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Feasibility in routine clinical setting of combined resting-state fMRI and DTI-tractography for surgical planning of brain tumors

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Purpose

In the field of advanced functional magnetic resonance imaging (fMRI) techniques, resting-state functional magnetic resonance imaging (rest- fMRI) represents a novel imaging technique.

The task-driven methods (task-fMRI) require a complete patient collaboration to perform specific tasks, thus allowing the selective activation of corresponding neuronal areas. As opposed to task-driven fMRI, rest-fMRI is acquired in the absence of any stimulus or task. Biswal et al.[1] First reported that the spontaneous activity of the resting system (without a specific input or output) is not random, but rather represents the neuronal activity that is intrinsically generated by the brain, organized in a specific way which represents regions of the brain that, even if not directly anatomically connected, are highly correlated.

Diffusion tensor imaging MRI sequence covering the entire brain volume is obtained and processed for tractography of the eloquent white matter fiber tracts.

The study aim is to describe the feasibility in routine clinical setting of a combined resting-state fMRI and DTI-tractography MRI protocol for surgical planning of brain tumors.

Methods and materials

Between May 2019 and August 2019, five patients affected by brain tumors underwent brain MRI at 3T (Discovery MR 750w; General Electric Healthcare, Milwaukee, Wisconsin, USA) with a 32-channel brain coil. Standard MRI T1-weighted three-dimensional spoiled gradient recalled acquisition in steady-state sequences (SPGR) (1 x 1 x 1 mm voxels, repetition time 8.6 ms, echo time 3.2 ms, field of view 240 mm, matrix size 256 x 256, flip angle 12°), acquired in the axial plane, before and after paramagnetic contrast agent administration (Gadovist; Bayer AG, Leverkusen, Germany), were used for coregistration with rest-fMRI.

Rest-fMRI sequence was acquired with an echo-planar MR imaging sequence sensitive to BOLD signal (3 x 3 x 3 mm voxels, repetition time 2000 ms, echo time 32 ms, field of view 240 mm, matrix 256 x 256, flip angle 90°). Neuronal activity creates a hemodynamic response that locally alters local brain concentrations of oxyhemoglobin and deoxy-hemoglobin [1]. This process produces time-dependent alterations in T2 and T2* relaxation times, forming the basis of blood oxygen level-dependent (BOLD) contrast imaging.1 Successful resting-state fMRI (rest-fMRI) was obtained in all patients instructed to stay still with eyes closed while relaxing. During the acquisition, the software BrainWave RT(General Electric Healthcare, Milwaukee, Wisconsin, USA) detects the movement of the patient's head and transfers it to a graph showing linear (mm) and angular (#) variations (Figure 1).The software BrainWave RT also take over data quality for the resting-state processing pipe-line. In Figure 2 is shown an uncooperative patient resulting in bad data quality. In Figure 3 is shown a collaborative patient resulting in good data quality. Resting-state preprocessing is performed by head spatial registration to correct head movement within sequences and spatial smoothing using a Gaussian kernel. Rest-fMRI raw data are coregistered to structural three-dimensional T1-weighted spoiled gradient recalled acquisition in steady state images. The transformed structural images are then segmented into gray matter, white matter, and cerebrospinal fluid. At the end of the preprocessing pipeline, the intrinsic brain function is derived by the indices based on rest-fMRI (Figure 4).

At the end of the preprocessing pipeline, the following rest-fMRI based indices of intrinsic brain function are derived. The most significative are: regional homogeneity (ReHo) [2] and seed-based correlation analysis of the functional connectivity (FC) of the sensorimotor network [3], language network [4], visual network [6], executive control network, lateralized frontoparietal network, temporoparietal network, and default mode network [7].

Diffusion tensor imaging MRI sequence covering the entire brain volume, for fiber tractography was obtained with the following parameters: single- shot echo-planar imaging sequences; repetition time 9000 ms; echo time 106.2 ms; slice thickness 2.3 mm;

matrix size 96 X 96; field of view 180 mm; number of acquisitions, 2; 64 diffusion-encoding noncollinear directions for each slice, with b 0, 1000 second/mm^2 values. (Figure 5)

Images for this section:

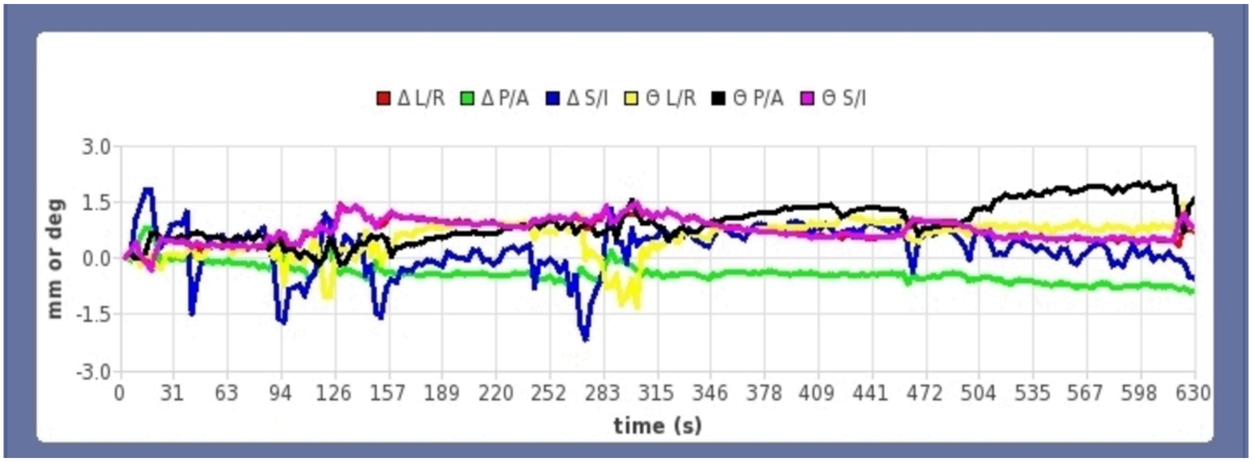

Fig. 1: The graph shows the patient's head movement

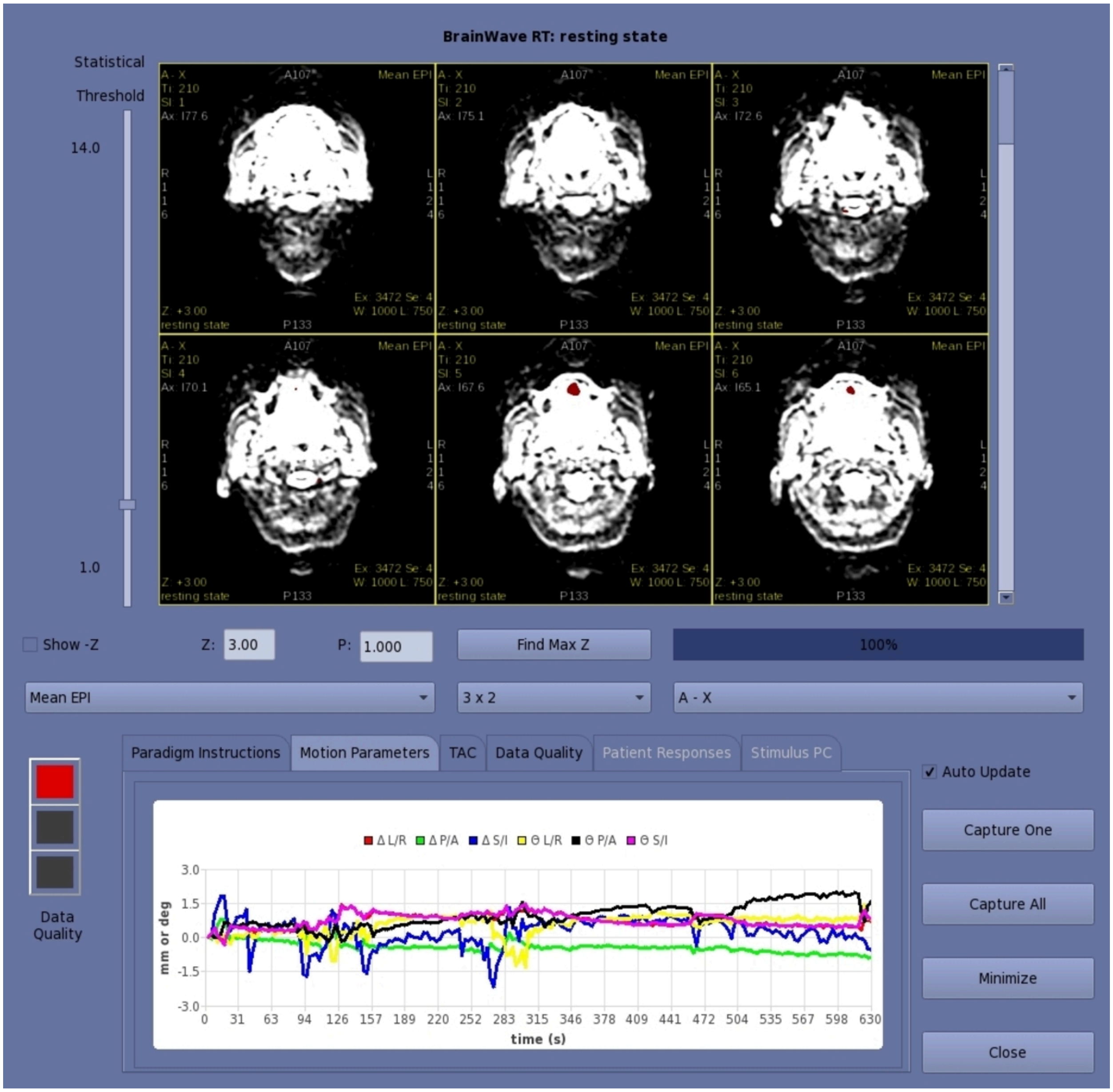

Fig. 2: Example of motion parameters on uncooperative patient resulting in bad data

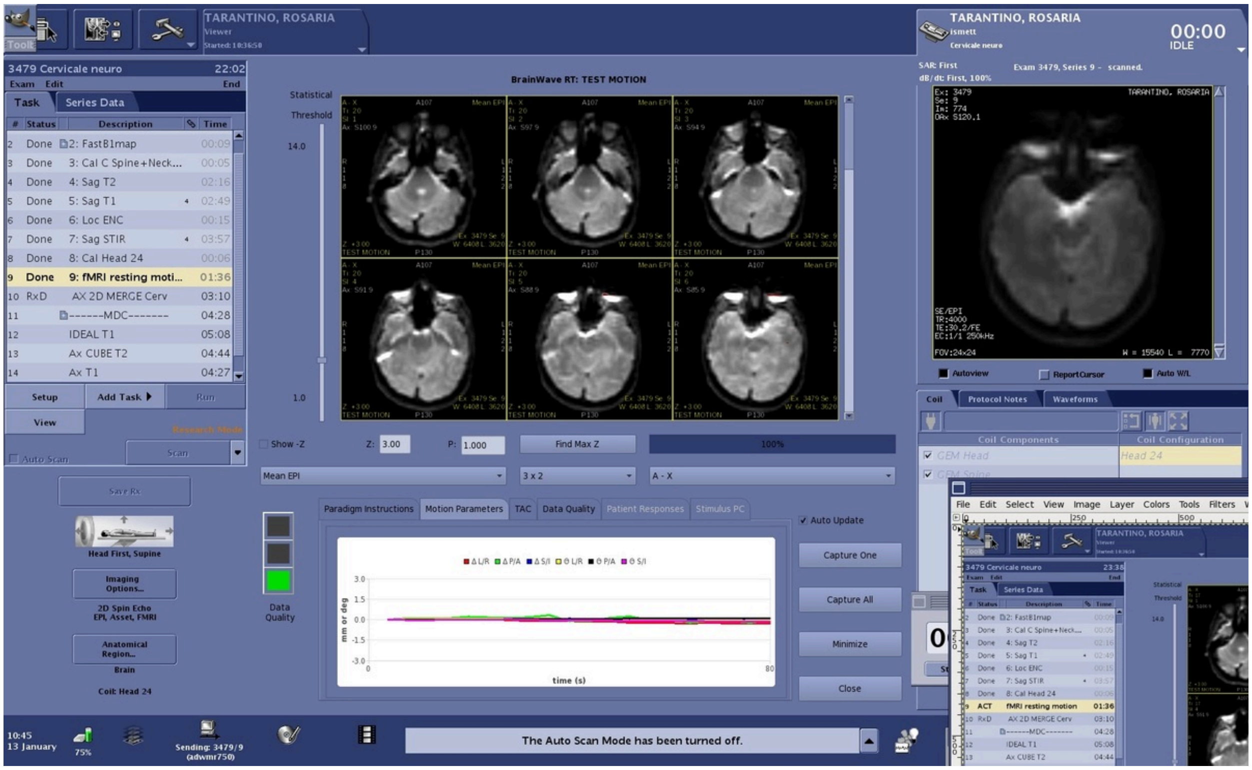

Fig. 3: Example of motion parameters on collaborating patient resulting in good data quality

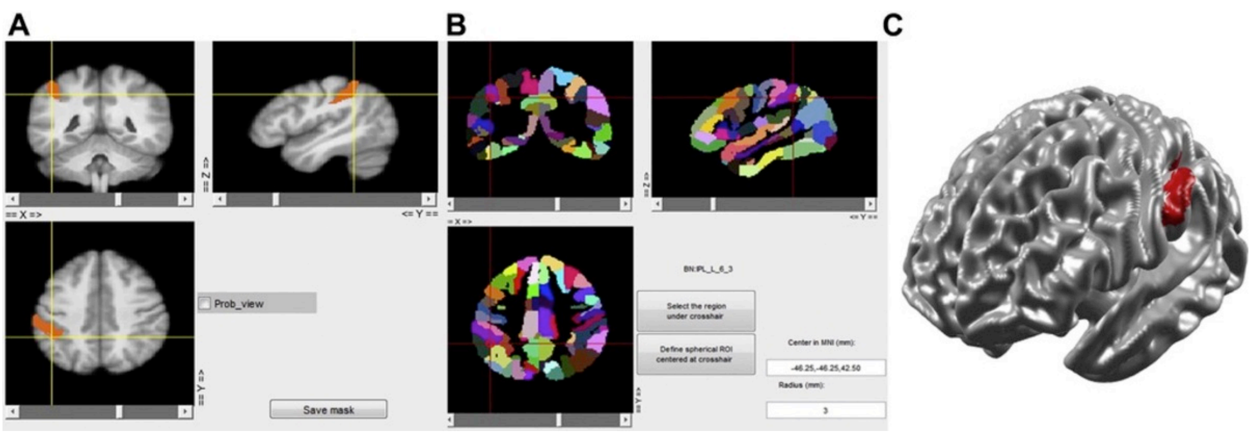

Fig. 4: Preprocessing for resting-state functional magnetic resonance imaging seed-based identification of brain functional network by using the Brainnetome Atlas. (A and B) Seed regions are placed using Brodmann atlas coordinates. (C) Three-dimensional brain volume rendering of the left auditory cortex (Brodmann area 40 left) identified with the seed-based region methodology. MNI, Montreal Neurological Institute

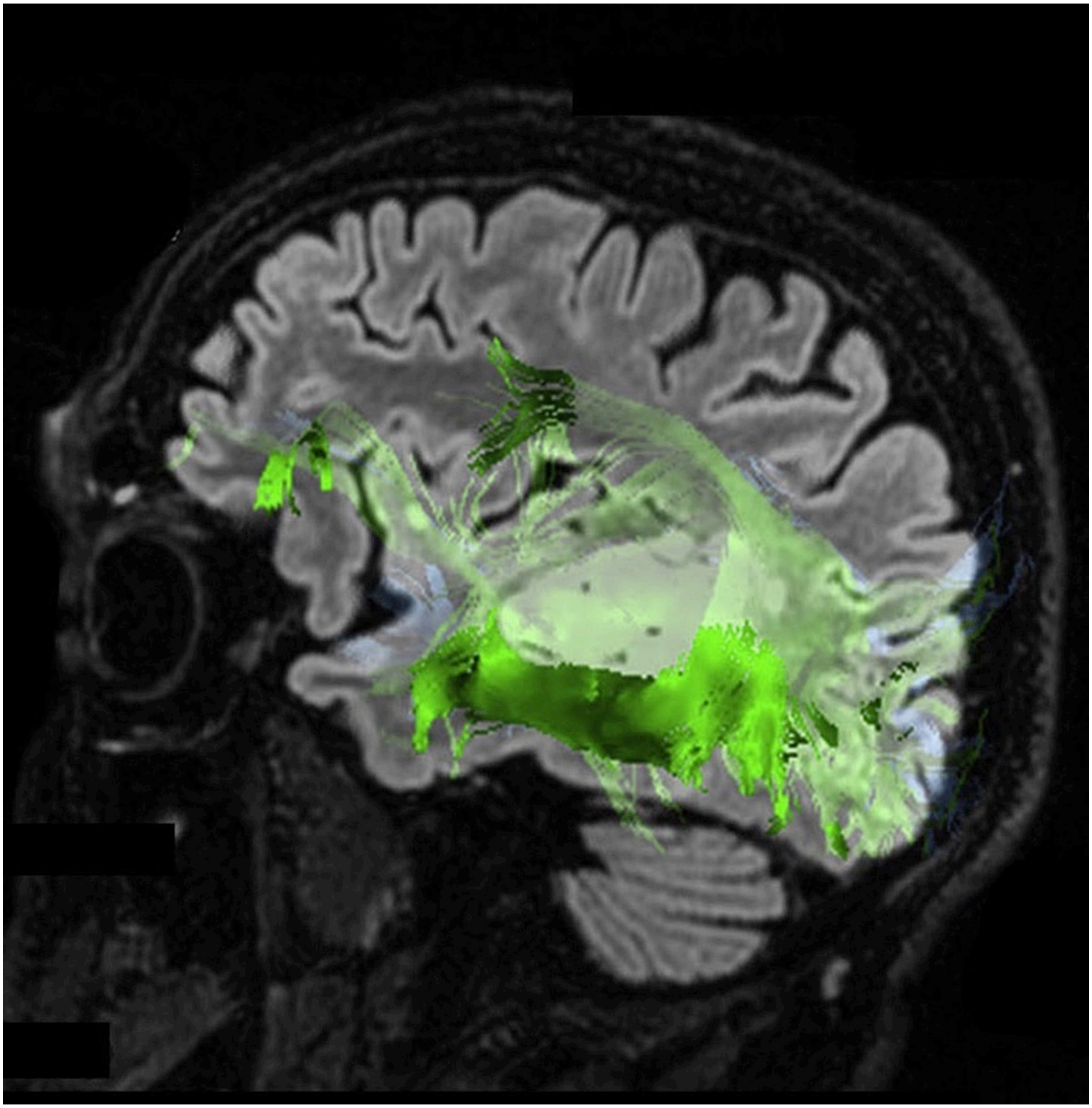

Fig. 5: Diffusion tensor imaging magnetic resonance tractography of the arcuate fasciculus (green)

Results

Rest-fMRI was performed before and after tumor resection. Imaging data collected were processed with a dedicated workstation (Advantage Windows, GE) using a seed-ROI technique [5] to obtain peritumoral and contralateral fiber tractography images. From rest-MRI was calculated regional homogeneity (ReHo) used as an intrinsic global brain function biomarker in resting state to compare its variation before and after surgery, and functional connectivity (FC) [5]. Detection of brain functional connectivity and whole-brain resting-state ReHo pattern before and after surgery potentially can be associated with the relief or worsening of neurologic deficits after surgery.

On outpatient follow-up rest-fMRI obtained 1 week after surgery, no statistically significant differences in ReHo values were found before and after surgery (Figure 6) and in the functional connectivity of the resting-state language network5 (Figure 7)

Images for this section:

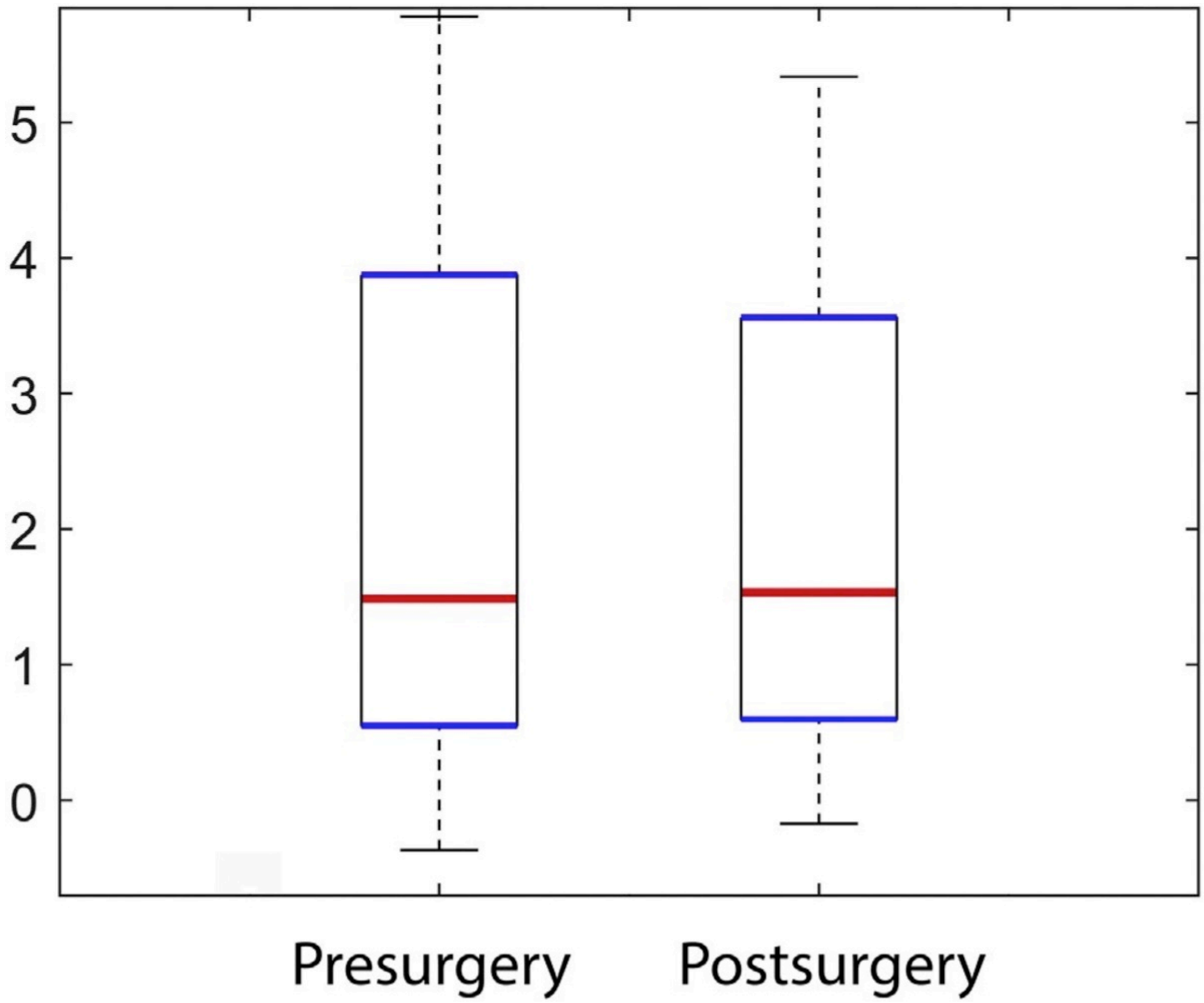

Fig. 6: Box plot of mean ± SD of regional homogeneity (ReHo) before and after surgery. No significant statistical differences ($P < 0.05$) were found in ReHo values before and after surgery confirming that no alteration of ReHo occurred after successful resting-state functional magnetic resonance imaging guided surgery.

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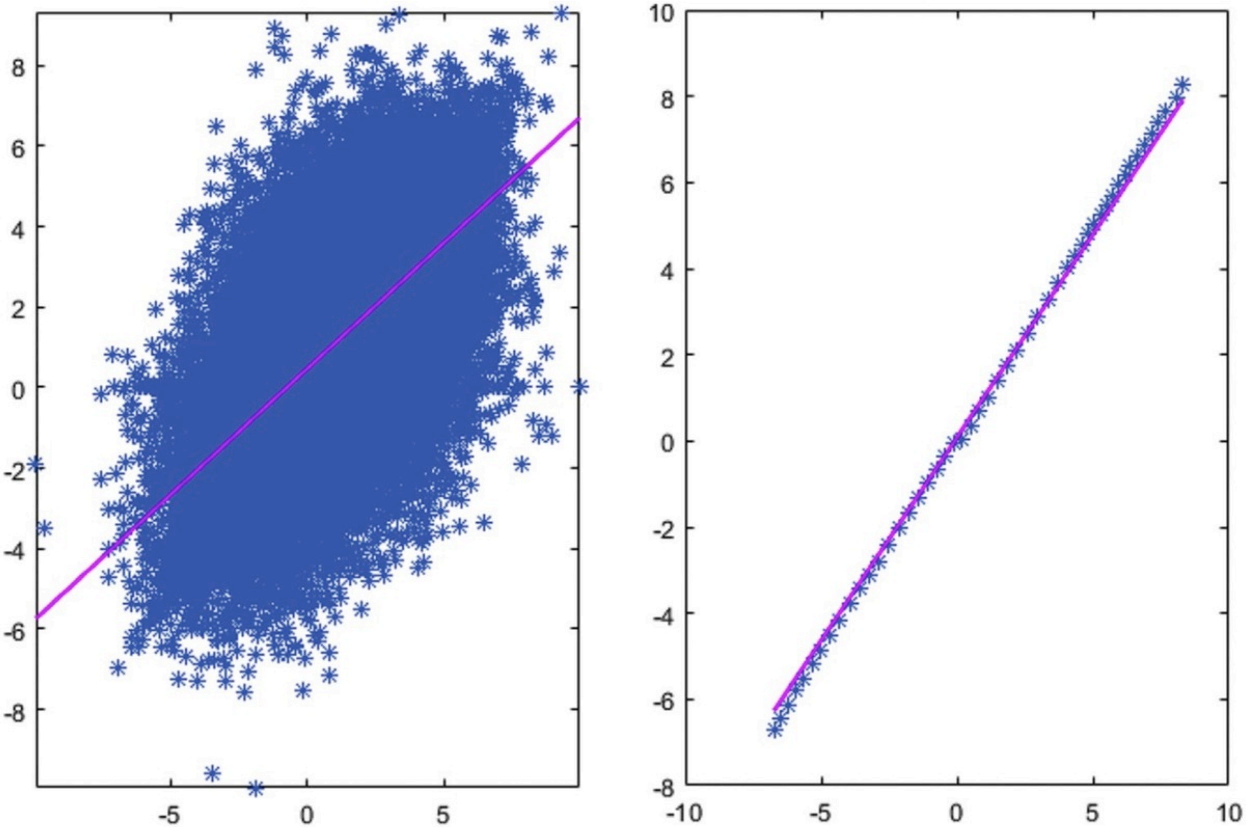

Fig. 7: Pearson correlation of functional connectivity of the resting-state language network before (x-axis) and after (y-axis) surgery. Significant ($P < 0.05$) correlation of functional connectivity values of the resting-state language network was found before and after surgery, confirming that no significant variation of functional connectivity language network occurred after successful resting-state functional magnetic resonance imaging-guided surgery. x-axis and y-axis scale = mean voxel signal intensity values.

Conclusion

Combined DTI-fiber tractography and rest-fMRI provides valuable information for surgical planning of brain tumours toprevent adjunctive neurologic deficits with accurate surgical planning, and can be implemented in presurgical settings. This MRI protocol, despite requires high-end postprocessing capability and knowledge can be easily acquired in routine clinical settings compared to task-driven fMRI which requires highly trained physicians and radiographers. Rest-fMRI does not need specific hardware or software and has the advantage of being able to be performed on patients who may not otherwise be able to actively cooperate, such as neurologically impaired patients, unconscious patients, pediatric patients, and patients under sedation. It provides valuable information, especially if task-fMRI cannot be acquired, such as can occur when patients are unable to cooperate with the task-fMRI requirements.

Personal information and conflict of interest

C. Tafaro; Palermo/IT - nothing to disclose S. Maggio; Palermo/IT - nothing to disclose G. Sparacia; Palermo/IT - nothing to disclose G. Parla; Palermo/IT - nothing to disclose G. S. Gallo; Palermo/IT - nothing to disclose D. Callari; Palermo/IT - nothing to disclose A. Pasta; Palermo/IT - nothing to disclose R. Gerasia; Palermo/IT - nothing to disclose

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