Three-dimensional Super-Resolution Technique for Whole-Heart Coronary MRA by Utilizing Graphical Processing Unit

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Target audience

Clinicians and scientists who aim to expand the use of coronary magnetic resonance angiography (MRA) for non-invasive diagnosis of coronary artery disease

Purpose

Whole-heart coronary MRA (WHCMRA) allows for noninvasive assessment of coronary artery disease. However, several technological constraints restrict image resolution of WHCMRA. In the brain MRI, a learning-based super-resolution (SR) technique has emerged as a method to increase image resolution and signal-to-noise ratio (SNR) (Rueda A, *et al.* Med Image Anal. 113-32 2013. Poot DH, *et al.* Med Image Comput Comput Assist Interv. 615-22 2010.). Our recent study demonstrated that two-dimensional (2D) learning-based SR technique can improve image resolution and SNR of WHCMRA. However, 2D SR technique cannot increase the through-plane resolution. While 3D SR technique can provide further increase in the through-plane resolution and SNR, it requires enormous computational time. Recent Graphics Processing Units (GPUs) allows for massive parallel processing that may considerably reduce the computational time to the level that can be accepted for clinical use. The purposes of this study were to develop a 3D SR technique optimized for WHCMRA by utilizing GPU, and to evaluate the usefulness of 3D SR technique for improving the image quality of WHCMRA.

Methods

Free-breathing WHCMRA images were obtained in 62 patients with known or suspected coronary artery disease by using a 1.5T MR system, 32-channel cardiac coils and a steady state free precession acquisition. A learning-based SR processing consists of two steps including generation of a dictionary describing relationship between low-resolution (LR) image patches and high-resolution (HR) image patches, and construction of SR images by embedding optimal patches selected from millions of patch-pairs in the dictionary. SR post-processing was performed by using a workstation equipped with two Intel Xeon Eight-Core CPUs at 2.6 GHz, 64 GB of RAM and four GPUs (NVIDIA GeForce GTX 780 Ti). Each GPU has 3072MB of memory and 2880 CUDA cores running at clock speed of 875 MHz. For evaluating the advantages of the 3D SR processing, WHCMRA images with 0.6x0.6x0.75 mm resolution were reconstructed from the down-sampled WHCMRA images (1.2x1.2x1.5 mm) by using 3D SR technique, 2D SR technique and 3D bicubic interpolation. The source WHCRA images with 0.6x0.6x0.75 mm resolution were used as reference standard to evaluate the fidelities of those reconstructed images.

Results

With Xeon Eight-Core CPUs, 3D SR processing of WHCMRA required the mean computational time of 4 h and 41.1 min +/- 32.8 min per patient. In contrast, the mean computational time per patient considerably reduced to 45.5 min +/- 11.6 min ($P < .001$) by utilizing 4 GPUs. As shown in Figure 1, the image quality of WHCMRA was substantially improved with 3D SR processing. The root mean square error, the peak signal to noise ratio and the structural similarity index between 3D SR WHCMRA images and the source images were 2.85, 23.5 dB, 0.984, being significantly greater than those values for the 2D SR technique (3.20/ 22.7 dB/ 0.983, $P < .001$) and 3D bicubic interpolation (3.59/ 20.6 dB/ 0.980, $P < .001$). Although 2D SR approach exhibited significantly improved SNR as compared with 3D bicubic interpolation (62.4 +/- 11.3 vs. 50.2 +/- 14.8, $P < .001$), the 3D SR approach proved further improvement in SNR (65.8 +/- 11.2, $P = .039$ compared with 2D SR).

Discussion

While 3D SR technique not only increases the image resolution but also improves the image quality by reducing the noises and the blurs, lengthy processing time precludes the use of this technique in clinical practice. The parallel implementation of recent GPUs (total 11520 CUDA cores) will permit the use of the 3D SR technique in clinical routine diagnosis.

Conclusion

The 3D SR technique developed in this study can provide high-resolution WHCMRA images with improved fidelity and SNR compared with the 2D SR approach. The prolonged computation time required for the advanced 3D SR processing can be overcome by using parallel processing with recent GPUs. Further study is warranted to determine if 3D SR approach can improve the diagnostic performance of WHCMRA for the detection of significant stenosis in the coronary arteries.

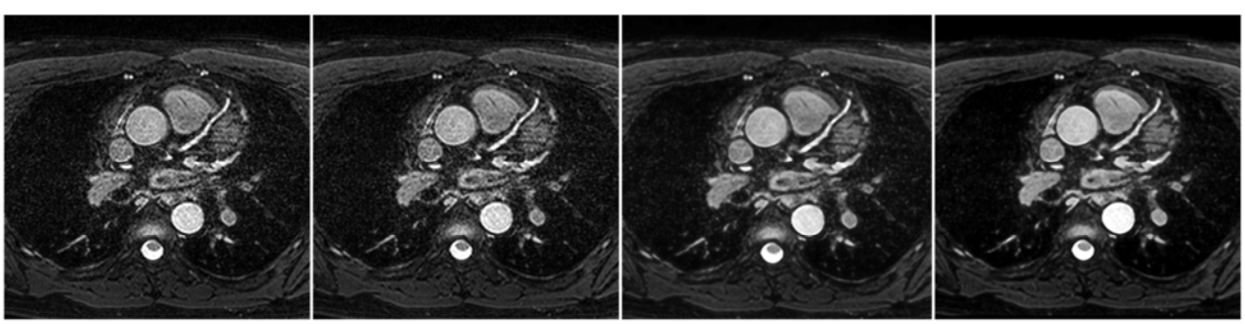

Figure 1 Source MRA image (512x512x80) | Reconstructed Image by 3D bicubic interpolation | Reconstructed Image by 2D SR technique | Reconstructed Image by 3D SR technique