Improvement of Quantification of Myocardial First-Pass Perfusion: A Wavelet Denoising Method

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Introduction

Quantification of myocardial blood flow (MBF) with first-pass perfusion imaging is rapidly becoming an important tool in the study of coronary artery disease. By applying MBF quantification procedures to the individual pixels of MR images, MBF maps can be generated that may provide valuable information and easy diagnosis about regional differences in myocardial perfusion. Because the SNR of an individual pixel is in general lower than that of a ROI, MBF values calculated in this way tend to be less reliable than values obtained using the ROI-based approach. In this paper, we show that the accuracy of pixel-by-pixel maps can be significantly increased through the use of a wavelet-based denoising method.

Materials and Methods

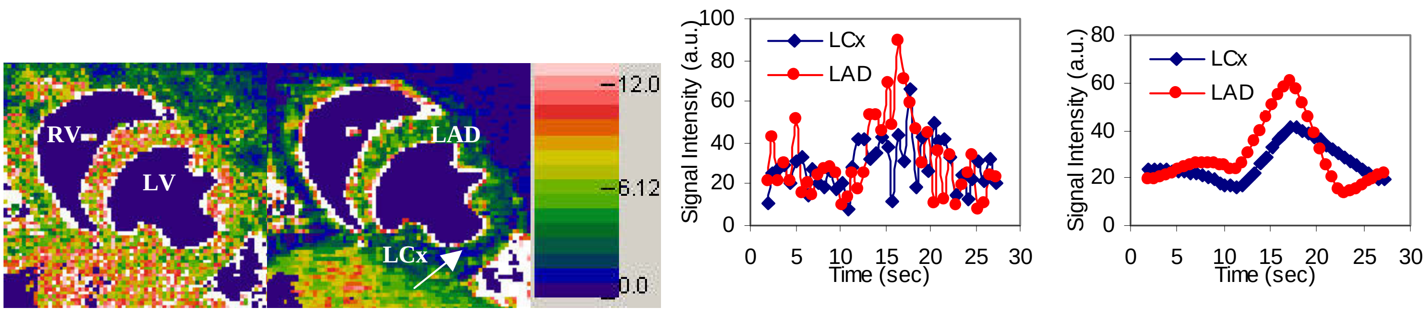
Wavelet Denoising Method We used an image denoising procedure that takes advantage of both spatial and temporal correlation between data in the first-pass signal-time curve. The method is built from a multi-resolution decomposition of a series of images, and is similar to techniques that have already been used successfully for denoising MR images [1,2]. To smooth a sequence of images, the images are first converted into a single, linear array of values. Next, the images are broken down into a series of localized waves of varying frequencies. This is done with a lifting implementation of a 9,7 biorthogonal, 3D wavelet transform, and is applied to the data. Each wavelet component's contribution to the overall image will be examined, and wavelet components that are most likely to represent noise will be removed from the image. This will be accomplished through "thresholding," a procedure in which wavelet components with coefficients smaller than a certain threshold value are removed. After the universal threshold has been applied, the wavelet transform will be inverted in the row and column dimensions. The resulting sequence represents the wavelet coefficients in the time dimension. All wavelet components with support of less than one second and with a coefficient less than a certain value will then be removed to ensure that mean curves are very smooth over time. Finally, the inverse wavelet transform will be performed in the time dimension to reconstruct the series of denoised images.

MR Imaging Three mongrel dogs with induced coronary artery stenosis were scanned for the assessment of regional MBF. The stenosis was introduced by an insertion of teflon ring (70% diameter narrowing) in the left circumflex (LCx) coronary artery. All studies were performed in a 1.5 T Siemens Sonata system. For each dog, the image session consisted of studies at rest (baseline) and during pharmacological induced vasodilation. The latter was accomplished by an intravenous infusion of a dose of 0.15 mmol/kg/min of dipyridamole for 4 min. Only one short-axis slice of left ventricle (LV) was scanned. In each study, MR first-pass perfusion data sets were acquired with a bolus injection of an intravascular contrast agent Gadomer at a dose of 0.015 mmol/kg. Color microspheres were injected simultaneously to obtain gold-standard MBF values.

Data Analysis MBF maps were generated from both the raw and denoised images by applying an established B-spline deconvolution-based technique to each pixel [3]. In these maps, four ROIs were drawn on the superior, lateral, inferior, and septal regions of the LV myocardial wall. Average MBF values obtained through the MR technique were then compared to MBF results obtained via microspheres.

Results

In our experience, for relatively low SNR (between 5 and 15), the procedure increased SNR, on average, by a factor of 5. For pixels with a relatively high SNR (15 to 22), the SNR was enhanced by a smaller factor of 2 to 3. Figure shows MBF maps during the vasodilation with and without denoising the raw data sets, clearly demonstrating better visualization of LCx defects (arrows) after performing denoising. The signal intensity time curves of a small region in LAD (normal region) are also shown. Correlation of MBFs measured by MR with microsphere results indicates a dramatic improvement with denoising method (The R^2 improved from 0.24 to 0.86).



(a) (b) (c) (d)

Figure. MBF maps obtained during the vasodilation in a dog with 70% area stenosis in its LCx. The SNR of raw images on a LAD region (superior) at baseline was 2.68. Image (a) shows a relatively uniform MBF distribution, but image (b) after denoising reveals LCx perfusion defects, particularly in the subendocardial region (white arrow). In addition, MBF was significantly overestimated in (a). These findings were confirmed by microsphere data. The signal-time curves of two 3-pixel regions on both LAD and LCx segments demonstrate noisy data without denoising and much smoother patterns after denoising. The color bar indicates the MBF in unit of ml/min/g. LAD = left anterior descending coronary artery.

Conclusion

It was found in this study that the wavelet denoising method provided a significant increase in the quality and accuracy of myocardial blood flow maps.

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Reference

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