Improvement of Myocardial BOLD Imaging By A Hybrid Median Filter Denoising Method

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INTRODUCTION

Myocardial oxygen extraction fraction (OEF) indicates the balance between myocardial oxygen supply and demand and reflects the myocardial functionality. Using deoxyhemoglobin as an endogenous contrast agent, we have demonstrated a novel method to assess the myocardial OEF [1] with blood oxygen level dependent (BOLD) imaging. Due to the cardiac and respiratory motion, myocardial T_2 was only acquired within a limited cardiac period in a short breathhold, which substantially limited the signal-to-noise ratio (SNR) of T_2-weighted images. The aim of this study was to improve the SNR of T_2-weighted images, and thus the quality of T_2 maps via a newly developed denoising method. The effect of the denoising on the accuracy of T_2 maps and derived OEF maps was evaluated in a number of normal dogs.

MATERIALS AND METHODS

Image Denoising Method MRI noise is signal-dependent and has an approximate Rician distribution, which makes the class of nonlinear filters (such as median filters), an attractive denoising algorithm. However, nonlinear filters fail to provide the same degree of smoothness in homogeneous regions as linear filters (e.g., moving average filters). In order to overcome the drawbacks of standard median filter and preserve the advantages of linear filter, we have synergistically combined the linear and median filter into a hybrid median filter (HMF) that adaptively provides good bias and variance properties [2]. Besides the variable of filter length (window size), a second variable was used to control the progressive cascade of HMFs, in which the shorter-length filters attenuate noise spikes near edges and the longer filters provide attenuation in flat regions [3]. Compared with wavelet denoising [4], the HMF denoising is simple to use and can efficiently remove impulse noise (outlier) that is frequently present in myocardial T_2 map.

MRI Studies All studies were performed on a 1.5 T Siemens Sonata system. A multi-cylindrical phantom consisting of a variety of solutions of Gd-DTPA (T_2 ranging from 40 to 100 ms) was scanned with a 2D segmented fast spin echo sequence with three echoes at TEs of 7.3, 43.8, and 58.4 ms, as in the *in vivo* dog study. The SNR of the T_2-weighted phantom images was adjusted to match the SNR range of the in vivo images. A standard spin-echo sequence was then used with different TEs to provide the true T_2 values of the phantom. For the animal study, five normal dogs (n=5) were used to assess the change in their global myocardial T_2 and OEF values. The dogs were scanned with the same fast spin echo sequence used in phantom study. A single slice short-axis view of left ventricle (LV) was acquired at mid-ventricular level. Each dog was scanned at rest (baseline, repeated 4 times) and during pharmacologically induced vasodilation, which is induced by an intravenous infusion of dipyridamole at 0.15 mmol/kg/min for 4 min. During vasodilation, the data was acquired at 10min, 20 min, and 30min after the injection of dipyridamole. Blood samples were collected simultaneously with the MRI scan from both the descending thoracic aorta and coronary sinus (AV sampling) to measure the oxygen contents and thus determine the global myocardial OEF invasively.

Data Analysis The proposed denoising method was applied on the T_2-weighted images. T_2 maps of the phantom were generated before and after denoising, with different denoising parameters; and then spatial variations, accuracy and reproducibility of T_2 maps were assessed with the actual T_2 values. The denoising parameter that provided the most SNR and T_2 accuracy improvement was determined for the following animal study. Myocardial T_2 maps were then calculated before and after denoising with a specific denoising parameter. A ring covering 50% of LV wall was drawn on the T_2 map for the quantification of global T_2. Myocardial OEF was then calculated with our previously developed methods [1]. Calculated OEF values were analyzed via correlation with results obtained through AV sampling to determine the accuracy of T_2 measurements *in vivo* indirectly.

RESULTS

In the phantom study, we found that a median filter followed by an HMF with a window size of 5 can provide the most spatial variation and accuracy improvement (spatial variation decreased 67%, accuracy increased 26%, reproducibility remained the same). In the dog study, with the denoising parameter determined from phantom study, spatial variation of T_2 maps at rest was improved 44% (Fig. 1 (a) vs. (b)) whereas reproducibility changed little. For the calculated OEF values, after denoising, a spatial variation improvement (Fig. 1 (c) vs. (d)) and a closer correlation between OEF measured by MR and AV sampling were reached (Fig.2, R^2 slightly improved from 0.77 to 0.83).

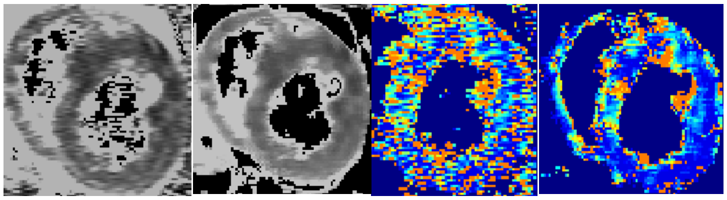

Fig.1 (a) T_2 before denoising; (b) T_2 after denoising; (c) OEF before denoising; (d) OEF after denoising

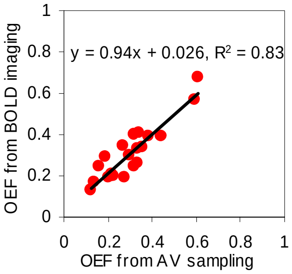

Fig. 2 Correlation of OEF measured from AV sampling and denoised MRI

CONCLUSION

We have demonstrated that HMF is an effective image post-processing technique for efficiently denoising images and improving the quality of myocardial T_2 maps for myocardial BOLD imaging. Although the accuracy of OEF calculation was improved marginally, this method is likely to help the detection of regional difference in myocardial oxygenation distribution or perfusion in diseased hearts.

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