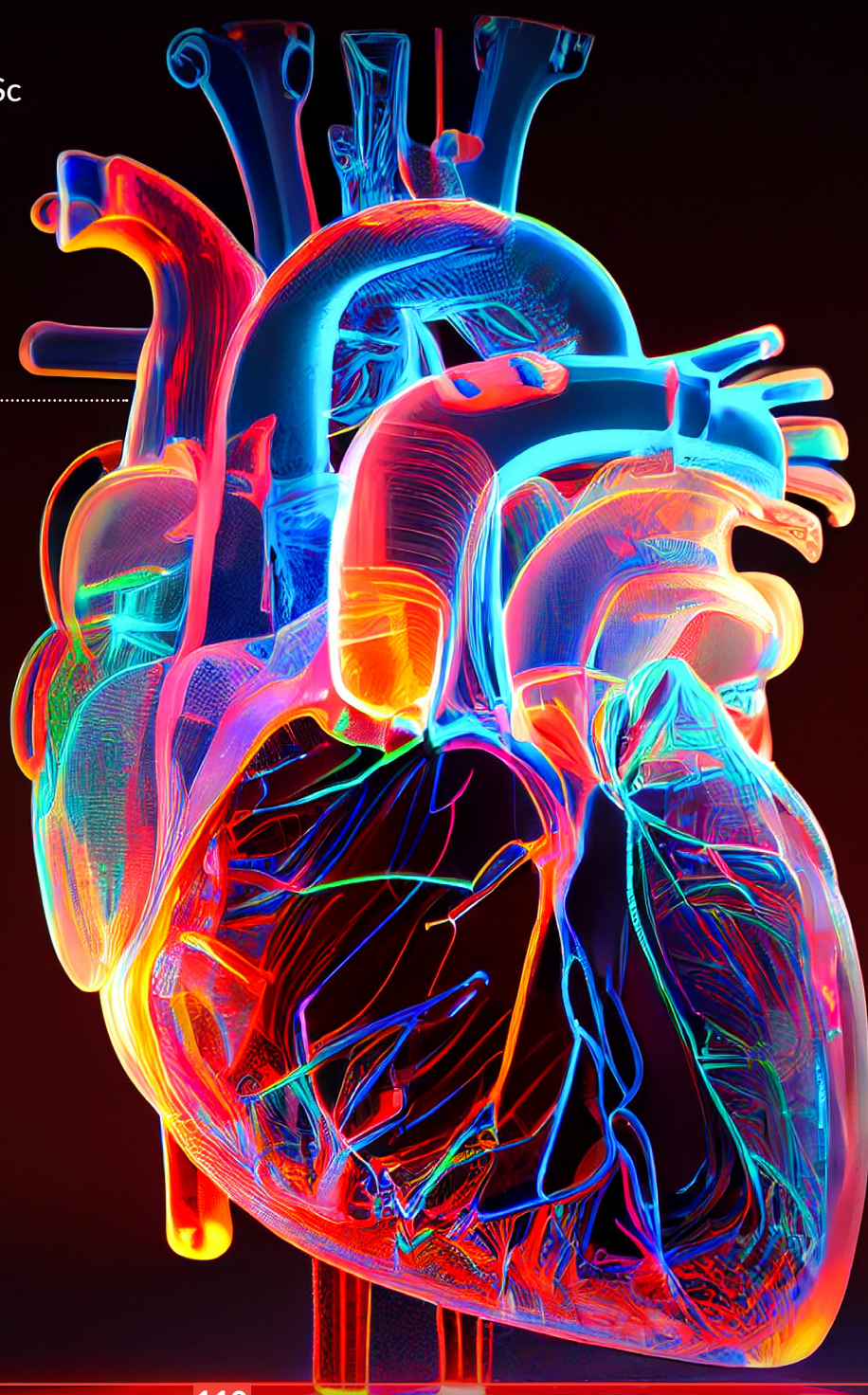


A new era in cardiac imaging: fast, comfortable and clear MRI for patients with implantable cardiac devices

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MRI of the heart with implantable cardiac devices is challenging

You probably know someone, or even yourself, with a cardiac implantable electronic device (CIED) such as a pacemaker or defibrillator. 75% of patients with CIED will require cardiac magnetic resonance imaging (MRI) during their lifetime. Cardiac MRI is a valuable diagnostic tool, providing highly detailed images of the heart and surrounding structures, but until recently, it was traditionally contraindicated in CIED patients for safety reasons, thus excluding them from MRI examinations.

Indeed, the strong magnetic field of MRI systems can interfere with these electronic devices, causing them to malfunction, overheat and displace, potentially putting patients' lives at risk. Advances in MRI-compatible devices since the 2000s have made cardiac MRI possible for many patients within strict guidelines, but long and complex procedures with rigorous preparation are still required to ensure patient safety and image quality.

When a patient with CIED is scheduled for cardiac MRI examination, a long and tedious visit involving numerous steps is planned. The CIED must first be evaluated to determine its compatibility

with MRI and patient safety. Then, if deemed MRI-compatible, it must be programmed to a special 'MRI mode' by a medical professional to avoid the induction of potentially life-threatening arrhythmias due to interference with the magnetic field. The patient is then accompanied into the MRI room and placed on a table with numerous electrodes attached to the chest to monitor the cardiac signal, known as the electrocardiogram. A coil is wrapped around the patient's chest to receive the MRI signal for image production, and the patient is finally placed inside the MRI bore to receive a cardiac MRI protocol for 45–60 minutes. Throughout this time, the patient's heart and CIED are closely monitored. After the examination, the CIED is reset to its original parameters to provide adequate patient care. The whole process is carefully coordinated by a team of specialists, including highly qualified cardiologists, radiologists and MRI technicians.

Still, cardiac MRI in the presence of CIED poses unique challenges that go beyond safety. They lie primarily in the interaction between the MRI system and the implant's metal components: image artefacts. This interaction can compromise image quality in the form of hyperintensity (bright areas obscuring the heart tissue), signal loss (black spots at the device location) and geometric distortion near the device, making it difficult to obtain clear, diagnostic images of the heart. Advanced imaging techniques, known as wideband MRI, have recently been developed to minimise these image artefacts, enabling clear images to be obtained for more accurate diagnosis (Gut et al., 2024a).

Wideband bright-blood imaging: a new way to capture clear heart images

Bright-blood imaging is a special MRI technique that enables cardiologists to see heart tissue in great detail (Kellman et al., 2002). It is commonly used to identify damaged or scarred areas in the heart, for example, following a heart attack. Bright-blood imaging is particularly effective at showing the contrast between healthy

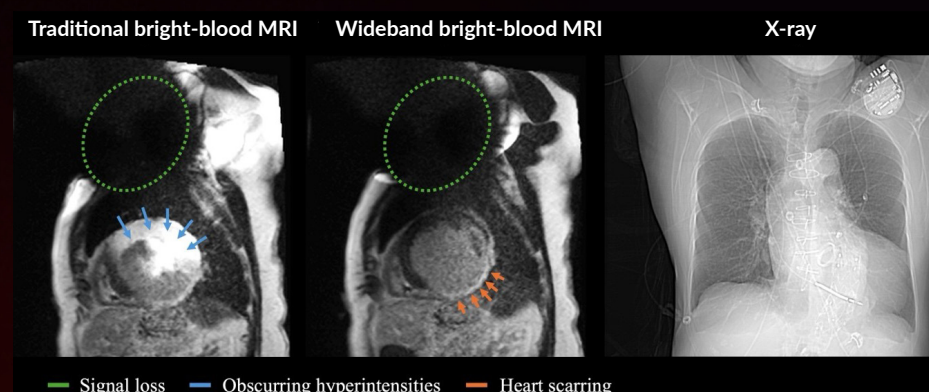


Figure 1: Left: example of the different image artefacts created in traditional cardiac bright-blood magnetic resonance images: black spots due to signal loss at the device location and bright areas called hyperintensities that partially obscure the heart. Middle: wideband bright-blood MRI provides images with suppressed hyperintensities, allowing clear heart images and scarring assessment. Right: x-ray showing the device location.

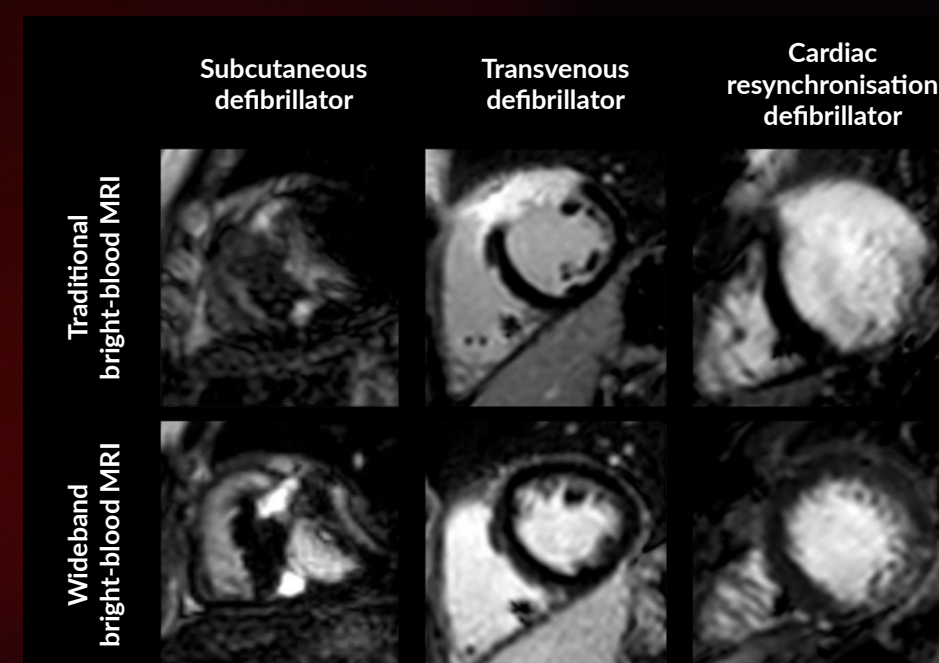


Figure 2: Example of the severity of image artefacts related to different types of CIEDs on traditional and wideband bright-blood MRI.

cardiac tissue and abnormal areas, using an inversion preparation pulse in the imaging technique and after the injection of a special contrast agent called gadolinium. However, when a person has a CIED, bright-blood imaging can encounter difficulties as the metal parts of the device interfere with the MRI magnetic field, creating the image artefacts mentioned previously.

Wideband bright-blood is an advanced version of the traditional bright-blood technique designed to tackle image artefacts caused by implants (Rashid *et al.*, 2014). Wideband bright-blood uses a wider range of frequencies in the inversion preparation pulse, known as wideband, during scanning, reducing CIED-related image artefacts by correctly inverting all spins with different precession frequencies in the heart due to magnetic field inhomogeneities created by the device itself. However, the contrast between areas of scarring in the heart and adjacent blood provided by traditional bright-blood and wideband techniques is quite low and can lead to ambiguities in the diagnosis of precise

areas of scarring.

Wideband black-blood imaging: a new way to capture clearer heart images

To solve the contrast problem with bright-blood imaging, black-blood imaging was developed to better detect areas of cardiac scarring adjacent to the blood (Liu *et al.*, 2008). It is called black-blood processing because it uses a technology that makes blood and healthy tissue appear black on images while highlighting scar tissue in the heart, using an inversion pulse to darken the healthy tissue, as with bright-blood imaging, but also a 'T2 preparation' that helps darken the blood at the same time (Bustin *et al.*, 2022; Sridi *et al.*, 2022). As with bright-blood imaging, traditional black-blood MRI is challenged by the presence of CIED, which causes hyperintensity artefacts, signal loss and geometric distortion in the image. Wideband black-blood MRI is an advanced version of the traditional black-blood technique that

reduces CIED-related image artefacts by correctly inverting all spins in the heart when using the inversion pulse and by correctly preparing the spins with the T2 preparation (Gut *et al.*, 2024b).

Free-breathing wideband black-blood imaging: a breakthrough in heart imaging, a step closer to easy MRI

Wideband black-blood MRI is a major imaging advancement for patients with CIEDs who need detailed imaging of the heart and scarring. It overcomes the limitations of traditional bright-blood MRI, making it easier for cardiologists and radiologists to detect small scars and scars adjacent to blood. However, one of the main limitations of all the previously mentioned techniques is that they require patients to hold their breath to obtain clear, unblurred images, which would otherwise be affected by respiratory movements.

Most patients with heart disease find it difficult to hold their breath, resulting in poor-quality images and potentially compromising diagnostic reliability. Moreover, repeated and tedious breath-holds require pauses between successive image acquisitions, lengthening the whole cardiac imaging protocol to a large extent. Free-breathing image acquisition is a step towards easier, faster scanning and greater patient comfort. Free-breathing combined with wideband black-blood imaging has recently been proposed (Gut *et al.*, 2024c), enabling accurate detection of cardiac scarring, the absence of image artefacts related to CIEDs, faster scanning and improved patient comfort. Unlike traditional MRI scans, which require patients to hold their breath, free-breathing wideband black-blood imaging uses advanced motion-correction technology.

After the image acquisition, complex computer algorithms correct any respiratory movement, ensuring sharp, diagnostic final images. By combining free-breathing capabilities with advanced imaging, cardiologists and radiologists can obtain high-quality images even in

patients who have difficulty meeting the requirements of traditional MRI. There is no need to hold one's breath during the examination, which is particularly beneficial for children, the elderly or patients with breathing difficulties and enables a smoother imaging experience. Patients with complex pathologies, who might otherwise be excluded from certain examinations due to their difficulty in holding their breath or the presence of an implant, can now undergo this type of MRI.

Conclusion

Free-breathing wideband black-blood MRI represents a significant advancement in cardiac imaging. It makes the process more accessible and comfortable for patients who find it difficult to hold their breath during traditional MRI examinations. Combining the comfort of free-breathing with wideband technology to resolve problems caused by metal implants and black blood to better detect cardiac scarring results in a confident and accurate diagnosis for many CIED patients suffering from heart conditions.

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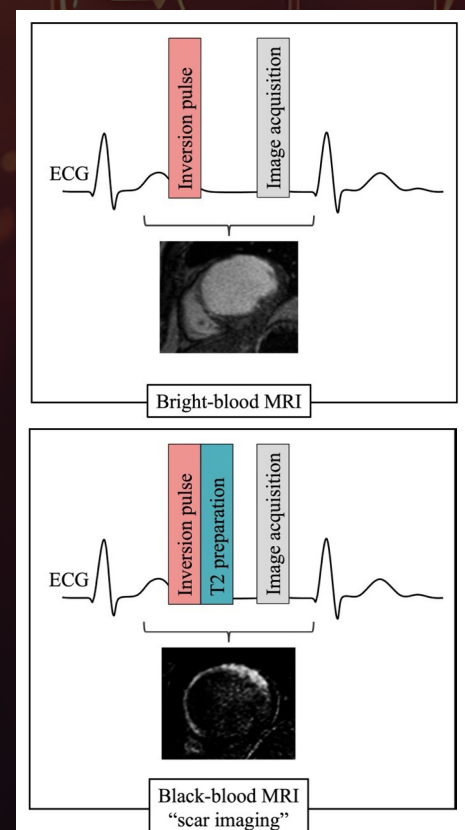


Figure 3: Left: principles behind bright-blood MRI. Right: principles behind black-blood MRI for improved heart scarring (white area) imaging.

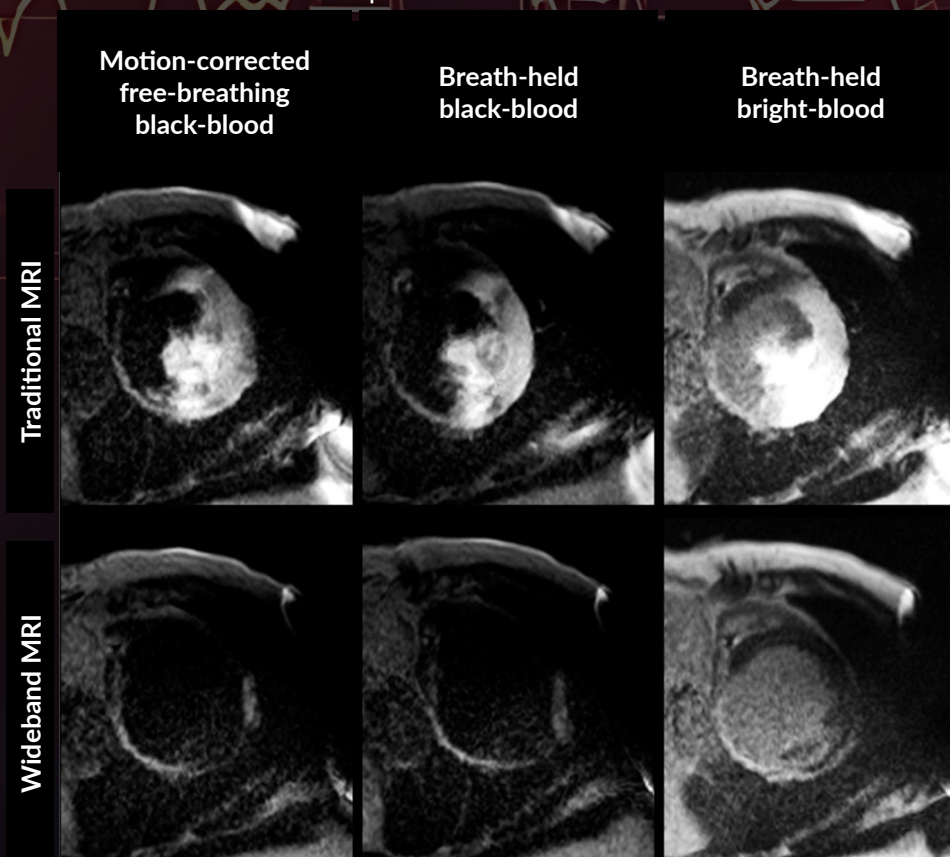


Figure 4: Next generation of cardiac MRI for patients with CIEDs using a free-breathing black-blood imaging protocol for faster image acquisition, enhanced heart scarring detection and improved patient comfort.

PROJECT SUMMARY

Cardiac MRI has traditionally been challenging for CIED patients due to safety concerns and image artefacts. While advancements in MRI-compatible devices have improved MRI access, imaging issues and patient discomfort remain significant hurdles. Free-breathing wideband black-blood MRI is a groundbreaking solution that reduces CIED-related image artefacts, enhances heart scarring detection and eliminates the need for breath-holding. This innovation not only improves diagnostic accuracy but also enhances patient comfort, making cardiac MRI smoother, faster and more accessible for individuals with CIEDs.

PROJECT LEAD PROFILE

Aurélien Bustin is an Assistant Professor at IHU LIRYC, the Heart Rhythm Disease Institute, at Bordeaux University (France) and a visiting researcher at the Department of Diagnostic and Interventional Radiology, Lausanne University Hospital and the University of Lausanne (Switzerland) since 2020. Dr Bustin is the project lead for SMHEART, which started in September 2023. His team has been publishing in the fields of radiology, cardiac magnetic resonance imaging and computer science.

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FUNDING

This research was supported by funding from the French National Research Agency under grant agreements Equipex MUSIC ANR-11-EQPX-0030, ANR-22-CPJ2-0009-01, and Programme d'Investissements d'Avenir ANR-10-IAHU04-LIRYC, and from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement 101076351).