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Intraoperative CT verification of electrode localization in DBS surgery in Parkinson's disease ☆

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Background: Precise and accurate placement of electrodes in DBS surgery is essential in achievement of proper therapeutical effect in movement disorders. Verification of their position in the target is necessary. It can be performed postoperatively. But more convenient for the patient is an intraoperative CT imaging in the operating room. We evaluated the results of DBS electrodes implantation in patients with Parkinson's disease by intraoperative CT.
Case series: 21 patients with Parkinson's disease were operated in 2010–2012 in the Military Clinical Hospital in Bydgoszcz, Poland. Standard procedure of electrode implantation was verified by intraoperative CT in operating room. CT scans were fused with preoperative MRI plan of target (STN) and trajectory and accuracy were assessed.
Results: Mean differences between positions of tips of electrodes implanted and intended coordinates of targets were: 0.9 mm; 1.6 mm; and 0.8 mm in horizontal line, in vertical line, and in lateral line respectively and remain within the limits of the intraoperative CT resolution. In 1 case the accuracy was not satisfying and replacement of electrodes in one stage surgery was required.
Conclusions: Intraoperative CT is a helpful tool in DBS procedures and enables comparison of preoperative plans with the final trajectory and localization of the tip of electrode visualized in CT in appropriate target. It eliminates necessity of post-op verification outside the operating room. All changes can be done during the procedure. It also allows to rule out the intracerebral haematoma caused by implantation.

Introduction

Deep brain stimulation (DBS) is a modern, approved method of treatment of movement disorders as Parkinson disease (PD) and dystonia although in our department we still perform thalamotomy in essential tremor and pallidotomy in dystonia. Implantation of electrodes is conducted in an operating room usually under local anesthesia with the use of stereotactic frame fixed to the head with screws. Target of implantation is set out basing on Magnetic Resonance Imaging (MRI) examination of patient's head performed before surgery. In PD the main target is subthalamic nucleus (STN) [1]. Stereotactic parameters of the target are estimated with the use of software enabling fusion of Computed Tomography (CT)/MRI scans and with help of anatomical stereotactic atlas in relation to anterior and posterior commissure. Physiological confirmation is achieved thanks to macrostimulation procedure which helps to attain sensory and motor responses and exclude side effects. Microrecording with the use of microelectrodes helps to identify the best physiological and anatomical target [2]. The electrode position is correlated with the surgical results. Precise placement of the electrode during surgery into the STN is crucial for the good clinical outcome and minimizes the risk of side effects [3]. Post implantation verification of the electrode position is necessary to evaluate the best stimulation site in DBS. It can be done by fusion of pre- and postoperative magnetic resonance images or postoperative CT with preoperative MRI.

The purpose of this study was to check the usefulness of intraoperative CT in DBS surgery and determine the accuracy of DBS electrodes implantation basing on a group of patients with PD qualified to STN stimulation.

Case series and methods

21 patients with PD were operated in 2010–2012 in the Military Clinical Hospital in Bydgoszcz, Poland. Surgeries were performed under local anesthesia after mounting of stereotactic frame (Micromar, Sao Paulo, Brasil) and after preoperative CT scanning of the head with the frame without additional fiducials. The isocentricity and precision of the system were checked before the arc was mounted on the frame. The target was identified on T2-weghted MR coronal and sagittal images of preoperative MR (1.5 T Philips, Eindhoven, Netherlands). Target position was verified on the overlaid human brain atlas of Schaltenbrand and Wahren. Standard procedure of

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electrode implantation into the STN was conducted in the operating room. No mapping with microrecording was performed. Monopolar macroelectrode, tip 1×2 mm (Elekta, Stockholm, Sweden) linked to a Leksell Neuro Generator was used for macro-stimulation (sensory: f = 133 Hz, PW = 100 ms, A = 2–3 V; motor: f = 3 Hz, PW = 1000 ms, A = 2–3 mA) and trajectory tunneling. Assessment of stimulation-induced antiparkinsonian effects was made. After indwelling of permanent electrodes for DBS under fluoroscopic control and before introduction to general anesthesia and implantable programmable generator (IPG) implantation, CT scans of the patient's head with the frame still mounted with four screws, with a 1 mm slice thickness were acquired in the operating room with 32-channel CT (Siemens, Erlagen, Germany). Image fusion of preoperative MR-images and intraoperative, postimplantation CT scans with the slice thickness of 1.5 mm was performed with the use of a multi-information algorithm software (BrainLab iPlan, FeldKirchen, Germany) to localize the electrodes. The position of each electrode tip was determined by stereotactic coordinates in intraoperative CT. The difference in tip position between the CT and fused preoperative CT/MRI was used to evaluate the registration accuracy (Figs. 1, 2). The lateral, antero-posterior and supero-inferior distances between tips of electrodes and planned targets were measured in the reformatted axial, coronal and sagittal images.

All patients gave the informed consent on surgical treatment defining risks, potential benefits and on evaluation of the effects of procedures according to recommendations of the Medical Ethical Committee at Military Medical Chamber in Warsaw, Poland.

Results

All 21 patients had DBS surgery in operating room where CT device is located. The procedure of intraoperative CT and fusion of postoperative CT to preoperative CT with stereotactic frame fused to preoperative MRI took every time around 10 min in one stage surgery.

Mean errors between positions of tips of electrodes implanted and planned targets were: 0.9 mm; 1.6 mm; and 0.8 mm in horizontal line, in vertical line, and in lateral line respectively (Table 1). In 1 case the accuracy was not satisfying and required replacement of electrodes.

Discussion

The DBS surgery is typically performed in an awake patient and involves stereotactic frame application. The main aim is to precisely place the DBS electrodes into the target which is the STN in majority of patients with PD. Good clinical effect is conditioned by proper targeting of electrodes. Several approaches are necessary: good quality of MRI scans with minimal distortion to visualize the subcortical nuclei, 1–1.5 mm thick CT scans of the patient's head with stereotactic frame, thorough CT–MRI automatic fusion, proper determination of the anterior and posterior commissures, suitable adjustment of the size of the third and lateral ventricle size in patient's MRI scan to the size of ventricular system in anatomical brain atlas, tailored surgical plan avoiding sulci, vessels and ventricles, correct

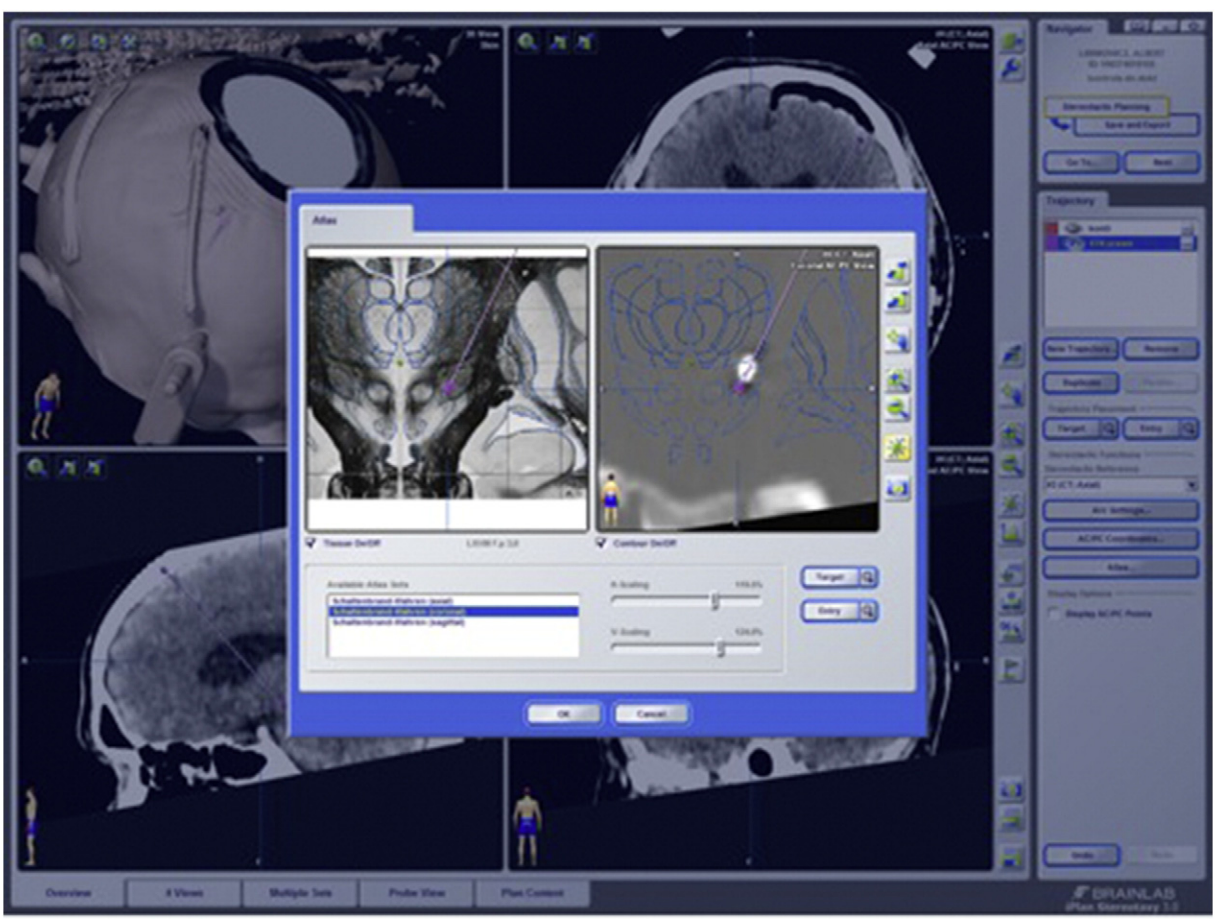

Fig. 1. Unilateral STN DBS surgery. CT showing the first contact of electrode implanted to right STN fused with trajectory of intended target determined on brain anatomic atlas (coronal view).

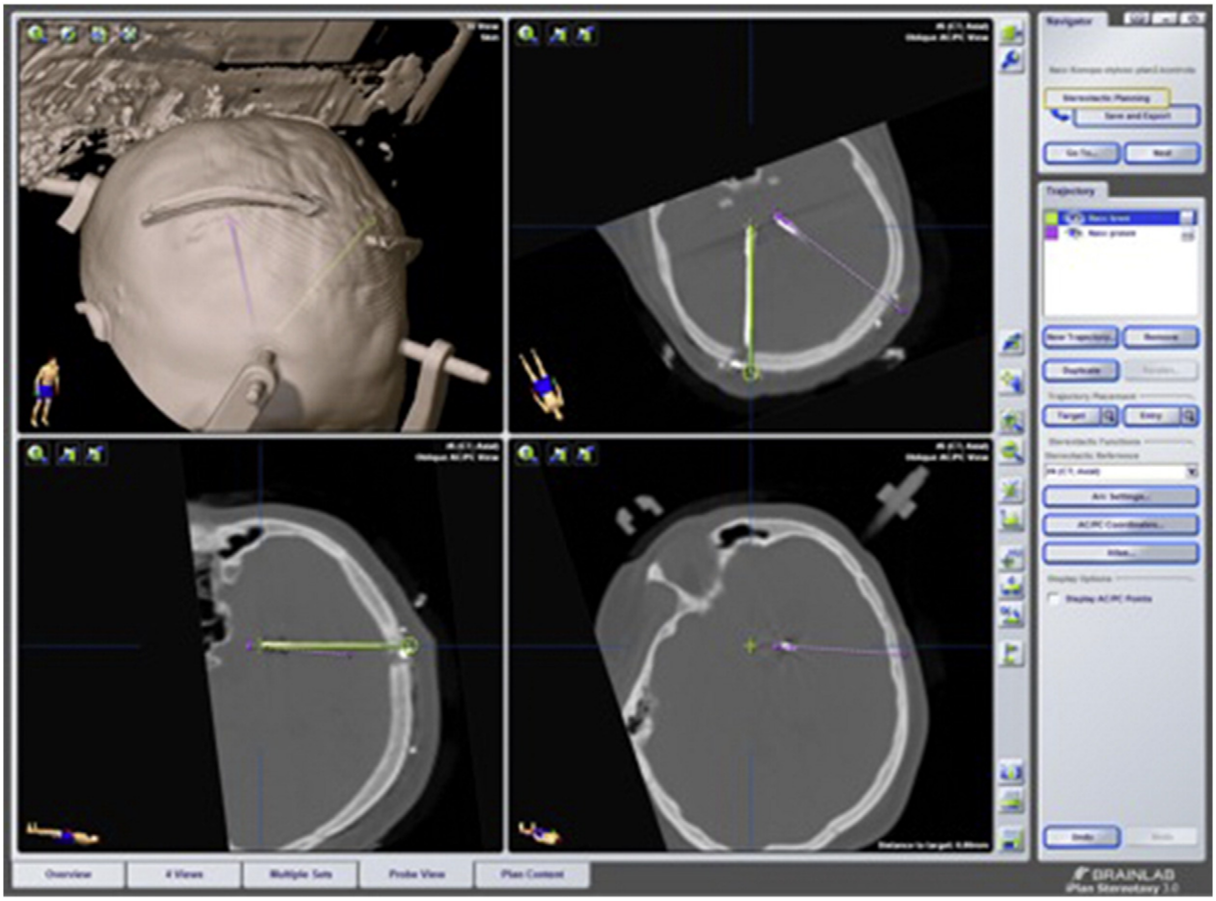

Fig. 2. Postoperative CT showing tips of electrodes fused to bilateral trajectories of planned STN DBS.

placement of the macroelectrode under fluoroscopy, intraoperative physiological monitoring of the target in the awake patient, placement of the DBS electrode in the same trajectory of the electrode for macro-stimulation and tight fixation of the DBS electrode to the cranium avoiding any shift. The final verification of all these steps is the intraoperative CT and automatic fusion of its scans with planned target that shows precision of the implantation [4–6]. In our short series of selected patients with PD electrodes in majority of cases were located in intended point. In 1 case the accuracy was not satisfying and we had to replace the electrodes.

The differences between the coordinates in three axes of intended target and implanted tip of electrode are more precise than 1 mm which is the result of the interpolation algorithm performed by software serving for planning. We have to state that differences within 1 mm are within the dimension of one pixel which has the size of 1 mm, with the slice thickness of 1.5 mm in our case and it is not possible with these tools to achieve better precision.

O'Gorman et al. checked the accuracy of 35 electrodes' position in 20 patients with postoperative CT/preoperative MRI fusion and attained mean error from 0.5 to 1.0 mm along three axes [7]. Ferroli had distances from 0.2 to 2.2 mm but in preoperative CT and postoperative MRI fusion [8]. Fiegele et al. determined the most optimal method of verification of electrode position measuring not only euclidian distance of the electrode's contacts from the planned target point but also deviation from the perpendicular axis of the target point which provides the most important parameter guaranteeing the final success [9]. Our study has this drawback since it does not show the results of deviation from the longitudinal axis of the target trajectory. However, all misplaced electrodes can be easily recognized after fusion of intraoperative CT on preoperative plan. If the error occurs it can be immediately corrected before permanent IPG implantation during the same procedure in the operating room.

The frequent cause of electrode displacement is anchoring system of electrodes to the cranium [10]. We use nowadays Guardian™ cranial burr hole system (ANS, Plano TX, USA) which is rather secure. Other reasons of discrepancies in the planned and the final trajectories are air bubbles or cerebral fluid leakage causing brain shift [9]. The greatest advantage of intraoperative CT is the possibility of identification of electrodes' position in the operating room during the same surgery. Pinsker found that stereotactic CT has higher value than MR imaging in terms of accuracy in electrode localization due to artifacts caused by electrode. On the other side MRI is better in ruling out postoperative complications e.g. hemorrhage [11]. Postoperative CT fused with MRI is a safe and practical technique for postoperative identification of DBS electrodes [7] although according to Ferroli preoperative stereotactic CT fused with postoperative MRI is also a simple and precise method of verification of DBS electrodes' placement [8]. CT in the operating room allows the neurosurgeon to avoid transportation of the patient to the radiological department, thus shortening the time of procedure. Intraoperative CT helps also to rule out possible complications after implantation e.g. intracerebral hematoma. Once the CT is taken, patient can be anesthetized generally for IPG and extensions implantation. Correction or reimplantation of improperly indwelled electrodes can be performed in one stage surgery.

Table 1
Coordinates of the target (STN) in preoperative CT fused to MRI and coordinates of the tip of the electrode in postoperative CT fused to MRI in 21 patients, and differences between the coordinates in three axes of intended target and implanted tips of electrodes with means and max and min values. Bold results show coordinates of tip before the intended target; others describe tips placed after it — in difference column.

PATIENT/ SIDE	Target in preop CT/MRI			Control in postop CT/ MRI			Difference		
	AP	Lateral	Vertical	AP	Lateral	Vertical	AP	Lateral	Vertical
O.E./left	2.7	12	4.7	4	12.5	8.6	1.2	0.5	3.8
B.B./right	2.1	16	60.1	2.7	16.3	58.9	0.6	0.3	**1.2**
R.M./right	2.3	11.3	60.8	2.4	12.1	58.4	0.1	0.8	**2.4**
Ś.J./right	1	11.3	42.6	1.3	11.4	42.7	0.3	0.1	0.1
K.I./right	6.7	14.3	61.6	6.6	14.9	59.6	**0.1**	0.6	2
P.J./right	2.3	14.7	58.1	2.1	14.6	55.5	**0.2**	**0.1**	**2.6**
W.A./right	1.1	14	49	1.5	13.8	49.3	0.4	**0.2**	0.3
U.Z./right	1.3	9.8	51.7	2.4	12	55.4	1.1	2.2	3.7
B.H./right	4	11.8	47.4	5	12	47.2	1	0.2	**0.2**
B.J./left	0.1	10.6	59.5	2.6	10.8	56.7	2.5	0.2	2.8
P.M./left	4.3	13.2	76.7	4.2	13.8	76.5	**0.1**	0.6	**0.2**
P.W./left	3.4	16.1	70.2	1.7	7.7	71.9	**1.7**	1.6	1.7
W.J./left	2.7	10.2	53.8	3.7	9.3	52.1	1	**0.9**	**1.7**
A.M./left	1.4	12.4	58	5	10.6	57.2	3.6	**1.8**	**0.8**
J.W./left	0.4	15.7	73.4	1.4	14.6	72	1	**1.1**	**1.4**
K.M./right	14.7	11.3	65.7	16.4	11.5	65.5	1.7	0.2	**0.2**
M.A./left	0.6	20.3	72.8	0.5	17.8	72.5	**0.1**	**2.5**	**0.3**
W.M./left	4.1	13.6	59	4.8	11.8	56.7	0.7	**1.8**	**2.3**
L.W./right	2.8	14.7	71.7	4.8	15.7	71.6	2	1	**0.1**
LW2./right	*2.8*	*14.7*	*71.7*	*3.9*	*13.2*	*69.5*	*1.1*	**1.5**	**2.2**
S.A./left	0.7	9.5	61.8	1.1	9.7	60.4	0.4	0.2	**1.4**
K.I./left	0.1	8.1	78.8	0.3	8.5	83.2	0.2	0.4	4.4
Mean							0.9	0.8	1.6
Max							3.6	2.5	4.4
Min							0.1	0.1	0.1

Conclusion

Intraoperative CT is a helpful stereotactic tool in DBS procedures and enables comparison of preoperative plans with the final trajectory and localization of the tip of electrode visualized in CT in appropriate target and eliminates necessity of post-op verification outside the operating room. All changes can be done during one surgery. It also allows to rule out the intracerebral hematoma caused by implantation.

Disclosure

The authors report no conflict of interest.

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