Unsupervised Inline Analysis of Cardiac Perfusion MRI

H. Xue[1], S. Zuehlsdorff[2], P. Kellman[3], A. Arai[3], S. Nielles-Vallespin[4], C. Chef D Hotel[1], B. Paniagua[1], C. Lorenz[1], and J. Guehring[1]

[1]Imaging and Visualization, Siemens Corporate Research, Princeton, NJ, United States, [2]CMR Research and Development, Siemens Medical Solutions USA, Inc., Chicago, IL, United States, [3]Laboratory of Cardiac Energetics, National Institutes of Health/NHLBI, Bethesda, MD, United States, [4]MED MR PLM AW Cardiology, Siemens AG Healthcare Sector, Erlangen, Germany

Introduction The quantitative or semi-quantitative analysis of first-pass myocardial perfusion MR time series is still a labor intense process. Reasons include cardiac and respiratory motion and low signal-to-noise ratio (SNR) of T1 weighted images. Typically, motion correction and noise suppression procedures are applied before the generation of analysis results (An illustration of variant perfusion parameters is given in Fig. 1). These processing steps often require substantial user interaction and dedicated expertise [1]. To overcome these disadvantages, we had substantially revised a recently introduced framework of inline perfusion analysis [2] and developed dedicated algorithms for perfusion motion correction, adaptive noise suppression and robust pixel-wise parameter map generation. To maximize the clinical applicability, the framework does not require any user interaction and has been integrated into the inline image reconstruction. The feasibility of proposed techniques was verified by in vivo studies on patients undergoing both stress and rest first pass myocardial perfusion imaging.

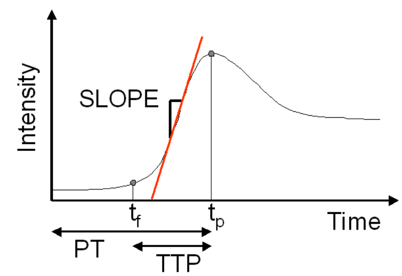

Fig. 1. ***Parameter map calculation.*** *For each pixel the signal-time curve is analyzed and upslope (SLOPE), time-to-peak (TTP) and peak time (PT) calculated.*

Material and Methods ***Sequence Design*:** A perfusion pulse sequence was implemented on a clinical 1.5T scanner (MAGNETOM Espree, Siemens AG Healthcare Sector, Erlangen, Germany) supporting the commonly used imaging modules [2], such as TurboFLASH, TrueFISP and GRE_EPI hybrid as well as temporal parallel acquisition techniques (TGRAPPA and TSENSE). The acquisition of proton density weighted images was also supported for surface-coil induced inhomogeneity correction which is often performed after the motion correction. ***Motion Correction*:** A previously described concatenated motion correction strategy [3] was integrated into the inline processing chain. This method consists of a rigid/affine image registration and a non-rigid motion compensation step [4]. The image at a time point selected for peak signal change during the first pass of contrast agent is used as the template and the images of all other time points are registered into the template coordinate system. The registration is more robust if the slices to be aligned have similar contrast. Therefore, registration is performed consecutively between temporally adjacent images, starting from the template and its direct neighbors (previous and next). This approach has shown robustness against variant pulse sequences and different myocardial anatomies (basal, medial and apical) [3]. ***Noise suppression*:** A wavelet based temporal noise suppression technique was developed and applied to clinical perfusion images on a per-pixel basis. This approach emphasizes preserving important features in the original time-intensity curves (TI curves), while suppressing superfluous fluctuations caused by noise. First, an optimal threshold which minimizes the loss of perfusion signal between filtered curves and unknown truth was estimated using the generalized cross validation (GCV) technique [5] in a pixel-wise fashion, because the GCV method does not require the knowledge of the unknown noise energy. The wavelet coefficients were then filtered using a soft-thresholding technique [6] which has been proven to favor the preservation of underlying signal [6]. ***Parameter Map Calculation*:** A novel robust perfusion map generation algorithm was developed based on the scale-space theory and non-maximal suppression [7]. First, a series of smoothed time-intensity curves are generated with different Gaussian scales. Only the stable features which appear consistently cross the whole scale space are kept and further used to determine the peak and foot of time-intensity curve. To improve the robustness of upslope estimation, a gradient magnitude weighted linear fitting strategy is employed. A scatter interpolation strategy is finally applied to fill the 'holes' which often appear on the noisy background where the algorithm can fail to find stable features cross the scale space. ***Inline Perfusion Analysis*:** All the processing steps including motion correction, noise suppression, and map generation were implemented within the Image Calculation Environment (ICE) of the MRI scanner. As a result, raw perfusion datasets are automatically processed using the proposed techniques without any user interaction. As recent image reconstruction computers are equipped with multiple processors, the entire processing chain was implemented to support concurrent calculation via simultaneous multi-threading. The original time series, the corrected time series, and the derived parameter maps are stored in the image database and are typically available in less than 1 minute after the data acquisition is finished.

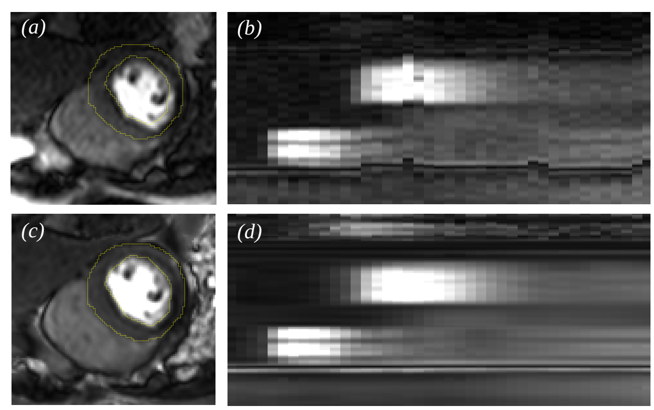

Fig 2. ***Inline process of cardiac perfusion datasets.*** *(a) A 2D slice overlaid with myocardium contour extracted from the template slice; (b) The intensity-time relationship for this series. After motion compensation and noise suppression: (c) the same slice as (a) and (d) the corrected intensity-time relationship.*

Patient Study In a patient study, stress and rest MR first pass perfusion images have been obtained using a saturation prepared TrueFISP sequence (256×192 data matrix, 60 heartbeats, TI = 100ms, TE/TR = 1.2ms/2.4ms, TGRAPPA acceleration factor 2) and all processing results have been successfully generated.

Results The processing time for a typical first pass perfusion dataset is ~40s on an image reconstruction computer equipped with 2 dual-core AMD Opteron CPUs. As shown in the patient study (Fig. 2), the proposed processing pipeline effectively corrected subject motion during the image acquisition and noticeably suppressed imaging noise. The generated parameter maps (Fig. 3) clearly show the hypo-enhanced regions, which are consistent with the signal attenuation on the original and motion corrected images.

Discussion The fully automated generation of corrected time series and semi-quantitative perfusion parameter maps combined with clinically acceptable processing time are in favor of the clinical acceptance of proposed techniques. However, the diagnostic value of generated results needs to be evaluated in further clinical studies. The parameter maps have to be compared with other clinically established approaches and the correlation between different techniques needs to be established.

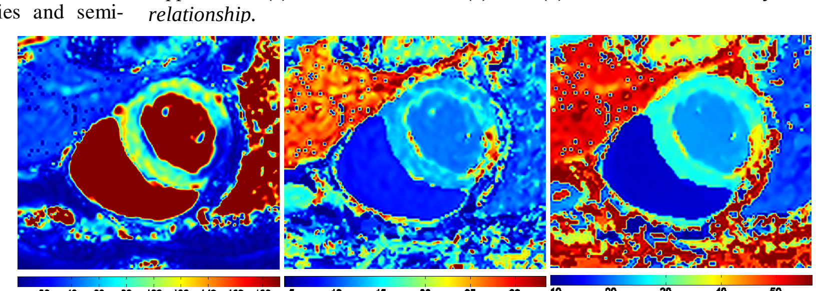

Fig 3. ***Parameter map for a patient with stress perfusion deficit.*** *In all parameter maps (from left to right: SLOPE, TTP, and PT) the hypo enhanced region is depicted.*

References **[1]** Jerosch-Herold M *et al.*, Mag Reson Med 19: 759-770 (2004) **[2]** Zuehlsdorff S *et al.,* Proc Intl Soc Mag Reson Med 16: 1006 (2008) **[3]** Xue H *et al.*, Proc Intl Soc Mag Reson Med 16:4116 (2008) **[4]** Chefd'hotel C *et al.*, IEEE ISBI: 753-756 (2002) **[5]** Jansen M *et al.,* Signal Proc. 56(1): 33-44 (1997) **[6]** Donoho L, IEEE IT 41(3):613-627 (1995) **[7]** Linderberg T, IJCV 30(2): 117-154 (1998)