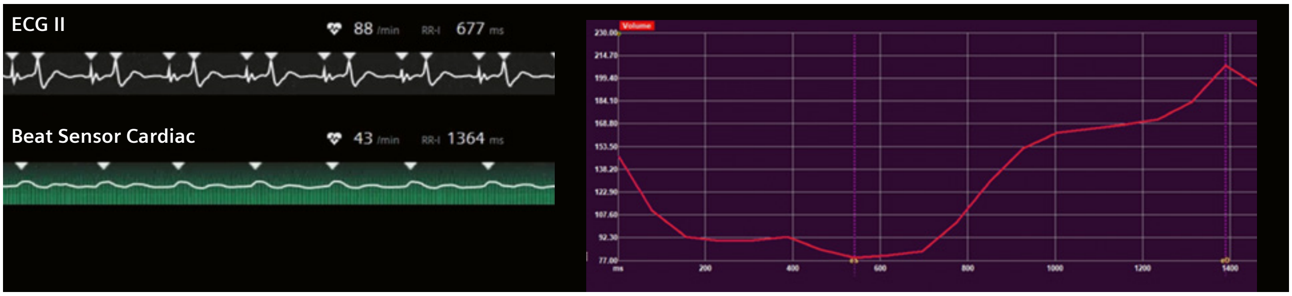
Bigeminy is a cardiac arrhythmia that repeats ventricular premature contraction (VPC) every other beat. When patients with bigeminy are scanned with ECG triggering, all R-waves including VPCs are triggered, which results in motion artifacts. Motion artifacts can influence image quality and the values of the resulting quantitative parameters in cine imaging, T1, T2 mapping, and late gadolinium enhancement. Like the Beat Sensor, ECG gating includes retrospective and prospective gating. When scanning arrhythmic patients with ECG gating, a cardiac arrhythmia detection function with retrospective gating can be performed to remove the arrhythmia dataset during the preset R-R interval. However, the arrhythmia detection function involves determining the appropriate phase manually, especially in the case of bigeminy. Although prospective ECG gating is useful for severe cardiac arrhythmia, it is impossible to capture cardiac information during the entire cardiac cycle. When using the Beat Sensor, it is possible to accurately trigger the timing of the diastolic phase without detecting small contractions related to VPC (Fig. 8). Beat Sensor skipped every second trigger, thus the cine contained one bigeminy period (2 heart beats) and resolved both the short and long cardiac cycle. Interestingly, an LV filling curve could be generated for the case with bigeminy, which can be distorted with ECG gating. The resulting LV filling curve can be seen in Figure 9.

2. Complete atrioventricular block

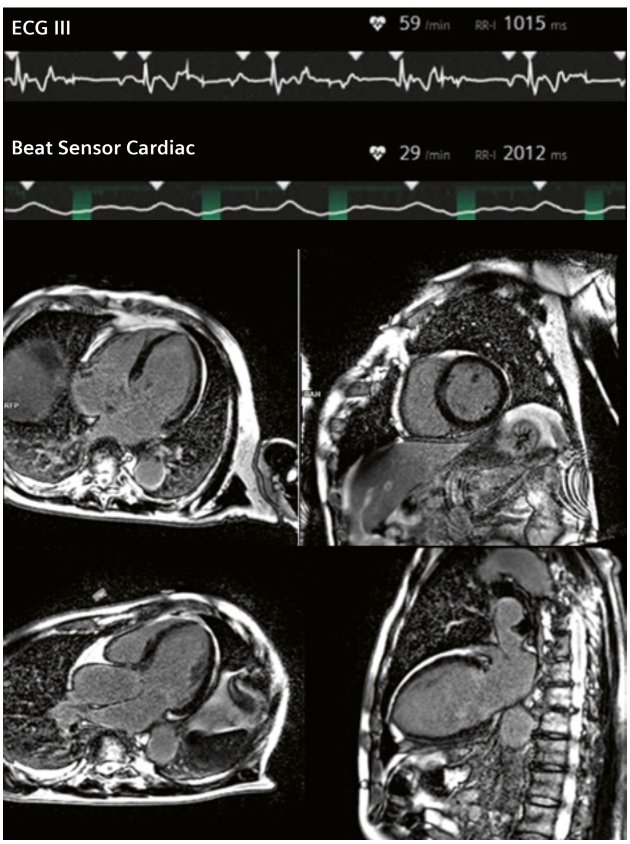
Complete atrioventricular (AV) block is a type of arrhythmia characterized by an incomplete electrical AV dissociation, with independent atrial and ventricular rates, which are often seen in patients with coronary artery disease or cardiac sarcoidosis undergoing cardiac MRI. As atria and ventricles function independently of each other during imaging with a complete AV block, all R-waves, including irregular R-waves, generate ECG triggers, thus diastolic imaging is impossible. Since the Beat Sensor is sensitive to the contractile motion of the heart, and generates triggers only after irregular R-waves. Therefore the Beat Sensor allows to synchronize acquisition to the diastole for still imaging. In the example with complete AV block in Figure 10, Beat-Sensor triggering was successful in acquiring interpretable images from a motion-corrected phase-sensitive inversion recovery (MOCO PSIR) acquisition and acts as an automatic arrhythmia detection function.



8 Comparison of late gadolinium enhancement images in a patient with bigeminy with ECG gating and the BioMatrix Beat Sensor. There is a motion artifact (green arrow) in late gadolinium imaging of the VPC patient using ECG gating, but no motion artifact with the Beat Sensor.



9 LV filling curve in a patient with bigeminy.



10 BioMatrix Beat Sensor with MOCO PSIR (free breathing). The Beat Sensor enabled capturing diastole with MOCO PSIR for the patient with complete atrioventricular block.

Conclusion

BioMatrix Beat Sensor is a new technology that enables cardiac MRI examinations without the need for ECG leads. Not only does it eliminate the need for electrodes and the discomfort of tape irritation and direct skin contact, but it also frees up technologists by streamlining the clinical workflow. By directly detecting cardiac motion, the Beat Sensor introduces novel cardiac synchronization with advantages in handling arrhythmic patient that were unattainable with ECG gating. Its efficacy warrants validation across multiple facilities to enhance clinical workflows by offering substantial support in advanced cardiac MR imaging.

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