Cardiovascular MRI at 3T & Beyond

Clinical Success & Failures at 3T & Above

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In recent years the high and ultra-high magnetic field MRI scanners have started to leave the confinement of specialized and research oriented laboratories and progressively are entering the clinical use. There are several reasons to justify the progressive increase of the field such as better quality of images that is better spatial resolution, better signal to noise and contrast to noise ratio, or better temporal resolution, etc. However, while for some organs such as the brain the use of higher static field has un-doubtfully induced a substantial improvement in diagnostic performance for other body districts such as the cardiovascular one there is still a debate on the cost-benefit of transferring patients to the fields higher than 1.5T that is 3.0 and/or 7.0T.

While, on one hand, pilot studies performed in highly qualified Centers show that there would be a significant benefit from the use of 3.0T mainly in some applications such as Myocardial Perfusion, Late Gadolinium Enhancement images and T1 mapping, on the other hand a systematic use of 3.0T has been considered unrealistic. This is because the overall quality of cardiac images is strongly affected by the presence of artefacts. Black blood images are much more prone to susceptibility artefacts while cine images show quite frequently the presence of flow related artefacts. Furthermore, in applications such as cine images, the advantages are more theoretical than real as the SAR limitation. A self block of the amount of energy transferred to the patient is unavoidably applied by the scanners, and this reduces the possible advantages related to the fast acquisition of images.

However, technological development is progressively reducing the incidence of artefacts at 3.0T. The introduction of advanced cardiac shimming procedures to compensate the field in-homogeneities (ex. GRE based fieldmap acquisition followed by the optimization volume (see Figure 1), etc) might significantly improve the quality. Similarly an effort on optimization of acquisition parameters in the single patient, a more accurate detection of ECG signal, the use of more sophisticated receiving coils, innovative approaches to fill the k-space, etc might produce either black blood or white blood images which are competitive with the ones obtained at lower field. As a result of this broad technological advancement it is not surprising any more that Centers scanning daily an high number of cardiac patients might routinely adopt a 3.0T scanner (even if some limitations have to be still considered. For example, in patients undergoing T2* mapping the susceptibility artefacts can reduce the capability of quantitative approach in detecting relaxivity on a regional basis.

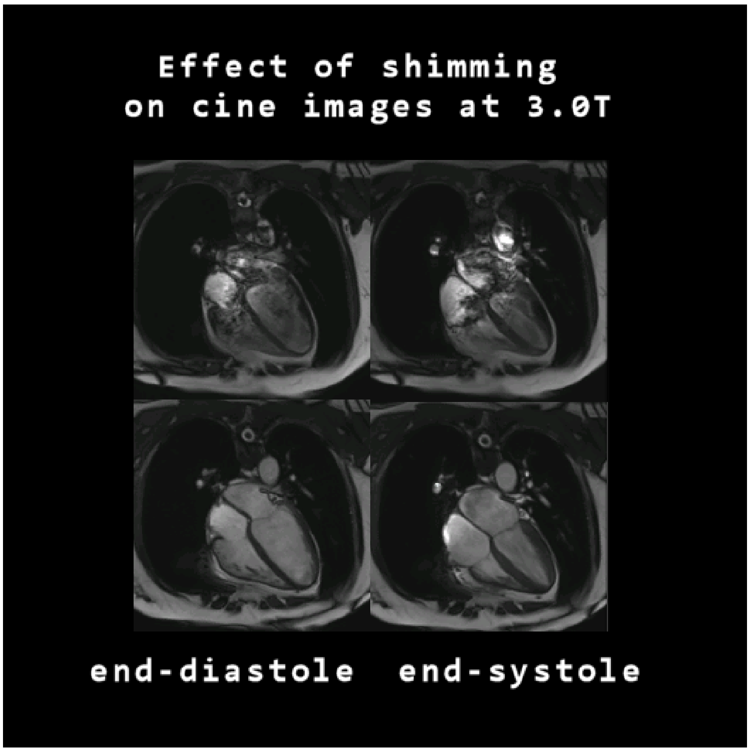
In the field of Magnetic Resonance angiography a better signal to noise and contrast to noise ratio at 3.0T with respect to 1.5T have been reported. In fact, the improved spectral resolution provides better water-fat separation and leads to a better and more uniform fat suppression than at 1.5T. This has been proven to contribute significantly to angiograms of better quality, as the improved background fat suppression allows a better Contrast to Noise Ratio. The clinical relevance of this improvement can be simplified considering that the 3.0 T scanner enables to achieve an image quality comparable to that of the 1.5-T scanner with a lower dose (the half!) of contrast media.

While the 3.0T technology is rapidly becoming clinically realistic, more challenging appears the use of ultra high field such as 7T. In the field of cardiac MR the use of this technology is still confined in the feasibility phase. Albeit the rationale of proposing ultrahigh magnetic fields of 7 T and eventually higher remains a further increase of the signal-to-noise ratio, which holds promise for a significant improvement of the spatial and/or temporal resolution as well as for new contrast mechanisms, B1 in-homogeneities, contrast variations transmission field in-homogeneities are still a major challenge at the ultrahigh field MRI and there are also partially unsolved safety problems. The use of ultrahigh field MRI is currently limited to special applications but none of them in cardiac MR for clinical purposes.

Also in this case, the use of more sophisticated transmitting/receiving multichannel coils, dedicated acquisition sequences, etc are currently under development and might improve the quality of images.
The current state of the art can be summarized by two examples:
a) since electrocardiography is corrupted by interference with electromagnetic fields and by magneto-hydrodynamic effects at 7T, acoustic cardiac triggering has been proposed for retrospective gating at 7T with good initial results;
b) in a recent feasibility study at 7.0 T, with the aim of evaluating effective transverse relaxation rate (R2*) mapping in the human heart the most severe susceptibility artefacts were detected in the inferior lateral wall. The mid-septum showed minor artefactual factors at 7.0 T, similar to those at 1.5 and 3.0 T. Mean R2* increased linearly with the field strength, with larger changes for global heart R2* values. The Authors concluded that at 7.0 T, segmental heart R2* analysis is challenging due to macroscopic susceptibility artifacts induced by the heart–lung interface and the posterior vein. Myocardial R2* depends linearly on the magnetic field strength. However the increased R2* sensitivity at 7.0 T might offer means for susceptibility weighted and oxygenation level-dependent MR imaging of the myocardium.
This studies show pretty well that the use of ultrahigh field for cardiac pathologies is still facing challenging problems and only an extensive research effort will contribute to make this technology available also in the clinical setting.

Conclusion

In recent years, Cardiac MR has gained the privilege of becoming the most innovative imaging modality in the hands of cardiologists with an impressive increase of applications covering the vast majority of cardiac diseases so that worldwide a significant number of scans, every day, are dealing with practical clinical queries. While the 1.5T technology remains the standard approach for clinical routine in the vast majority of MR centers, technological improvement is supporting the concept that the use of higher magnetic field such as 3.0T can further improve the value of this imaging modality. Despite the fact that the use of 3.0T scanners for routine activity in the cardiologic field is still limited to few specialized centers , we might argue that for 3.0T there is “some bright light at the end of the tube” as the technology appears much more robust than in the recent past. However, it has to be admitted that still there is no evidence that the use of a 3.0T would lead to an improvement of performances and namely to improvement of diagnostic accuracy. In the field of Magnetic resonance Angiography there is already evidence that the improved SNR and CNR are such that 3.0 T scanners are already competitive with respect to the 1.5T ones. The ultrahigh fields still represent challenging research frontiers, and the route toward clinical applications still seems to be very long.



The Figure 1 shows the dramatic improvement of image quality due to advanced shimming procedure to compensate field inhomogeneities. SSFP images. Upper panels without shimming. Lower panels obtained in the same patient after having adopted an advanced shimming procedure. (images provided by Stefano Muzzarelli, Cardiology Department Cardiocentro Ticino, Lugano, Switzerland).

No conflict of interest to declare.

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