Unveiling the unseen: next-generation cardiac magnetic resonance imaging

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MRI of the heart is too complex

If you've been informed that you require a cardiac magnetic resonance imaging (MRI) scan, you're likely curious about the anticipated wait time. Perhaps you've heard that the waiting period for a cardiac MRI examination can be quite extensive, ranging from one to five months.

A brief visit to any radiology department can shed light on the reasons behind this seemingly prolonged wait. The complexity of performing cardiac MRI examinations necessitates highly specialised individuals to gather and analyse the data, requiring full cooperation from patients.

Patients undergoing this procedure often endure 40 to 60 minutes inside a noisy and imposing machine. Breath-holding is frequently required throughout the process to capture clear images. On the medical side, highly skilled magnetic resonance (MR) technicians meticulously plan and execute the collection of nearly 1000 images per examination. These images vary in contrasts and resolutions and are acquired using specific tools referred to as 'sequences'.

Planning these sequences involves careful consideration of the patient's comfort and breath-holding pace. To provide perspective, a typical cardiac MRI examination demands over 400 mouse clicks, a magnitude greater than more straightforward procedures like brain MRIs.

Once the images are finally collected, radiologists devote a considerable amount of time per patient manually drawing circles on the images. This is done to precisely localise the heart and identify any pathologies, extracting the relevant diagnostic elements.

Despite the time-consuming nature of this process, cardiac MRI is an invaluable tool for evaluating the function and anatomy of the beating heart. Importantly, it achieves this without exposing patients or operators to potentially harmful ionising radiation, as is the case with CT and PET scans.

A European project aimed at constructing the heart MRI system of tomorrow

As a mathematician venturing into the realm of clinical cardiac imaging, I was struck by the intricacies of the field and the noticeable lack of collaboration among the diverse experts shaping the development of cardiac MRI. MRI scientists, mathematicians, engineers and clinicians seemed to operate in isolated silos, resulting in the accumulation of numerous independent and complex techniques , each offering only a partial view of the intricate landscape of cardiac diseases. It's time to change this.

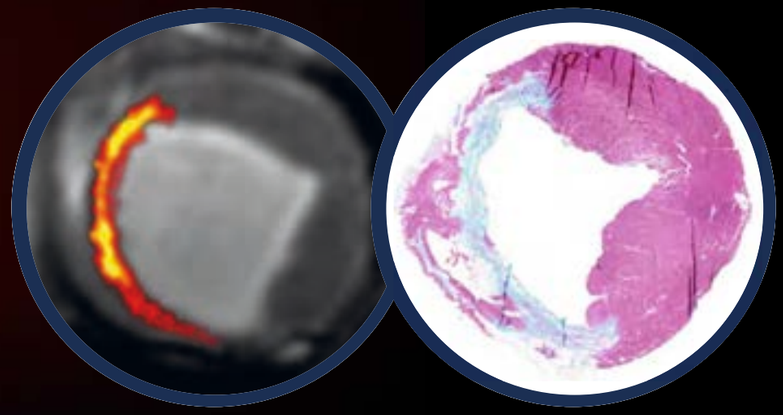

Figure 1: Next-generation cardiac magnetic resonance imaging (left) compared to histology (right).

A ground-breaking initiative is underway, featuring a new multidisciplinary team comprising of MR physicians, mathematicians, computer scientists and clinicians. This team is poised to revolutionise our approach to cardiac MRI through the ERC project SMHEART. The mission is to unlock the full potential of cardiac MRI and reshape patient journeys by introducing a completely automated comprehensive imaging pipeline applicable to diagnosis, prognosis and therapy selection in cardiology (Bustin *et al.*, 2023).

The project team will pursue a three-pronged strategy to achieve this goal.

i. **Revolutionising CMR technology:** the team will develop a novel CMR technology capable of collecting data in a single continuous free-breathing scan. This approach takes into account post-processing requirements right from the inception of CMR sequence design, streamlining the entire imaging process.
ii. **Harnessing unique contrasts:** the team will leverage the distinctive contrasts generated by this cutting-edge technology to automatically extract quantitative markers related to cardiac anatomy, function and tissue characteristics. This promises a more comprehensive understanding of the intricate details of cardiac health.
iii. **Translating innovation to clinical practice:** the ultimate objective is to transition this transformative technology from a pre-clinical setting to a fully functional clinical environment. By bridging the gap between theory and practical application, the team aims to bring about real-world change in the way we approach cardiac imaging and patient care.

This collaborative effort seeks to break down the barriers between disciplines, fostering a more integrated and holistic approach to cardiac MRI development. The ultimate goal is to empower healthcare professionals with a powerful tool that enhances our understanding of cardiac diseases and, consequently, improves patient outcomes.

Approach: one-click comprehensive heart imaging

Novel 'single mouse click' MRI

Our solution involves the use of push-button CMR sequences (Figure 2). These sequences allow for continuous mutli-parametric data collection without interruptions, significantly shortening examination times (Di Sopra *et al.*, 2019). By eliminating the need for meticulous scan planning, patient comfort will be enhanced, and the overall time efficiency will be increased. Instead of relying on intricate manual adjustments, a simple click of a button initiates a seamless process that not only reduces the burden on skilled operators but also enhances the accessibility and efficiency of cardiac MRI for a broader population. This innovation marks a significant step towards making cardiac imaging more user-friendly, efficient and widely accessible.

Beyond black and white: transforming diagnosis with colourful precision

Bright-blood late gadolinium-enhanced (LGE) imaging stands as the current benchmark for evaluating myocardial injuries in patients. Within LGE images, the presence and distribution of scar serve as pivotal indicators for diagnosing the aetiology of structural heart diseases. Additionally, the transmurality of scar, indicating its depth, plays a crucial role in assessing myocardial viability in ischaemic patients and predicting the potential benefits of subsequent procedures, such as revascularisation. Furthermore, research has demonstrated that the burden and heterogeneity of scar on LGE images can serve as a robust predictor of ventricular arrhythmias. This predictive capability has the potential to significantly enhance the primary prevention of sudden cardiac death, particularly when considering the implementation of implantable cardioverter-defibrillators.

Despite these promising clinical applications with direct implications for patient outcomes, challenges arise due to the suboptimal contrast at the blood-scar interface, with blood and scar signals having similar bright intensities. This limitation results in reduced sensitivity to small scars and compromises the robustness of scar quantification, which is heavily reliant on precise delineation of the endocardial border (Sridi *et al.*, 2022; Maillot *et al.*, 2023).

In response to these challenges associated with conventional bright-blood cardiac MRI images, we have introduced colour-enhanced heart imaging (Bustin *et al.*, 2022) (Figure 3). This innovative technique has proven effective in revealing scar patterns that might otherwise be obscured by blood signal, offering a potential solution to the limitations observed in traditional imaging methods (Figure 4).

Artificial intelligence-driven healthcare

Perhaps the most remarkable aspect of colour-enhanced heart imaging is the easy visualisation and, thus, segmentation of the scar. We believe that joint colour-enhanced imaging of the heart is ideally suited to perform artificial intelligence-based automated myocardial scar mapping and quantification. Indeed, with blood and healthy myocardium signals being completely cancelled and scar signal predominantly bright on the images, robust scan segmentation and quantification become reachable. This would allow for accurate scar localisation, robust scar transmurality measurements and automated 3D whole-heart modelling (Bustin *et al.*, 2021). This should transform myocardial scar characterisation into a smart, effortless and accurate procedure. Finally, all these developments are being integrated into a comprehensive and dedicated software, which will benefit all stakeholders: consortium, clinicians and patients.

"This novel technology addresses a 20-year-old conundrum in cardiac MRI."

Prof. Matthias Stuber, Centre Hospitalier Universitaire Vaudois (CHUV), Lausanne, Switzerland.

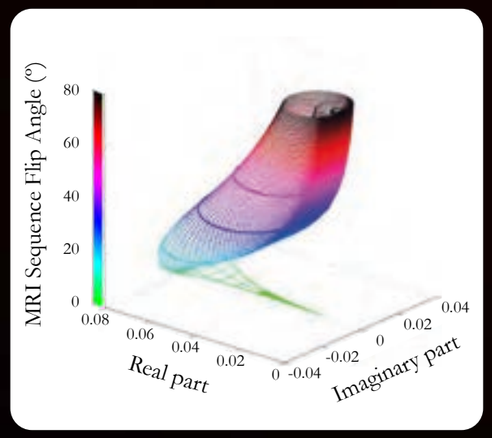

Figure 2: A multi-dimensional MRI signal signature obtained with the proposed one-click sequence.

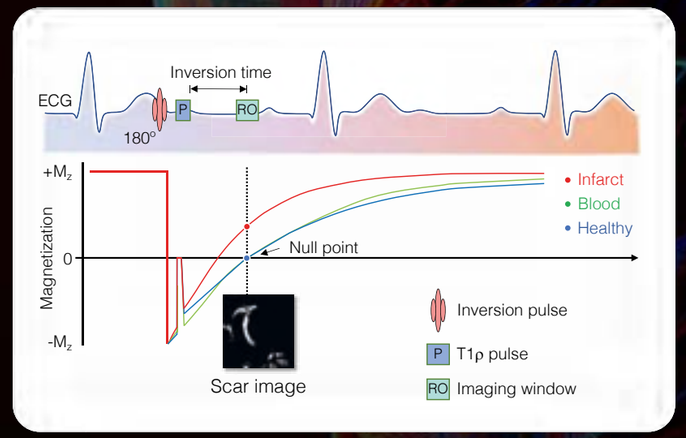

Figure 3: Principles behind black-blood myocardial scar imaging.

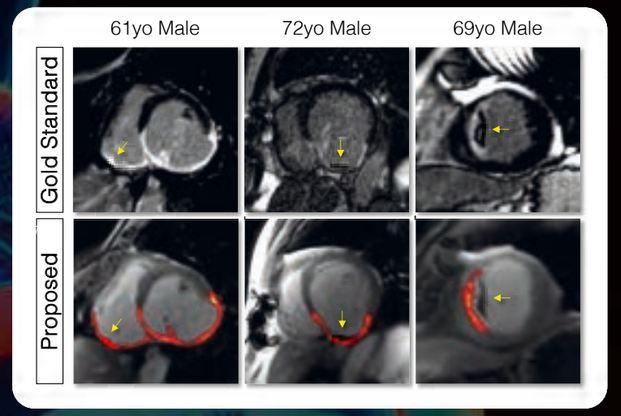

Figure 4: Next-generation colour-enhanced radiation-free imaging of the heart. Images collected at Bordeaux University Hospital.

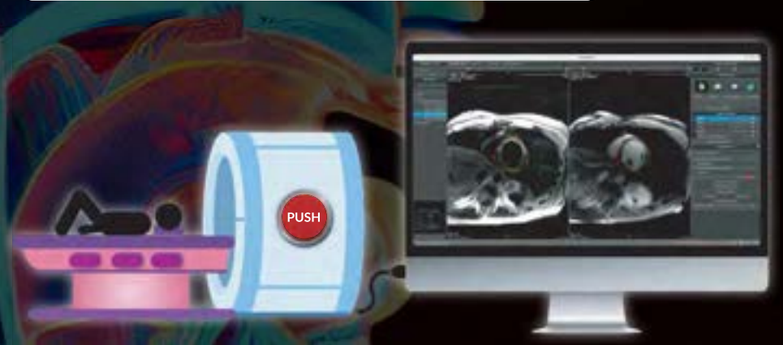

Figure 5: The SMHEART software platform for fully automated heart diagnosis.

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SMHEART
Next generation cardiac imaging

PROJECT SUMMARY

Cardiovascular disease (CVD) claims over 1.8 million European lives yearly, surpassing cancer, chronic respiratory disease and diabetes fatalities. Cardiac magnetic resonance imaging (CMR) is crucial for understanding and treating CVD, offering radiation-free comprehensive heart assessment. However, current CMR systems are slow, complex and require specialised expertise, limiting widespread adoption. SMHEART aims to revolutionise CMR with a one-click approach, creating a unique 3D whole-heart volume for automated cardiology diagnosis, prognosis and therapy selection. This project streamlines CMR, facilitating broader acceptance and optimising its impact on personalised patient care, including diagnosis, risk stratification, therapy selection, monitoring and image-guided interventions.

PROJECT LEAD PROFILE

Aurelien Bustin is an Assistant Professor at IHU LIRYC, the Heart Rhythm Disease Institute, at Bordeaux University (France) and 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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