Investigation of brain segmentation with FIRST by using different hybrid contrasts and registrations

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TARGET AUDIENCE – Researchers interested in brain segmentation.

PURPOSE – Automated brain segmentation is required to quantify volumes and to characterize shapes of brain structures in large-cohort clinical studies. Among the non-commercial tools, FMRIB's Integrated Registration and Segmentation Tool (FIRST)[1] is one of the most popular used. FIRST is a model-based subcortical brain segmentation tool and utilizes the shape and intensity of the structures of interest on T_1-weighted (T_1w) MR images. With its default pipeline, the affine registration of the individual T_1w data to MNI space is performed first, and then the segmentation is done for every deep gray matter structure, based on the Active Shape and Appearance Models using T_1w training data. Image contrast and registration are two important issues that determine the success of the FIRST segmentation. Therefore, the purpose of this study was to investigate automated segmentation of deep gray matter (DGM) nuclei using FIRST depending on image contrast and registration accuracy of the individual data to MNI space.

METHODS – *Data acquisition:* Data were acquired from seven healthy volunteers (21–41 years) on a 3T whole-body MRI scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany). The local ethics committee approved the experiment and informed written consent was obtained from each recruited subject. The T1w data was acquired with a magnetization prepared rapid gradient echo (MP-RAGE) sequence using the following sequence parameters: TE=3.03 ms, TR=2300 ms, TI=900 ms, FA=9°, isotropic voxel size of 1 mm. Acquisition parameters of the dual-echo gradient echo (GRE) acquisition were: $TE_1/TE_2/TR$=12 ms/40 ms/46 ms, FA=20°, and a voxel size of 0.47 x 0.47 x 0.94 mm^3. *Data processing:* The signal intensity of the T_1w images was normalized so that the intensity value of white matter (WM) was centered on the numerical value of 110. GRE data were used to compute susceptibility maps (QSM) by employing sophisticated harmonic artifact reduction for phase data (SHARP)[2] and homogeneity enabled incremental dipole inversion (HEIDI)[3].

The effect of image contrast on the performance of FIRST's segmentation was studied by generating hybrid contrast (HC)[4] images by combining T_1w images and QSM due to the exquisite DGM contrast on the susceptibility maps[5]. Firstly, the susceptibility maps were registered to the T_1w data using a rigid body model. Secondly, volumes-of-interest (VOI) were manually defined for cortical gray matter, WM, CSF, and DGM nuclei (caudate nucleus, globus pallidus [GP], putamen, accumbens, hippocampus, thalamus) in the T_1w images and susceptibility maps of all subjects, as well as in FSL's MNI atlas. Thirdly, the mean intensity of the VOIs was determined for all three image types and was used in a least-square (LS) approach to calculate coefficients *a* and *b* for combining T_1w and susceptibility images, respectively, to yield a contrast similar to that of FSL's MNI atlas. The image contrast was then modified by adjusting the susceptibility weighting with the coefficient λ according to

$HC = a*T_1w + \lambda*b*QSM$.

To investigate FIRST's segmentation performance depending on the accuracy of registration of the individual T_1w data sets to MNI space, they were registered non-linearly to the FSL MNI atlas using ANTs (advanced normalization tools)[6]. Using the non-linearly registered data sets as the starting point, misalignment was mimicked by modifying the initial affine matrix that was used to initialize FIRST in order to induce misalignments in translation, rotation, and scaling. This procedure was performed along all three spatial directions. FIRST was applied subsequently on the original T_1w, the hybrid contrast, and misaligned images. The accuracy of the FIRST segmentation on the DGM structures was analyzed using Dice index and false negative rate (FNR)[7], compared to the manually defined VOI.

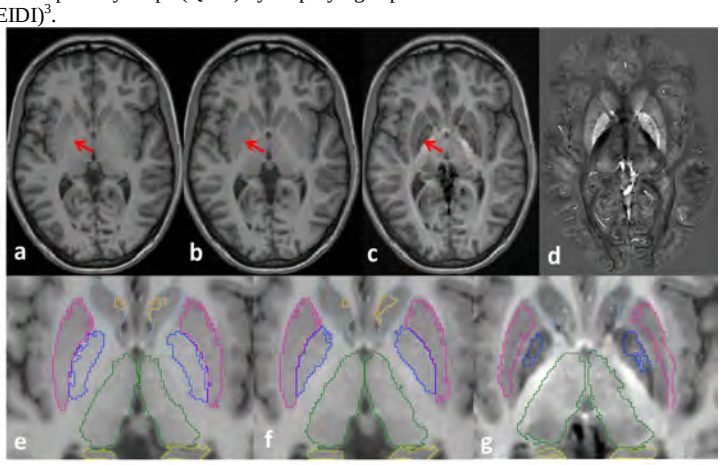

Fig. 1: Different image contrasts and the corresponding segmentation results. a: original T1w image, b: LS-hybrid contrast image (λ=1), c: LS-hybrid contrast image with increased susceptibility weighting (λ=5), d: susceptibility map, e-g: FIRST segmentation of image a-c, respectively.

RESULTS – Fig. 1 demonstrates the results of FIRST segmentation using different image contrasts. Combining the original T_1w image (Fig 1.a) and the susceptibility map (Fig 1.d) with weighting coefficients of 1.67 and -145.28 resulted in the hybrid contrast image (Fig 1.b). Increasing the susceptibility weighting, a visually improved contrast of the DGM was obtained (Fig 1.c) as exemplified by the improved discrimination of the GP from the surrounding tissue (see red arrow). Fig 1.e-g show corresponding FIRST segmentation results, where the segmentation on Fig 1.f outperforms the others, especially for the GP. The quantitative analysis of FIRST's segmentation based on different weighting coefficients (λ) is summarized in Fig. 2 for all 7 subjects. For λ less than 1, segmentation accuracy does not substantially change (Fig 2.a). The FNR, a measure to judge wrongly segmented voxel, decreases for λ values between 0 and 5. The high Dice index and rather low FNR at λ=1 suggests that this hybrid contrast improves segmentation accuracy. Fig 3 summarizes the FIRST segmentation results with rotational, scaling and translational misalignment. With increasing translational and rotational misalignments, segmentation accuracy deteriorates almost linearly. Similarly, the segmentation accuracy decreases if the scaling factor deviates from 1.

DISCUSSION & CONCLUSION – Using a hybrid contrast based on T1w data and quantitative susceptibility maps as input for FIRST yields robust and accurate segmentation results. However, the weighting coefficients for T1w and susceptibility should be selected very carefully. A visually better contrast does not always guarantee a better segmentation (Fig 1.c&g) as FIRST is based on T1w training data. Special care, however, should be taken for the initial step, the registration of the individual data to MNI space, in order to obtain accurate segmentation results.

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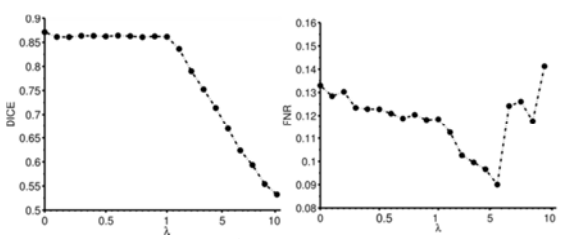

Fig. 2: Quantitative analysis of FIRST's segmentation result on the basis of different image contrasts across 7 subjects. Left: DICE coefficient as a function of λ. Right: FNR as a function of λ.

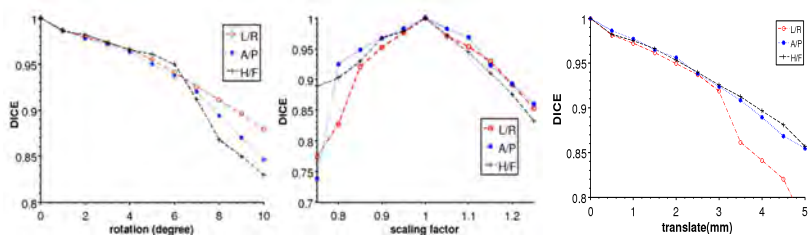

Fig. 3: Influence of misaligned registration on FIRST's segmentation results. Left: Dice coefficient as a function of the rotational misalignment. Middle: Dice coefficient as a function of the scaling misalignment. Shrinkage and enlargement of the nonlinearly registered data is indicated by scaling factors smaller and larger than 1, respectively. Right: Dice coefficient as a function of the translational misalignment.