Localization of subdural electrodes on MRI cortical surface images for evaluation of epilepsy patients

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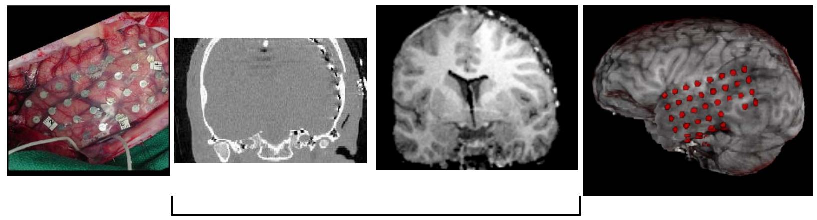
Introduction Presurgical evaluation of surgical treatment of epilepsy patients often requires implantation of subdural grid electrodes on the cortex. The exact locations of implanted electrodes are essential to evaluate cortical lesions related to seizure onsets and delineate eloquent brain areas. The process requires registration via multi-modality image warping and inter-subject brain warping, and correction of pre- and post- craniotomy brain deformation. Previously published work mapping pre- and post-implantation images, by rigid-body transformation, cannot completely avoid errors associated with brain changes during and after the grid implantation[1]. Subdural grid electrodes are implanted on the cortex through open craniotomy during which the loss of CSF fluid commonly occurs and is followed by the presence of epidural or subdural hematoma. This work presents an accurate mapping of electrodes extracted from post-implant CT data to either pre- or post surgery, anatomical MRI by intersubject and intermodality image warping and cortical surface images to determine accurate positions involved in electrocortical stimulation. We also address brain shifts by mapping pre- and post-craniotomy MRI volumes.



Grid implant craniotomy → | Post-grid CT mapped to MRI and thresholded to extract electrodes | Electrode positions on post-grid MRI

Fig. 1. Electrode positions from CT registered to post-grid MRI cortical image.

Methods

The post-grid CT data sets were acquired on GE MDCT LightSpeed machines, LS16, LS16pro, LSultra(8) and LS4slice scanners in axial slices through electrodes, slice thickness of 1.25 mm.

MRI data were acquired on a 3.0 T Philips Achieva MR scanner (Philips Medical Systems, Best, The Netherlands). The pre- and post-, grid implant T1-weighted MRI anatomical volume data sets were acquired with a 3D T1 Turbo Field Echo (T1TFE) sequence with: TR=9.8 ms, TE=4.6 ms, flip angle=8º, FOV= 24 cm, voxel resolution=1 x 1.2 x 1 mm^3, image matrix = 256×256×120.

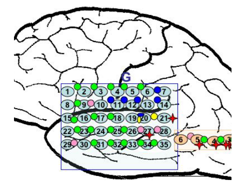


Fig.2 Grid electrode mapping diagram.

Image registration was performed using a fully automated 3D registration package, Mutual Information Automated Multimodality Image Fusion (MIAMI Fuse©) was used for linear and non-linear image mapping[2, 3].

Cortical surface projection images were generated from pre-grid MRI data. First, the brain volume was segmented by an intersubject warping of pre-grid (non-deformed) MRI with the standard brain atlas labeled with grey values by the thin-plate-spline function using a fixed set of control points (150 degrees of freedom), and then logically masking the intracranial segments of the atlas to remove all extradural structures. Electrodes extracted from the CT image were mapped onto the anatomical MRI by applying the full affine and warping solutions as the following diagram.

Table 1

pre-implant	Brain Atlas Anatomical MRI: T1w	]- warping 150 DOF		"AND" ----->	cortical surface projection
post-implant: brain shift	CT MRI	]-full affine →	grid position on post-grid MRI	] warping 150 DOF →	pre/post MRI mapping: grid position on MRI surface

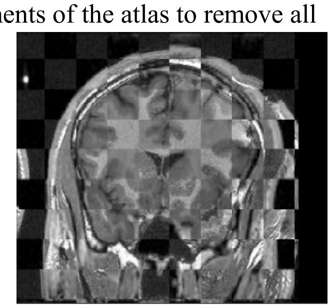


Fig 3 Pre- and post-grid MRI mapping.

Results Each electrode position can be identified in the MR surface projection image, Fig. 2. Brain shift was compensated by pre- and post-grid implant MRI registration via thin-plate-spline warping using 50 control points for the brain deformation due to the CSF loss during the surgery. Thus, the extra-operative electrocortical stimulation mapping can be localized in the cortical surface in the patient's MRI coordinate system without the brain deformation (Fig 3).

Conclusions Our work focuses on the mapping technique that effectively corrects brain deformation to map pre-implant brain MR images with post implant CT data to extract electrodes, which are mapped to the post implantation MRI to determine accurate positions of electrodes for cortical stimulations. The brain deformation between the time of craniotomy, during which the brain shrinks due to the CSF loss, and after the shape is recovered can be also accounted for by this method. Position errors caused by brain shifts after and during craniotomy, and recovery and hematoma immediately following the craniotomy can be corrected. This mapping procedure may be an essential tool for the assessment of correlation with other non-invasive functional image techniques such as functional MRI or diffusion tensor images.

References **1.** Ken, S, et al, Mag.Res.Img, 2007, 25, p883**;** **2**. Meyer, C.R., et al., Med.Img.Analys, 1997, 3, p195; **3**. Kim, B., et al., NeuroImage, 1997, 5: p. 31;

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