

Simultaneous Measurement of Myocardial Perfusion by Dynamic Contrast Enhancement MR and Ammonia PET

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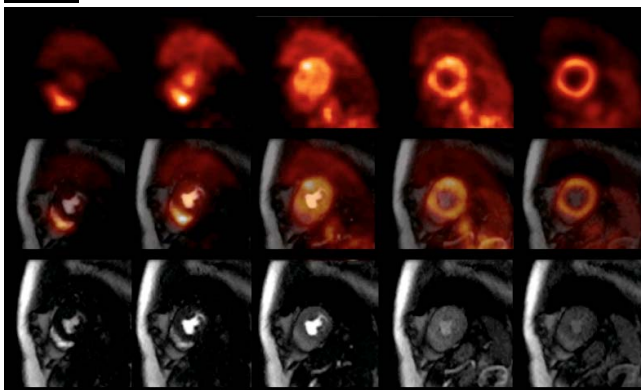
Introduction The assessment of myocardial perfusion has shown to provide high diagnostic and prognostic information for the management of patients with coronary artery disease. Absolute quantification of perfusion remains a challenge for the measurement of myocardial perfusion reserve by a variety of invasive and non-invasive imaging techniques. Previous studies established PET as a noninvasive gold standard for the quantification of myocardial perfusion under rest and stress conditions[1]. Newly developed integrated PET/MR devices are uniquely suited to directly compare perfusion measurements in patients under identical physiological conditions. This study aims to establish a protocol for parallel acquisitions of myocardial perfusion by PET and MR, and to compare simultaneous measurements of myocardial perfusion at rest and during pharmacologic stress.

Methods

Image Acquisition: The cardiac scans were performed on an integrated whole-body 3T PET/MR system equipped with body matrix and spine matrix surface coil sets (Siemens Healthcare, Erlangen, Germany). The overall acquisition scheme is illustrated in Fig 1. Gd-DTPA was injected at 0.05 mmol/kg and 4 mL/s for each stress and rest scan. The acquisitions were ECG gated and performed under free breathing. Motion and surface coil corrected images were generated inline [2]. MR images were obtained using a 2D saturation recovery single-shot gradient echo sequence. After each cardiac trigger, one basal slice (TE= 0.65 ms and TD= 9 ms) was acquired to serve the arterial input function with the linearity of signal intensity vs. Gd concentration demonstrated in phantoms (data not shown) of R_1 up to 30 sec⁻¹. During each ECG interval, two to three short axis slices (TR/TE= 3.24/1.77 ms, TD= 100 ms and FA= 15°) were acquired with in-plane resolution of 2.08 mm and thickness of 8 mm. The ammonia ¹³NH₃ tracer injection was performed as slow bolus over 30 sec. The PET data was acquired in list-mode for 15 mins and attenuation correction (AC) was based on tissue segmentation of Dixon-based MR images acquired prior to the perfusion scans.

Data Analysis: The motion corrected MR images were analyzed by a custom-built MATLAB program. Using T1 maps acquired right before the perfusion scans, the signal intensity was first converted to contrast agent concentration based on the relation of $R_1=R_{10}+r_1 \cdot [Gd]$ with Gd relaxivity r_1 assumed at 3.7 mmol/L/sec at 3T and $S=N \cdot [(1-\exp(-R_1 \cdot TD)) \cdot a^N + (1-E) \cdot (1-a^N)/(1-a)]$, $E=\exp(-R_1 \cdot TR)$, $a=E \cdot \cos\theta$ with N being the number of phase-encoding lines to reach the k-space center. The convolution of a 3-parameter Fermi model [3] as impulse response function with the arterial input function was least-square fitted against the tissue dynamic curve restricted to the first pass portion. The perfusion value was calculated as the initial amplitude of the impulse response function. The PET data was reconstructed into frame rate of 10 sec for the initial 3 minutes followed by longer frames of 30 sec and 60 sec. The PET quantification was performed using a two tissue compartment model with spill-over and partial volume correction [4]. Both analyses were performed by two experienced observers blinded to the results from the other modality.

Results



Ten patients referred for assessment of myocardial perfusion reserve were included. All patients had no previous infarctions document with negative late gadolinium enhancement. Simultaneous rest and stress acquisitions were successfully performed in all cases. Mean resting perfusion for PET was 0.82 ±0.21 ml/min/g (MRI: 0.74±0.24 ml/min/g) and increased under stress conditions to 1.91±0.41 ml/min/g (MRI: 2.06±0.83 ml/min/g). This significant increase in myocardial perfusion yielded a myocardial perfusion reserve of PET: 2.45±0.71 (PET) and 2.73±0.35 (MRI). Linear correlation between PET and MRI resulted in $R^2=0.67$ for the rest and stress perfusion and in $R^2=0.48$ for the perfusion reserve.

Figure 2 (left): Dynamic illustration of ¹³NH₃ PET perfusion (upper row), Gd-DTPA MR perfusion (bottom row) and co-registration of both modalities (middle row) at a mid-ventricular slice.

Conclusion and Discussion PET/MR offers a unique research tool to cross-validate physiologic measurements in humans. Myocardial perfusion estimates using both ammonia PET and first pass DCE MRI techniques match well under rest and stress conditions in patient data. However, it is challenging to achieve the simultaneity under stress physiological conditions given the difference of the tracer injection speed and acquisition length of the two modalities. The complementary information obtained from MR perfusion imaging can potentially be used to combine a low resolution perfusion assessment with full spatial coverage with PET and a high resolution approach in selected slices with MRI and to reduce the radiation dose when using PET only under stress conditions. **References** [1] Ibrahim T. et al. *J Am Coll Cardiol.* 2002; 864-70. [2] Xue H. et al. *Med Image Comput Comput Assist Interv.* 2009; 741-9. [3] Jerosch-Herold M. et al. *Med Phys.* 1998:73-84. [4] Hutchins GD et al *J Am Coll Cardiol.* 1990:1032-42.

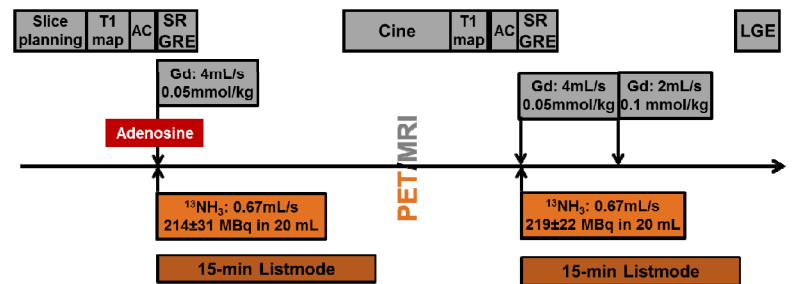


Figure 1. The acquisition scheme of simultaneous PET and MR myocardial perfusion examinations.