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Poor Correlation between Pre and Post-operative Coordinates for Deep Brain Stimulation Targeting

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Purpose

Subthalamic Nucleus (STN) Deep Brain Stimulation (DBS) has demonstrated its efficacy and has become the surgical treatment of choice for Parkinson's disease. Accurate STN targeting is crucial for the success of DBS surgery. Although MR imaging studies are reliable to directly identify the surgical target, the STN is unfortunately not always clearly identifiable on standard T2-weighted images. In these adverse scenarios, manual targeting or the use of registration algorithms together with computerized atlases, provide only an estimation of the real STN location.

Over the last years several image processing based methods have been proposed for accurate pre-operative targeting when direct STN identification on imaging studies is not possible. At the same time, the evolution of the stereotactic head frames and related surgical devices provide accurate coordinates of the electrode's contacts.

Nevertheless, pre-operative STN targeting and the final placement of the active contact of the electrode often do not match. The aim of this work is to cross-validate and quantify the differences between expert's targeting variability, stereotactic atlases, automatic registration methods and post-operative electrode's coordinates.

Methods

After exhaustive inspection by neurosurgeons and radiologists, position of 16 clearly identifiable STNs were assessed by two experts on IR-T2 weighted MRI. Since no statistical differences were encountered between both target coordinates sets, the mean coordinates were used as pre-operative real target (RT). Those RT coordinates were reported on the corresponding 3D T1-weighted images. The most clearly visible STN was considered as reference (atlas). The experts' targeting variability was computed as Euclidean distances from single expert target to the RT. Estimation of the automatic pre-operative targeting (ET) was performed on T1-weighted MRI using Shaltenbrand and Wahren atlas coordinates as well as the best feature-based registration algorithm (among a set of 4 well-known methods tested). Euclidean distances (ED) from ET to RT were calculated. Finally, those pre-operative data were cross-validated against the final active electrode contact coordinates (FT) obtained from the surgical navigation devices. Again ED from FT to RT were calculated. The comparison of these data with expert's targeting variability and the RT, emphasizes pre and post-operative differences and provides valuable information about the possible source of targeting errors.

Results

The mean and unbiased pre-operative target estimation errors given by the stereotactic Shaltenbrand and Wahren atlas (AC-PC), a radial basis function (RBF) based registration algorithm and the expert's variability, referred to the pre-operative real targets (RT), are shown in Table 1. The same statistics for the distance from post-operative (Post-OP) final coordinates to the RT are also shown.

Methods vs. RT	mean $\pm$ std (mm)
AC-PC	1.96 $\pm$ 0.90
RBF	1.83 $\pm$ 0.53
Expert 1	1.61 $\pm$ 0.29
Expert 2	1.40 $\pm$ 0.38
Post-OP	2.61 $\pm$ 1.01

Table 1. Pre-operative targeting errors using atlas-based (AC-PC) and Radial Basis Functions automatic registration method (RBF). Inter-experts targeting variability (Expert 1 and 2). Last row shows the statistics of the distance between real pre-operative targeting and final location of the active contact.

An analysis of variance (ANOVA) test at a 5% significance level and a Tukey's test for multiple comparison of means was performed to enlighten the differences between pre and post-operative target coordinates. The results of these tests are presented in Figure 1. Statistically significant differences were found between pre and post-operative targets. Significant p-values are also shown.

Figure 1. Tukey's and ANOVA tests between pre-operative targeting errors using atlas based (ACPC) and automatic registration (RBF) methods, expert's targeting variability and post-operative (PostOP) target coordinates versus pre-operative real targets.

Conclusions

Although automatic pre-operative targeting procedures are reliable for surgery planning, they showed significant differences with the final placement of the therapeutic contact of the electrode. The results of this work suggest that an intra-operative real-time adjustment of the pre-operative estimated target need to be considered. Further investigation has to be carried out to evaluate whether a brain shift correction method is able to cope with the pre and post-operative gap.