Superresolution improves MRI cortical segmentation with FACE

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Introduction

Brain cortical surface extraction from MRI has applications for measurement of gray matter (GM) atrophy, functional mapping, source localization and preoperative neurosurgical planning. Accurate cortex segmentation requires high resolution morphological images and several methods for extracting the cerebral cortex have been developed during the last decade (Dale 1999, Kim 2005, Eskildsen 2006). In many studies, the resolution of the morphological image acquisition sequence is chosen to be relatively low (~1mm^3) due to time and equipment constraints. To improve segmentation accuracy, such low resolution images can be upsampled using various interpolation techniques. However, many interpolation methods lead to blurred images where high frequency information (e.g., edges) is badly reconstructed. To overcome this issue, superresolution methods have been proposed (Manjón 2010a), that have the ability to effectively increase the image resolution while preserving sharp features of the underlying anatomy. In this study, we investigated the effect of applying superresolution as proposed in (Manjon 2010a) to the accuracy of cerebral cortex segmentation.

Methods

Ten T1-weighted high-resolution (HR) MRI scans were acquired from healthy volunteers on a Philips Achieva 3T system using a 3D fast gradient echo SENSE sequence with TR/TE=9.5/4.6 ms, 8° flip angle, FOV=240 mm, 480×480 matrix, and a slice thickness of 0.5 mm.

Fig. 1 shows the processing steps. Images were denoised using the SANLM filter (Manjon 2010b), bias field corrected using N3 (Sled 1998) and intensity normalized. Linear registration (Collins 1994) to MNI space was performed using a HR version of the MNI152 average non-linear template (Fonov 2011) followed by a brain extraction using BEaST (Eskildsen 2012). Low resolution images (LR) were created by downsampling the denoised HR images to 1 mm isotropic voxel sizes. HR images were "reconstructed" by two different methods: i) using B-spline interpolation (BS), and ii) using superresolution (SR) (Manjón 2010a, Fig. 2). LR, BS and SR images were normalized using the bias fields, transformations and brain masks calculated for the original images. Finally, Fast Accurate Cortex Extraction (FACE) (Eskildsen 2006) was applied to all images to obtain surfaces delineating the cortex (Fig. 3).

The cortical surfaces from the LR, BS and SR images were compared to cortical surfaces from the original HR images (ORG) by calculating the RMS and the Hausdorff distance between the surfaces.

Results

The resulting SR images have sharper features than the BS images and the intensity differences are smaller (Fig. 2). Surfaces from the LR images clearly lack the subtle features found in the surfaces from the ORG images (Fig. 3), while surfaces from BS and SR images regain these features. Though differences between BS and SR surfaces are hard to observe directly, the error maps clearly indicate higher errors in the BS surfaces.

The WM surface errors decrease significantly with the construction of higher resolution images for both BS ($p=0.003$) and SR ($p<0.001$) (Fig. 4). The GM surfaces are also improved, however, only significantly with the SR method ($p<0.001$). Using the SR method improves the reconstruction accuracy significantly compared to the BS method for both WM ($p=0.020$) and GM surfaces ($p<0.001$). While increasing the resolution with either improves the Hausdorff distance over the LR image, no difference between BS and SR was detected.

Conclusion

Increasing the resolution of MRI images improves the accuracy of cortical surface based segmentations. Our results show that using the superresolution method provides sharper features and results in higher segmentation accuracy than using upsampling with B-spline interpolation. Superresolution methods can advantageously be used for reconstructing the cerebral cortex and can potentially reveal subtle patterns otherwise hidden where circumstances restrict the acquisition of native high resolution images.

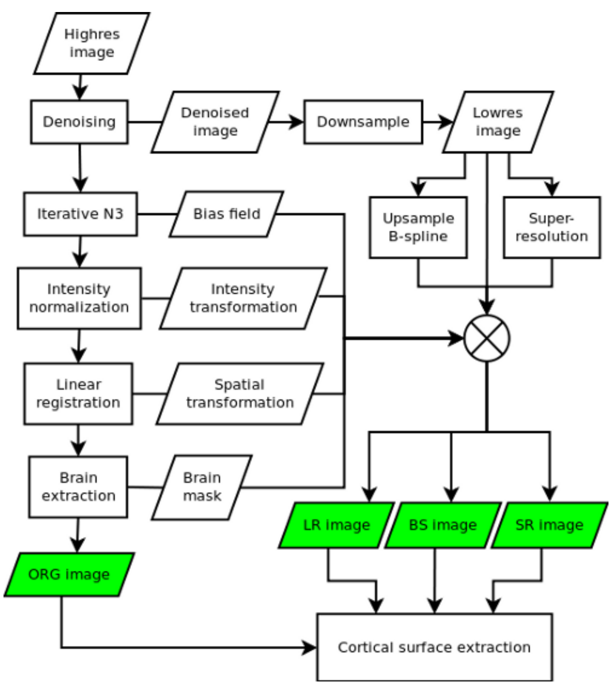


Figure 1. Processing steps for normalizing high resolution image (ORG) and generating artificial high resolution images using B-spline interpolation (BS) and superresolution (SR).

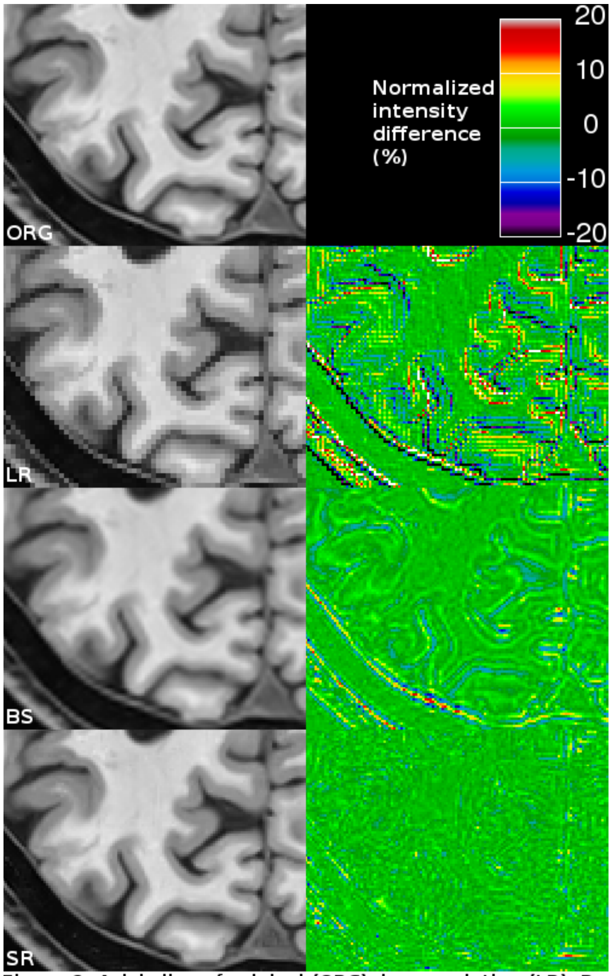


Figure 2. Axial slice of original (ORG), low resolution (LR), B-spline interpolated (BS) and superresolution (SR) images with corresponding intensity error map.

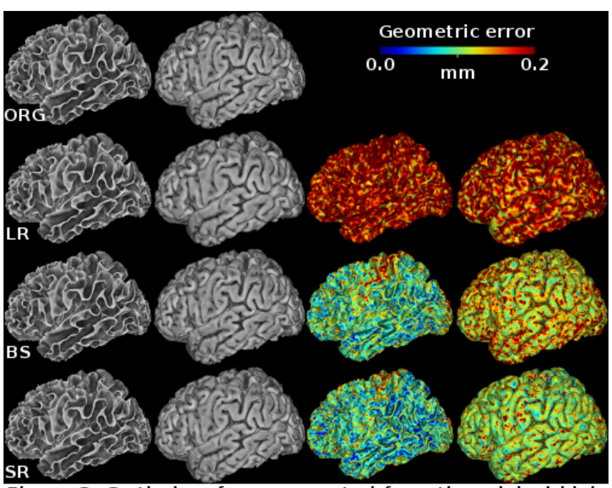
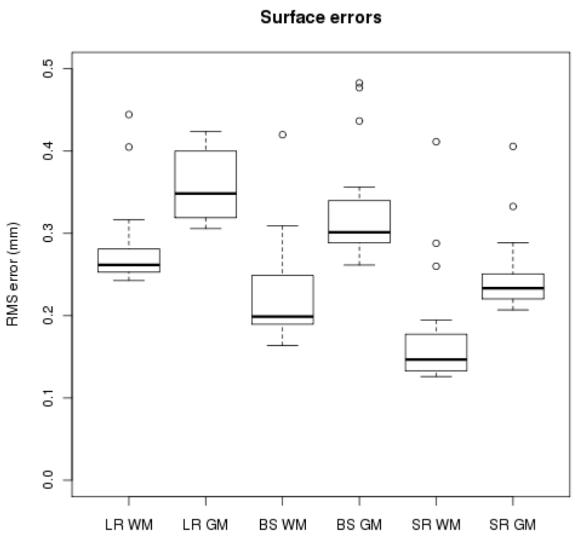


Figure 3. Cortical surfaces generated from the original high resolution image (ORG), the low resolution image (LR), the B-spline interpolated image (BS) and the superresolution image (SR) with corresponding geometric error maps.



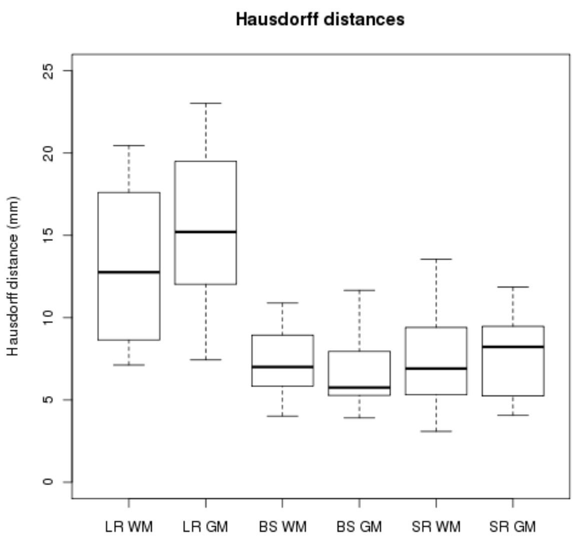


Figure 4. Geometric surface errors and Hausdorff distances for low resolution images (LR), B-spline interpolated images (BS) and superresolution images (SR) for WM and GM surfaces (pooled left and right hemisphere).

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