Assessment of Myocardial Perfusion Using Cardiac MR: Technical Foundations

Thoralf Niendorf[1,2]

[1)] Berlin Ultrahigh Field Facility (B.U.F.F.), Max-Delbrueck Center for Molecular Medicine, Berlin, Germany
[2)] Experimental and Clinical Research Center (ECRC), Charité Campus Buch, Humboldt-University, Berlin, Germany

Abstract

A growing number of methodological and clinical reports refer to explorations into the assessment and reproducibility of myocardial perfusion using cardiac magnetic resonance (CMR) [1-3]. Realizing the progress, promise and challenges of perfusion weighted CMR this presentation outlines current trends in enabling MR technology tailored for probing myocardial perfusion. For this purpose the basic imaging concepts of first-pass contrast agent bolus perfusion techniques will be outlined. The remaining obstacles to an even broader clinical acceptance of conventional first-pass perfusion will be discussed. Here the focus will be on (i) the limited anatomic coverage achievable while accomplishing one- or two-heart-beat temporal resolution to track the contrast agent passage and on (ii) the limited in-plane spatial resolution commonly used in today's clinical CMR practice which increases the propensity to Gibbs ringing artifacts [4]. Simply speaking, Gibbs ringing artifacts are due to signal truncation and manifest themselves as signal intensity ripples parallel to the blood/myocardium interface and hence might mimic subendocardial perfusion deficits. Gibbs ringing artifacts vanish with increasing matrix size, which would also help to improve the spatial resolution. To reach the goal of (sub)millimeter in-plane spatial resolution, while preserving single-heart-beat temporal resolution, the baseline SNR advantage of high-field imaging can be exploited together with the traits of parallel imaging [5]. Substantial signal-to-noise ratio, contrast-to-noise ratio and overall image quality improvements, as compared to the 1.5 T approach, were noted for first-pass perfusion imaging at 3.0 Tesla [6,7]. In the meantime clinical studies demonstrated that accelerated perfusion weighted imaging yielded image quality superior to that of the conventional approach, primarily as a result of enhanced spatial resolution and the substantial suppression of Gibbs ringing artifacts [8,9]. The ability to produce exquisite in-plane spatial resolution may offer greater diagnostic value for myocardial perfusion assessment and supports an extension of the perfusion assessment to the right ventricle. With sufficient acceleration and imaging speed, perfusion imaging is on the verge for 3D acquisitions that afford whole heart coverage in the single breath-hold [10,11]. With this in mind early applications of 3D perfusion weighted imaging and their clinical implications for explorations into cardiovascular diseases are explored [12]. A concluding section ventures a glance beyond the horizon and explores future directions including massively accelerated perfusion imaging. In this context it is also conceptually attractive to develop alternatives for the assessment of myocardial perfusion using blood as an endogenous marker which can be exploited for myocardial blood oxygenation level dependent [13-15] or for arterial spin labeling based perfusion imaging [16]. The goal here is not to be comprehensive but to inspire the biomedical and diagnostic imaging communities to throw further

weight behind the solution of the many remaining unsolved problems and technical obstacles of perfusion CMR with the goal to transfer MR physics driven methodological advancements into extra clinical value.

References:

1. Coelho-Filho OR, Rickers C, Kwong RY, Jerosch-Herold M (2013) MR myocardial perfusion imaging. Radiology 266: 701-715.
2. Larghat AM, Maredia N, Biglands J, Greenwood JP, Ball SG, et al. (2013) Reproducibility of first-pass cardiovascular magnetic resonance myocardial perfusion. J Magn Reson Imaging 37: 865-874.
3. Gerber BL, Raman SV, Nayak K, Epstein FH, Ferreira P, et al. (2008) Myocardial first-pass perfusion cardiovascular magnetic resonance: history, theory, and current state of the art. J Cardiovasc Magn Reson 10: 18.
4. Di Bella EV, Parker DL, Sinusas AJ (2005) On the dark rim artifact in dynamic contrast-enhanced MRI myocardial perfusion studies. Magn Reson Med 54: 1295-1299.
5. Maredia N, Radjenovic A, Kozerke S, Larghat A, Greenwood JP, et al. (2010) Effect of improving spatial or temporal resolution on image quality and quantitative perfusion assessment with k-t SENSE acceleration in first-pass CMR myocardial perfusion imaging. Magn Reson Med 64: 1616-1624.
6. Gutberlet M, Noeske R, Schwinge K, Freyhardt P, Felix R, et al. (2006) Comprehensive cardiac magnetic resonance imaging at 3.0 Tesla: feasibility and implications for clinical applications. Invest Radiol 41: 154-167.
7. Shin T, Hu HH, Pohost GM, Nayak KS (2008) Three dimensional first-pass myocardial perfusion imaging at 3T: feasibility study. J Cardiovasc Magn Reson 10: 57.
8. Manka R, Vitanis V, Boesiger P, Flammer AJ, Plein S, et al. (2010) Clinical feasibility of accelerated, high spatial resolution myocardial perfusion imaging. JACC Cardiovasc Imaging 3: 710-717.
9. Motwani M, Lockie T, Greenwood JP, Plein S (2011) Accelerated, high spatial resolution cardiovascular magnetic resonance myocardial perfusion imaging. J Nucl Cardiol 18: 952-958.
10. Vitanis V, Manka R, Giese D, Pedersen H, Plein S, et al. (2011) High resolution three-dimensional cardiac perfusion imaging using compartment-based k-t principal component analysis. Magn Reson Med 65: 575-587.
11. Shin T, Nayak KS, Santos JM, Nishimura DG, Hu BS, et al. (2013) Three-dimensional first-pass myocardial perfusion MRI using a stack-of-spirals acquisition. Magn Reson Med 69: 839-844.
12. Motwani M, Jogiya R, Kozerke S, Greenwood JP, Plein S (2013) Advanced cardiovascular magnetic resonance myocardial perfusion imaging: high-spatial resolution versus 3-dimensional whole-heart coverage. Circ Cardiovasc Imaging 6: 339-348.
13. Heinrichs U, Utting JF, Frauenrath T, Hezel F, Krombach GA, et al. (2009) Myocardial T2* mapping free of distortion using susceptibility-weighted fast spin-echo imaging: a feasibility study at 1.5 T and 3.0 T. Magn Reson Med 62: 822-828.
14. Hezel F, Thalhammer C, Waiczies S, Schulz-Menger J, Niendorf T (2012) High spatial resolution and temporally resolved T2* mapping of normal human myocardium at 7.0 Tesla: an ultrahigh field magnetic resonance feasibility study. PLoS One 7: e52324.
15. Friedrich MG, Karamitsos TD (2013) Oxygenation-sensitive cardiovascular magnetic resonance. J Cardiovasc Magn Reson 15: 43.
16. Zun Z, Varadarajan P, Pai RG, Wong EC, Nayak KS (2011) Arterial spin labeled CMR detects clinically relevant increase in myocardial blood flow with vasodilation. JACC Cardiovasc Imaging 4: 1253-1261.