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Analysis of deep brain stimulation electrodes: A semi-automatic approach of contact localization

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Introduction

Deep brain stimulation (DBS) has proven to be a highly efficient treatment for Parkinson’s disease (PD). By stereotactic surgery, 4-contact electrodes (Activa 3389, Medtronic, Minneapolis, USA) can be placed very precisely in the brain. To improve the understanding of the mechanism of action of DBS it is necessary to analyze precisely the anatomical position of each electrode contact and to compare it to the corresponding clinical outcome. Such an analysis necessitates preoperative anatomical images, a postoperative anatomical image series (electrode artifact) and the correspondence between both image series (transformation parameters). We propose in this study a tool able to semi-automatically identify contact positions on postoperative CT or MR images and their projection on the preoperative image for detailed anatomic analysis. The results obtained with this method were compared to those obtained by manual identification for eight patients.

Image data

- Preoperative stereotactic MRI (Siemens)
  - White Matter Attenuated Inversion Recovery (WAIR) T2-weighted sequence
  - TR: 4500 msec; TE: 13 msec; Voxel size: 0.52x0.52x2.00 mm³
- Postoperative CT (GE)
  - Rotation time of 1s, tube voltage 140 kV, effective mAs of 280
  - Isotropic voxel size after axial reconstruction of 0.43x0.43x0.43 mm³

Materials and Methods

a) Manual electrode identification

- Merging of preoperative MR images and postoperative CT scan (iPlan, Brainlab, Munich) – mutual information algorithm
- Artifact analysis on the CT scan using the stereotactic planning software (iPlan, Brainlab, Munich) (Figure 1)
  - Middle of artifact in axial direction = electrode
  - Lateral black artifacts = beginning and end of the electrode
  - Deduction of the four electrode contacts and their centers on the CT image
- Extraction of the MR image coordinates (possible due to image fusion) of the contact centers via a neuronavigational software (VVLink, Brainlab, Munich)

b) Semi-automatic electrode identification

Two routines were developed (Borland C++ Builder) to semi-automatically identify the electrode contacts based on the homemade software ImageLib:

1) - Indication of the tip and the direction of the electrode in the postoperative image (Figure 2a) by the user
  - Calculation of the contact position in image coordinates by the software (Figure 2b,c)
    - Minimization of the squared difference between the expected intensity in artifact center and the voxel intensities
    - Electrode contacts sampled in radial way (tricubic interpolation to obtain sub-voxel accuracy)
2) - Extraction of the transformation parameters between both image series given by the iPlan software
  - Calculation of the corresponding MR image coordinates and visualization of the determined contacts (center) on the preoperative image (Figure 2d)

c) Comparison of results obtained with both methods for eight Parkinson patients treated by DBS

Results

<table>
<thead>
<tr>
<th>mm</th>
<th>Δ x</th>
<th>Δ y</th>
<th>Δ z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>0.31 ± 0.19</td>
<td>0.14 ± 0.13</td>
<td>0.44 ± 0.36</td>
</tr>
<tr>
<td>Min/ Max</td>
<td>0.01/ 0.69</td>
<td>0.01/ 0.50</td>
<td>0.01/ 1.23</td>
</tr>
</tbody>
</table>

Table 1: Differences between manually and semi-automatically identified contact coordinates in x, y and z-direction

Discussion

Results show a low mean error compared to slice thickness and pixel size of MR and CT images. The maximal error in the z-direction of 1.23 mm could be due to uncertainties at several levels. In conclusion, we can say that our automatic tool makes the contact localization more objective. Its application can be enlarged to postoperative MR images and to other diseases treated by electrical stimulation. In the future, it should be envisaged to visualize the contact in its dimension on the preoperative MR images (1.5 mm height, 1.3 mm diameter) in order to further increase the precision of the anatomic position analysis.