Optimizing N3 parameters leads to better segmentation accuracy on 3T scanners

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Introduction. Intensity non-uniformity can have detrimental effect on the accuracy of automated measurements of brain structures and can often be corrected only retrospectively. Among existing correction approaches, the nonparametric non-uniformity intensity normalization method N3 (1) is one of the most frequently used. However, at least one recent study (2) suggested that its performance on 3T scanners with multichannel phased-array receiver coils can be improved by optimizing a parameter that controls the smoothness of the estimated bias field. The present study not only confirms this finding but also demonstrates the beneficial effect of reduced to 30-50mm parameter values (default value is 200mm) on the quality of white matter surface estimation and reliability of cortical thickness and subcortical volume measurements.

Methods. We scanned 30 subjects on a head-only Siemens Allegra 3T scanner (TR=2250.00 ms, TE=2.60 ms, TI=2.60 ms, FA=9 degrees, resolution 1x1x1.1mm^3) and 13 subjects on a full-body Siemens Tim Trio 3T scanner (TR=2530.00 ms, TE=1.64 ms, TI=1200.00 ms, FA=7.00 degrees, resolution 1x1x1mm^3). The volumes were processed by Freesurfer (FS) segmentation pipeline (http://surfer.nmr.mgh.harvard.edu/) and the resultant GM/WM output, edited by an expert, was used as ground truth. The subjects scanned on the Allegra scanner were further subdivided into data set 1 (15 subjects) which required little or no editing of FreeSurfer segmentation results and data set 2 (15 subjects) which required substantial manual editing. We also scanned 8 healthy volunteers within short interval on Siemens Allegra 3T and Siemens Tim Trio 3T to evaluate the reliability of segmentation performance.

We conducted a series of experiments to evaluate the effect of changing N3 smoothing distance from 30 to 200mm on the quality of intensity inhomogeneity correction, accuracy of the white matter surface segmentation and reliability of cortical thickness and subcortical structures volume measurements. The quality of nonuniformity correction was evaluated based on the coefficient of variation of white matter, CV(WM). The white matter surface accuracy was measured using a modified Hausdorff distance, designed to separate underestimation and overestimation errors. The reliability of the cortical thickness measurements was evaluated using intraclass correlation coefficient (ICC) (3) and the mean absolute thickness difference (4). Reliability of the subcortical structures was estimated using ICC and the percentage of volume change (5).

Results. Our results confirmed Boyes' findings that the smaller smoothing distances lead to better inhomogeneity correction; the best correction was achieved for smoothing distance of 30mm for both Allegra and Tim Trio scanners.

Smaller smoothing distances reduced the WM surface underestimation and had no effect on the WM surface overestimation. We identified eight cortical regions that were consistently underestimated in data set 3 when smoothing distance of 200mm was used. Four of these regions (entorhinal, fusiform, inferior temporal, and temporal pole) showed statistically significant reduction when smoothing distances of 30mm and 50mm were used (corrected $p<0.05$), see Fig 1. Underestimation was also reduced in the other four regions, although reduction was not statistically significant. There was no effect on the rest of the cortical regions (Fig 1).

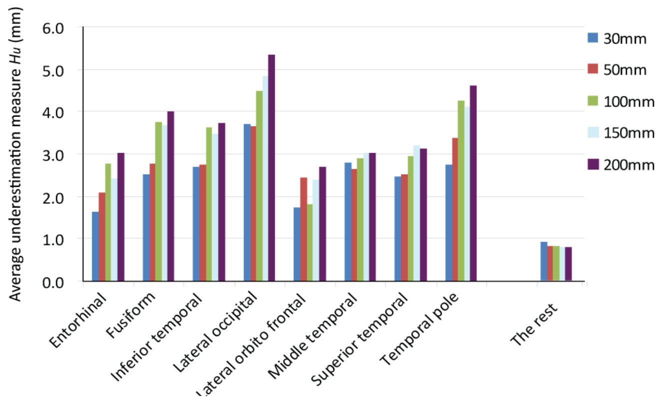

Fig. 1. Underestimation measures under varying N3 smoothing distances for eight selected regions and average of the rest regions.

Smaller smoothing distance also led to better reliability of segmentation performance. The effect was especially large for cortical thickness measurements on Allegra data, where the average ICC reliability and mean absolute thickness difference (Δt) over all cortical structures was improved from (ICC= 0.327and E=0.104mm) at 200mm to (ICC=0.487 and E=0.067mm) at 30mm. This effect can be visually observed using scanner plots of repeated thickness measurements (Fig 2). The effect on within Tim Trio scanner reliability (reduction from E=0.07mm to E=0.06mm) and between scanner reliability (reduction from E=0.156mm to E=0.135mm) was less pronounced. The change in N3 parameter had little effect on reliability of subcortical volume measurements, with only one structure (pallidum) significantly improving reliability on Tim Trio scanner.

The mean absolute thickness difference of cortical measurements on Allegra scanner (0.067mm) was almost the same as that of Tim Trio scanner (0.06mm) when smaller smoothing distances of 30-50mm were used, suggesting that head-only scanners can reach the same reliability as full-body scanners when properly corrected for intensity nonuniformity.

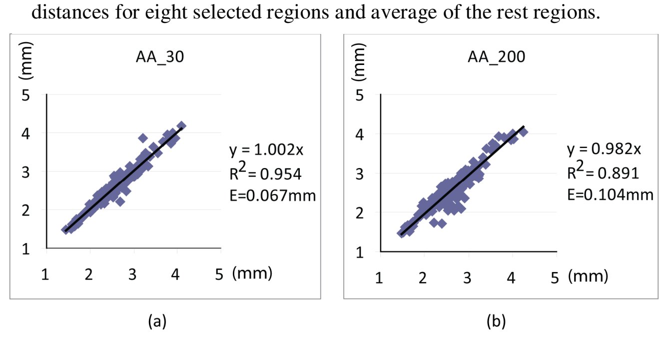

Fig. 2 . Scatter plots of regional cortex thicknesses measured within Allegra scanner with smoothing distances 30mm and 200mm; E represents the mean absolute thickness difference.

Conclusion. Reducing smoothing distance of N3 from default 200mm to 30-50mm significantly improves not only the quality of intensity inhomogeneity correction but also the accuracy and the reliability of brain tissue segmentation. The findings promise to increase the feasibility of longitudinal neurological studies based on the cerebral cortex thickness and cortical structures.

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