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Dear readers and colleagues,

It is a great honour to contribute as Editor of the MAGNETOM Flash SCMR 2020 Edition. Writing this as the decade is coming to a close, I chose to reflect about what are the things in store for cardiac MRI. As the merciless pace of the digital revolution in cardiology and healthcare at large heralds disruption and causes uncertainty, how will this affect the cardiac MRI field? Will this huge engineering achievement withstand the emerging digital apps at our fingertips [1]? Will the primary weakness of cardiac MRI, its enormous complexity and lack of scalability beyond the hands of experts, set its limitation? Or will the electricity-hungry magnets soon pose social and ecological problems? Can they be run by some source of renewable energy [2]? While these thoughts may sound perturbing, the field of cardiac MRI has also been an undeniable front-cover success story for over two decades, coping with a number of diverse challenges. As we celebrate the many achievements of cardiac MRI, we also will revisit some of the most pressing challenges to get a better sense of future direction.

CMR can provide a plethora of diagnostic information, but can it also guide clinical management?

Cardiac MRI is a masterpiece of healthcare engineering, and at the same time, the crown jewel of evidence-based imaging diagnosis. It never has been the usual R&D story, a spin-off with colossal growth, eventually taken over by big industry. Rather, CMR has remained in a distinguished niche, a niche which has given everyone space to thrive, to harness the demanding MRI physics and engineering, and the shelter to co-develop a more sustainable model for a complex technology. Once it achieved the impossible, i.e. seeing the beating heart, it did not cease to fascinate – seeing the heart in its entirety, in action, in-depth. Clinicians were quick to appreciate its particular clinically advantageous features; the accuracy, the absence of radiation, needles or rib-poking probes, but most of all, unlike any other imaging modality, the non-invasive histology, practically on the go. Clinicians also helped to enshrine these important and clinically relevant opportunities in the substantial body of clinical evidence – which is beyond due diligence – the validation work, clinical comparative and effectiveness studies, vouching for the precision, the quality and the depth of its clinical meaning [3].

Yet, the benefits of CMR remain a tricky sell when it comes to the mainstream clinical world. In reality, cardiac MRI is often the second to third line diagnostic technique, despite its obvious advantages, superior evidence and informative diagnostic readouts. Unlike any other diagnostic imaging, cardiac MRI remains too complex to be 'traditionally scalable' i.e. squeezed in between the largely self-driving 'knees and spines'. As such, it will be naturally turned to very late in the course of disease, after a long series of diagnostic procedures, and typically, much procrastination and deliberation about its potential benefits. The eventual 'go' frequently consists of an over-extensive wide-cast-net exam, trying to solve the riddle of a heart condition that remains not fully understood. The resulting lengthy nature of the eventual exam sets can make cardiac MRI a "once in a lifetime" experience. In their own words, the weary patients having experienced little in a way of direct benefit from the first exam, will reproducibly express scepticism if asked to submit themselves to yet another lengthy exam. Clearly, cardiac MRI on such terms bears little appeal beyond the single use, a far cry from a routine diagnostic means, which could also serially monitor disease progress and the effects of treatment.

Clinical evidence must link CMR with improving patient outcome

A number of things can (and must!) help us to urgently evise this situation. We must celebrate the successes of the 2019 studies, including MR-Inform, Spins and the yet-to-be published Gadacad, as they recognisably add to and boost to our common cause. Other important unresolved aspects include uncertain long-term business prospects of the field, related to the largely non-existent reimbursement in most countries. The poorly vetted short-term commercial interests – huge expenses for scanners, still rather complex and time-consuming postprocessing softwares and the overwhelming maintenance charges, resonate with the convoluted arguments about the high costs of the technique. Perhaps the most important lesson here is the realization that it continues to be the massive enthusiasm together with the selfless face of medical vocation that presently sustains this field. These issues collectively hinder the realization of the accomplished hard work and ingenuity, making the path to roll-out the benefits of cardiac MRI rather stony.

On a positive note, the cardiology practice guidelines are evolving, and the role assigned to cardiac MRI is growing. Admittedly, the phrasing remains careful. CMR is at best described as 'a promising' diagnostic tool with a 'great potential' to illuminate the underlying aetiology of heart disease. This rather reserved stance about cardiac MRI continues to be defended by the many contraindications to MRI (although in reality only a few still persist) and the perceived lack of availability (a term used to summarily denote a lack of scanner access, skill and expertise). Interestingly, this argument is in stark contrast with the view that the overall MRI market is already saturated in terms of satisfying the imaging needs with an average 12–15 units per million inhabitants as is the situation the EU (with Germany leading at 35 units per million capita) [4]. Elsewhere, the highest per capita number of MRI units include Japan (n = 55), followed by the U.S. (n = 38). Approximately 5000 additional units are being produced each year, and many existing machines are being refitted and upgraded to keep them going. So, no lack of machines, or so it would seem. Furthermore, there is a well-rehearsed argument about overuse and so-called 'unnecessary' MRI imaging, since the incidence of the overall morbidity and mortality has not been reduced in keeping with constant increase in imaging over the years. Clearly, such arguments are based on the misconception that imaging the disease somehow equates with a cure. Unlike drugs or medical devices, diagnostic tests are not required to provide evidence that their use can positively enhance treatment strategy and patient outcome. The breakdown of organ-specific MRI scans is even more enlightening. Currently, the prevalent deployment of MRI units is for imaging of brain, spine and extremities (altogether 70% of scanner utilization worldwide), whereas cardiac MRI amounts to only 1% of all imaging [4]. In fact, this prioritization of non-cardiac indications may explain the lack of relationship between overall imaging and mortality, as current efforts cannot counter the magnitude of problems created by heart disease, the major contributor to morbidity and mortality worldwide.

A regulatory requirement for a more evidenced-based approach to imaging evaluated in terms of clinical effectiveness in delivery of medical care such as guiding treatment to change outcomes might in fact be of tremendous benefit to cardiac MRI. Something similar to the concept of companion diagnostics, where diagnostic testing which can be shown to guide effective treatment receives a licenced indication for its application. This concept could be beneficially expanded to all imaging modalities to distinguish between the methods available. This would ensure the best deployment of resources for a wider population. In other words, the current absence of regulatory pressure is eloquently exposed by an average level of evidence C supporting cardiac imaging in clinical guidelines, equating with expert consensus and not supported by evidence of improved outcome. In fact, there has never been a better opportunity for randomized clinical trials to demonstrate the benefit of cardiac CMR against a weak conventional standard of care, which is often either invasive, reliant on radiation or simply non-diagnostic [5].

CMR is particularly suited for assessing both ischaemic and non-ischaemic cardiomyopathies

The nature of heart disease has changed thanks to the considerable advances that have helped reduce the deadly share of ischaemic heart disease. With effective prevention and treatment of acute coronary syndromes, non-ischaemic cardiomyopathies now increasingly prevail as the cause of heart failure. Efforts to improve diagnostic approaches to the latter have been rather unsuccessful for several reasons. Firstly, these conditions are difficult to detect with the current first line diagnostic tools, such as echocardiography, which at best can recognize wall-motion abnormalities or severe systolic dysfunction, both of which

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are hallmarks of ischaemic heart disease. On the contrary, non-ischaemic cardiac cardiomyopathies are characterized by a slow evolution of intrinsic global and diffuse myocardial changes over many months or even decades, with the pumping function being long preserved. Also, the onset of these conditions is not punctuated by the textbook 'heart-related' symptoms modelled on patients experiencing a heart attack. Rather, the symptoms ensue after decades of a subclinical course due to eventual development of heart failure, essentially synonymous with the advanced disease stages. The understanding of a modern cardiac patient is crucial to avoid the pitfalls of the classical approach to heart failure, which deliberates the recognition of the heart disease worthy of treatment to the late stages.

Clearly, this is also tantamount to the state of evidence for current treatment, as all trials have focused on these late disease stages, frequently beyond the remedial tipping point. Cardiac MRI has played an enormous role in bringing to light the above-mentioned pathophysiology, the in-depth understanding of non-ischaemic heart conditions, by recording the in-vivo patterns of tissue changes in symptomatic patients with overt heart failure [6], and increasingly, by collecting the phenotypical snapshots of disease evolution in subclinical stages [7]. This has led to important novel discoveries, including characterization of the relevant tissue substrates that drive disease and determine the prognosis. These unique diagnostic abilities are the essential must-haves of a modern diagnostic toolbox, primarily consisting of myocardial perfusion, late gadolinium enhancement (LGE) imaging and myocardial tissue mapping (as exemplified by the GoetheCVI® Examcard[1]).

Myocardial perfusion is essentially a concept transferred from another imaging modality, but much improved through high-spatial resolution and a better contrast afforded by gadolinium contrast agents [8]. Myocardial perfusion with CMR is the most accurate non-invasive functional test to determine the presence of relevant ischaemia, and of recently, to guide treatment with revascularization. The MR-INFORM clinical trial used a randomized clinical trial design to demonstrate that patients presenting with typical angina have a similar 1-year outcome, when receiving non-invasive treatment-guidance with cardiac MRI compared to invasive catheterization with FFR measurement [9]. LGE can visualize myocardial scar and its pattern, and by this recording the overall brunt, the cumulative toll of the disease, as well as the underlying aetiology [10–13]. The 2016 ESC guidelines for heart failure specifically highlight the role of CMR with LGE with regards to the type of scar (when present) in differentiation between the ischaemic vs. non-ischaemic pathophysiology [14]. A further advance comes by way of quantitative tissue characterization using T1 and T2 mapping. These magnificent imaging tools of non-invasive histology took their initial hints from the concept of myocardial T2* imaging in cardiac iron overload [15]. These quantifiable diagnostic tests are unique in providing the absolute values of myocardial tissue measurements, which reveal the presence of disease, reflect the disease character by indicating the underlying tissue substrate, as well as disease activity and stage of disease [5]. The mapping tools, more than anything else in cardiac MRI, build on its primary asset, to inform about the underlying pathophysiology – while the disease is still developing and as such potentially reversible – for delivering a timely cure, which may also improve mortality.

[1] *The information shown herein refers to products of a 3rd party and thus are in their regulatory responsibility. Please contact the 3rd party for further information.*

Quantitative tissue mapping tools are exciting, but meaningless without proper standardization

The widespread adoption of these novel tools suffers in an extension of the general issues surrounding cardiac MRI, because the 'must-have standard diagnostic toolbox' is neither standardized nor routinely available. What is more, it often needs to be purchased extra, making cardiac MRI an unattractive addition to the general imaging. The additional areas of uncertainty, distinctive to the mapping tools, pertain the overall lack of experience with quantitative imaging tools, a rather new concept to imagers. Mapping tools require a mental switch away from visualization [16] – into the area of analytical tests [17], i.e. recording a number and reading its meaning on a quantitative scale, with the reference ranges, abnormal, prognostically unfavourable range, etc. Perhaps more intuitive if thought along the lines of the blood markers. Any quantifiable tests, mapping tools included, require analytical validation, clinical qualification and standardization – prior to the application into clinical use. After deployment the tests must be subject to all the elements of quality control to ensure safe delivery of an intended, clinically meaningful result. For quantitative diagnostic tools, purchased for clinical use, the burden of standardization and validation remains firmly within the domain of the manufacturer or other providers of imaging biomarkers using the MRI technology. Equally important is that the MRI engineers, physicists and computational scientists, involved in developing either acquisition or postprocessing software realize that nudging of prepulses, pauses and beats in mapping acquisition or application of any correction factors in the postprocessing steps is a deviation from the original method, which must trigger a new cycle of analytical validation and qualification against a hard-core physiological meaning, even if this means years of intense work. Poorly calibrated and non-standardized quantitative methods simply cannot be used outside the research domain.

A further difficulty lies in qualification of imaging tests as conveyors of worthy clinical messages beyond the circle of trained imagers, i.e. capturing the attention of the intended recipients of our reports. An illustrative example is my long-held view that myocardial T2* measurement might be inherently more intuitive to the target physicians (i.e. haematologists) if it featured embedded in the blood results, as opposed to be sunk deep in an imaging report [15]. Such an approach might help to overcome the hesitation that ordering an imaging test – even for a crucial value – is rather excessive compared to 'a simple blood test'. T1 and T2 mapping suffer from a similar dissociation between image and its clinical application. Mapping results may appear more clinically worthwhile if they mentally trace the lines of cardiac biomarkers, such as troponin, or come framed similarly to histological results of endomyocardial biopsy. In fact, the first perceptible advantage of the mapping tools for the everyday clinician may be in receiving immediate clarity on the tissue processes, contrasting the weeks of delay until the results of the biopsy are available.

The most pressing need to achieve long-term viability of cardiac MRI is the evidence that a standardized cardiac MRI toolbox can improve treatment of heart diseases.

Urgent need for a standardized CMR toolbox to emancipate the discipline and increase access to serve patients

The most pressing need to ascertain the long-term viability of cardiac MRI is the evidence that the standard cardiac MRI toolbox can deliver a major change to improve the current approaches to treatment of heart diseases. Such evidence requires conducting well-controlled randomized clinical trials, assuring the value of cardiac MRI deployment for treatment purposes and improvement of prognosis, as exemplified by the aforementioned MR-INFORM clinical trial. Our own niche-like culture perhaps no longer helps the cause; we force the confusing technicalities (such as, about the image acquisition) on each other, as if to claim the supremacy of knowledge or skill, while effectively leaving most users clueless and unphased, as their primary interest is in the clinical benefits of the whole endeavour. With many sensational technical developments this remains rather elusive. The increasing technical maturity of cardiac MRI by faster scanning and a number of automated processes – clearly, an overdue homework, may allow more clinically oriented researchers and the large group of non-research dominated clinicians to finally move into the field without being overwhelmed by technical issues, a difficult and specific language and exams which require knowledge on artefacts and underlying physics.

In this context, we appreciate the many innovations of Siemens Healthineers MRI engineering which address the need for standardization and facilitate the ease of performing cardiac applications – especially the Cardiac Dot Engine, a tool which uses automation to support cardiac planning. Several articles in this edition address the capabilities of this powerful standardization tool. Another milestone which deserves our attention is the introduction of the MAGNETOM Sola Cardiovascular Edition system, a dedicated Cardiovascular MRI scanner, which heralds the emancipation of cardiac MRI as its own discipline. When speaking of emancipation, we should also recognize the important ground work being done around the world by giving voice to the quiet thoughts of the cardiac MRI clinical community, fighting the odds of the everyday reality. In this issue, we created a blog of shared experiences on starting out the local CMR services around the world, recalling the unique situations, as well as reiterating the common lines of the down-to-earth challenges. In the section titled "Cardiovascular MRI Around the World" we learn that in most cases the first stumbling block is the lack of a simple start-up toolbox for a cardiac MRI program. The emerging automated cardiac MRI approaches will certainly ease some of the current pressures experienced when starting a CMR program [18].

Finally, to really unfold the potential of cardiac MRI, the costs of running and maintaining the machines and effective postprocessing tools, as well as the need for lengthy training of specialized personnel must be overcome. If we achieve this, the pressing reimbursement issues – a crucial issue for viability of cardiac MRI – will be easier to solve. What is more, we cannot ignore the need to generate quality evidence based on standardized approaches and fully locked and approved diagnostic and therapy essays with strict quality control. We must demand that industry partners support us in performing large scale therapeutic trials using CMR as the central method for guiding therapy; by phenotyping and individualizing therapy, guiding patient management and – consequently – improving outcome. Only a sure place in clinical management based on its clinical effectiveness will render this method scalable and worthwhile. Even if the onus remains on those who sell technology to make it more affordable, and even if we cannot expect the everyday clinical CMR community to sustain this for much longer, it is up to us to shout out loud to change things, enabling us to better serve patients. In the end, it is we, who need life to have a meaning [19].

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