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Targeting the Subthalamic Nucleus for Deep Brain Stimulation in Parkinson Disease: The Impact of High Field Strength MRI

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1. Introduction

Functional neurosurgery is the only surgical alternative treatment for patients with Parkinson's disease (PD) (Agid, 1999; Benzzouz & Hallett, 2000; Beric et al., 2001; DeLong & Wichmann, 2001; Dowsey-Limousin et al., 2001; Hariz & Fodstad, 2002; Kopper et al., 2003; Krause et al., 2001; Vesper et al., 2002). Dopamine deficiency in Parkinson's disease leads to increased neuronal activity. Regulation of this overactivity using electrical stimulation of the basal ganglia (deep brain stimulation – DBS) has become an attractive neurosurgical option of alternative treatment strategy (Limousin et al., 1998; Kupsch & Earl, 1999). The subthalamic nucleus (STN) is the key structure for motor control through the basal ganglia and is mostly used as stimulation target since here, all cardinal symptoms of PD can be effectively ameliorated (Anderson et al., 2005; Benabid et al., 1998; Dujardin et al, 2001; Limousin et al., 1998; Martinez-Martin et al., 2002; Koller et al., 2001; Krack et al., 1998; Lopiano et al., 2001; Volkmann et al., 2001). Possible mechanisms of DBS include depolarization blockade, release of local inhibitory neurotransmitters, antidromic activation of inhibitory neurons, and jamming of abnormal neuronal firing patterns. The clinical experiences and practice confirm the beneficial effect of chronic bilateral STN-DBS.

Especially the definition of the target area as well as positioning of test and permanent electrodes are subjects of ongoing debates, reflecting the different possibilities, including ventriculography, CT-guidance, MR-imaging and combined techniques (Hariz & Bergenheim, 1990, 1993). Advances in image acquisition, image postprocessing as well as potentials of multimodality including image supported surgery, microelectrode-recording (MER) and macrostimulation technologies have been the driving forces behind the resurgence in the use of functional stereotaxic surgery. Besides the precise selection of Parkinson patients, which are ideal candidates for deep brain stimulation, correct preoperative target definition and intraoperative target localization are the most important factors for surgical success and good clinical outcome (Lopiano et al., 2002).

This is the first comparative study, which evaluates the value of 3 Tesla MRI data for the definition of the STN as the target region for deep brain stimulation in patients with PD. This study shows the results of DBS-electrode placement using different MR-imaging (T1w,

T2w; 1,5T, 3T), which were used for preoperative visualization of the target region and anatomical landmarks as the precondition for the definition of target coordinates. In the next step, we systematically investigated the effects of bilateral STN-DBS on motor functions and medication in both groups in a twelve-month follow up.

2. Methods

The described prospective study included 27 patients (20 male, 7 female) with idiopathic PD in whom STN-DBS surgery was realized. Patient age ranges from 39-75 years. The mean age of males and females was 62.9 years. The mean duration of the disease was 12.3 years, ranging from 4 to 17 years.

Patients qualified for stereotaxic and functional neurosurgery, showed no evidence for psychiatric illness, cognitive impairment, severe brain atrophy, or other substantial medical problems of laboratory abnormalities, dementia, major focal or severe diffuse brain abnormalities, extensive brain atrophy nor any severe systemic internal disease, which could exclude stimulation therapy.

For targeting procedure image fusion of preoperative acquired 3D T1w and T2w 1.5T MR-image series ("Intera", Philips, Germany, 13 patients, group I) and 3D T1w 1.5 T and T2w 3 T MR-image series (Bruker, Germany, 14 patients, group II) was used and the possible benefit of 3 T MRI was evaluated, analyzing surgical and clinical data. In all cases with PD we preferred a bilateral electrode insertion in a single session, beginning with the more symptomatic side. Direct magnetic resonance imaging-based anatomic targeting was used.

2.1 Image acquisition and planning procedure

At present time a wide variety of target localization and implantation techniques exists (Limousin et al., 1998; Kupsch & Earl, 1999). Traditional stereotaxic algorithm has been based on an externally fixed stereotaxic frame that encompasses the patient´s head and upon which the micromanipulating equipment can be mounted and maneuvered with highest accuracy (Dujardin et al., 2001; Martinez-Martin, 2002). Corresponding to the existing stereotactic frames and their refinements, all stereotaxic frames have been optimized to allow nearly artefact-free image data sets and to guarantee a precise and reproducible definition of target and entry points. Typically, these frames are mounted on the day of surgery, just before acquisition of planning image data sets.

Beginning this step of functional neurosurgery the patient is free of any L-Dopa medication as a precondition for macrostimulation and awake-neurological examination. Consequently, tremor-related motion artefacts during image acquisition are encountered, despite of the patient´s head fixation using headholders (CT) and headcoils (MRI), which reduce the accuracy of image co-registration theoretically and possible practically. Nevertheless, the delay involved with frame fixation, image acquisition, planning and three dimensional checking can take several hours depending on personal and institutional experiences and the patient´s properties as a kind of stress just before surgery.

In our study on the day of surgery the patient's head was fixed in an MR-compatible ceramic head holder (Zamorano-Dujovny, ZD, Fa. Stryker, Howmedica, Leibinger, Germany) in local anaesthesia. Position of the head ring was chosen in such a way that pin

placement and expected metal artefacts of the screw tips were away from the axial plane of the target point (STN) and any structures of interest.

For functional and surgical planning it is necessary to map points and regions of interest from one patient image to another that has been taken at a different time or/and with a different image method. In this study the combination of T1w and T2w image series seemed to be the most practical way. The rational behind this procedure is that T2w image data allow an excellent visualization of target structures (STN) and neighbouring anatomical landmarks (Nc. ruber). The T1w images are used for stereotaxic planning and realization of surgery.

Fig. 1. Postprocessing result (image fusion) for following definition of target coordinates basing of 3D T1w and T2w MR image data of the region of interest (T1w 1.5 T MRI and T2w 3 T MRI)

Corresponding to the different possibilities we analysed two patient cohorts: in the first group (group I) 1.5 Tesla T1w (3D-magnetization-prepared rapid gradient echo-TE 4,6 msec, TR 25 msec) and T2w (Turbo spin echo-TE 120 msec, TR 4389 msec) image series with the following parameters: matrix 256 x 256, slice thickness: 1 mm ("Intera", Philips, Germany, 1.5 Tesla) were acquired and fused together slice identically (Fig. 1). In group II the 1.5 Tesla T1w image series ("Intera", Philips, Germany, 1.5 Tesla) was combined and fused with the

T2w image series, acquired in the 3 Tesla Bruker MRI (matrix 256 x 256, slice thickness: 1 mm, Turbo spin echo-TE 355 msec, TR 3500 msec), Max-Planck-Institute of Cognition and Neuroscience, Leipzig, Germany. Just before magnetic resonance image acquisition (T1w MRI) contrast media was given in both groups in a standard dose (0.1 mmol/kg bodyweight Gd-DTPA, Magnevist, Schering, Germany) to improve detail informations as well as to identify passing vessels.
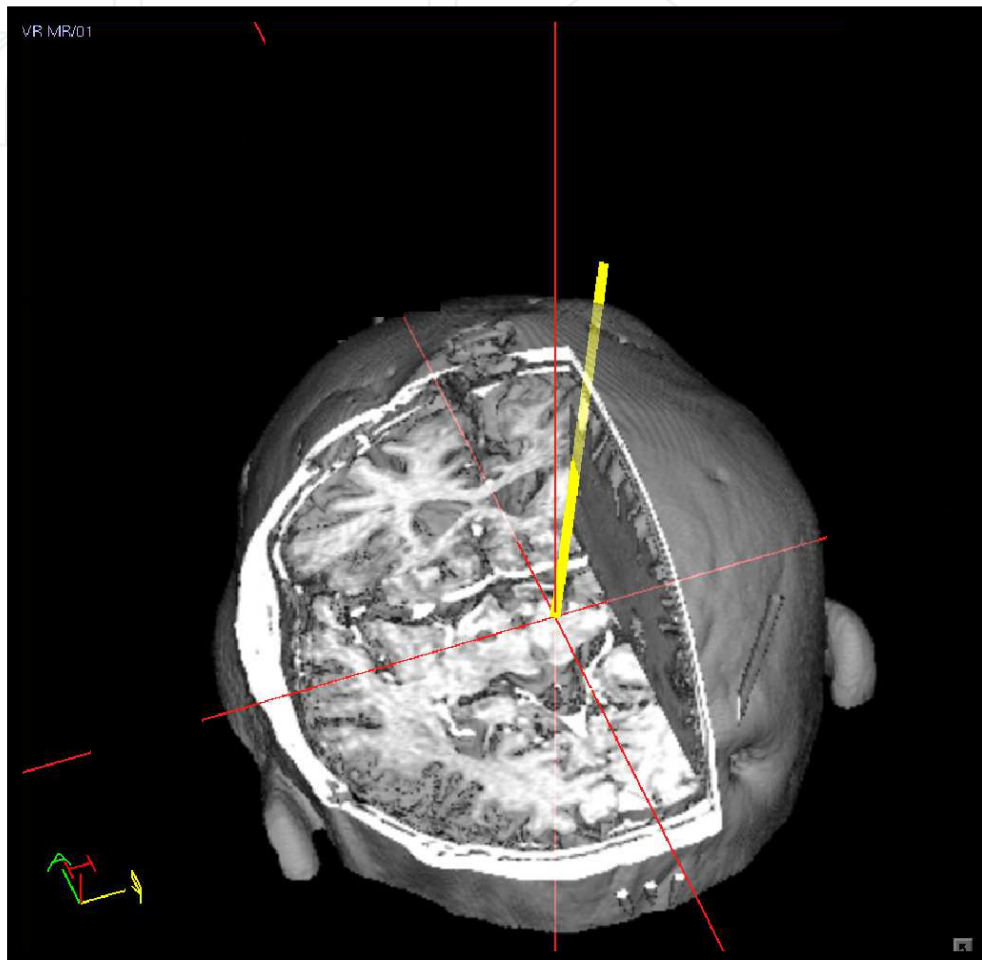

Fig. 2. Virtual 3D reconstruction of planned electrode trajectory

Stereotaxic coordinates were calculated with the "Remote surgical planning software" (RSPS, Fa. Stryker, Howmedica, Leibinger, Germany) or with the VoXim® / microTargeting™ , IVS Technology, Germany, FHC, USA. In the following steps, image postprocessing, definition of functional, entry and target coordinates and visualization of planed trajectories take place. In general, the final stage in the presurgical planning process involves reviewing the proposed trajectory interactively in the sagittal, axial and coronal plane and checking the coordinates verified that the cannula passes exactly to the defined target point. The surgical planning process involved the identification and adaptation of the target using the typical appearance of the STN and the Nc. ruber in T2w image series and reviewing the proposed trajectory interactively in the sagittal, axial and coronal plane. Any field inhomogeneities of the used MRI could be ruled out in previous studies (Figure 3).

Entry and target points were chosen and the coordinates of the space were calculated automatically by the special „frame-based stereotaxy" software program, including the A, B, C, D and E values for the target device of the stereotaxic system. These coordinates were the base for the intraoperative used target arc system, which was connected with the stereotaxic head ring (Zamorano-Dujovny, ZD, Leibinger, Germany). A phantom system called target point simulator was used for intraoperative control of coordinates. Checking the coordinates verified that the cannula passes exactly to the defined target point.
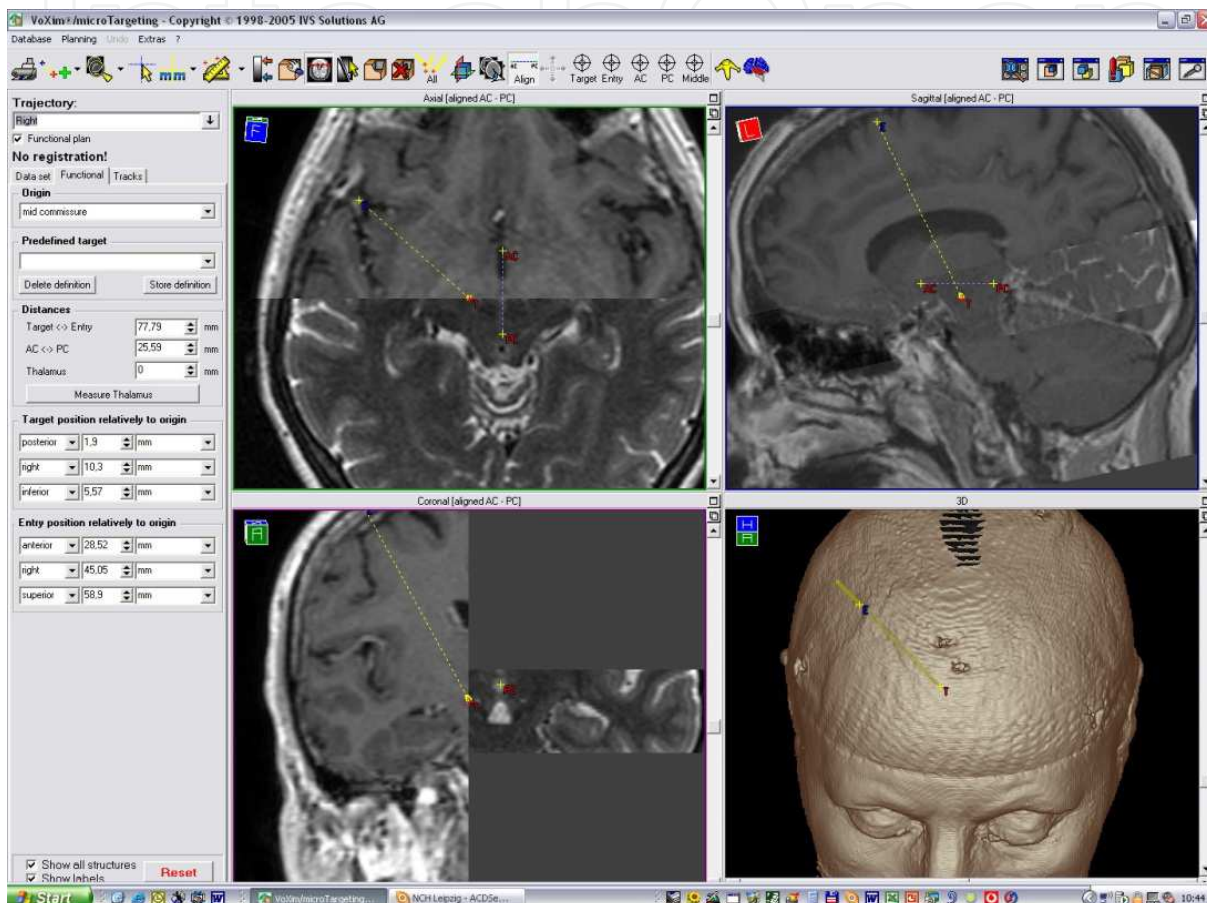

Fig. 3. Identification and adaptation of the target-coordinates using the sagital, axial and coronal plane.

2.2 Functional neurosurgery

In the surgical part, the mild sedated patient was transferred to the operating theatre without a possibility of frame dislocation and was fixed normally using a special adapter unit. In the operating theatre patients was lying in a 45° upright position and was mild sedated with intermittend injections of midazolam to allow motor and verbal testing during intraoperative testing stimulation.

Head was cleaned and draped with the entry site in view. Under local anaesthesia and mild sedation, a burr hole craniotomy was made at the desirable entry point and the target arch was installed. The burr hole was placed in the standard location near the coronal suture and approximately 3 to 5 cm from the midline. Five stainless-steel microelectrodes were inserted stereotaxically using multi-channel microelectrodes (Leadpoint 4, medtronic, USA).

Microrecording was performed to identify the STN signature (frequency, pattern, amplitude) as a reliable criterion for the correct electrode position. Target signals were analysed for defining STN target, including frequency, firing rates and interspike intervals (Hutchison et al., 1998, Raeva et al., 1991, 1993).

Recording was started 10 mm above the target and was continued to 4 mm below the supposed STN. The target for the final placement of the electrode was confirmed by macrostimulation using the microelectrode housing cannula. The target was confirmed by the responses of the patient to stimuli (130 Hz frequency, 0-5.0 mA stimulation amplitude, 60 sec pulse width) delivered through the macroelectrode. During test stimulation eye movement, speech, contraction of the contralateral face, neck, tongue, skeletal muscle, and the suppression of tremor and rigidity were checked. Mostly, clinical testing indicating a dramatic improvement of tremor, akinesis and rigidity of the contralateral limb and showed a disappearance of drug-induced dyskinesia postoperatively (Figure 4)
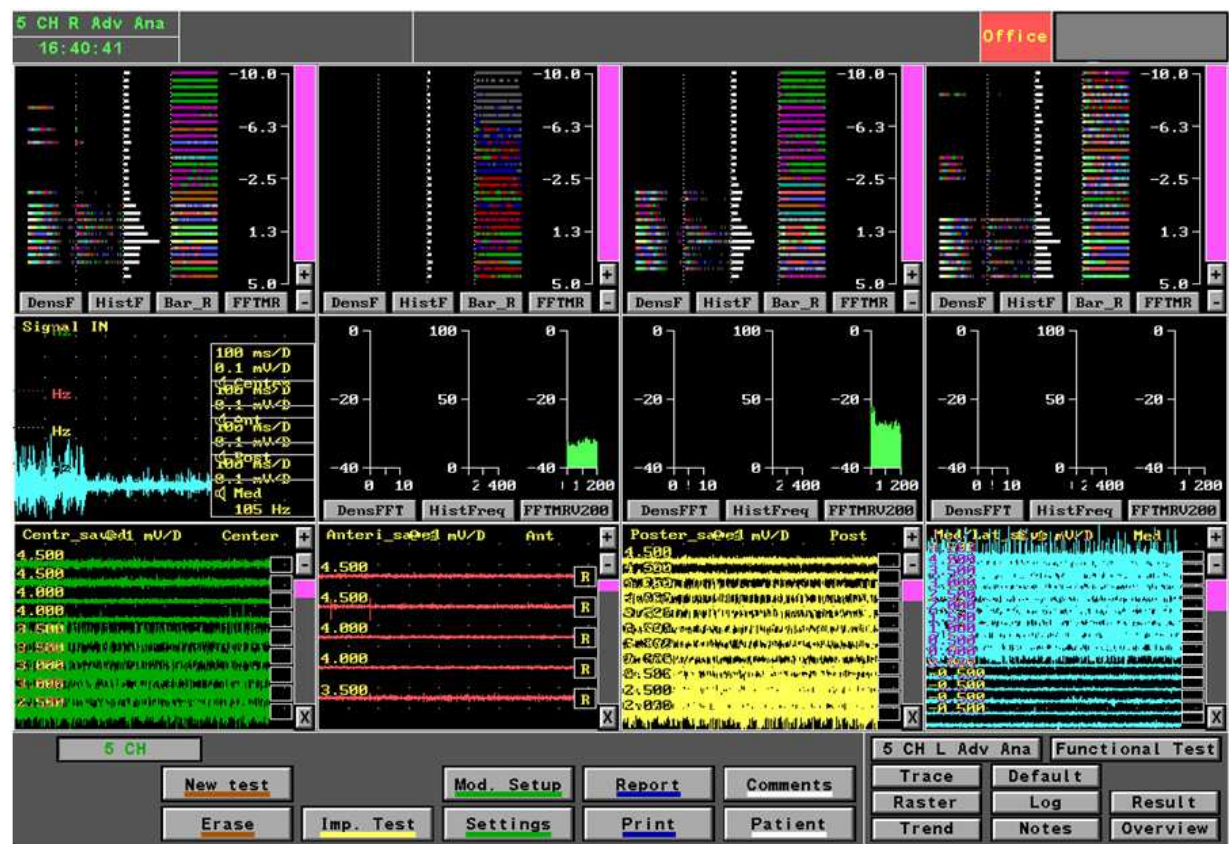

Fig. 4. Microelectrode – recoding for visualization of typical STN-signature along the z-axis

Final positioning of the permanent electrode (DBS electrode, model 3389, Medtronic, USA) was monitored on the fluoroscopy screen to avoid discrepancies between planned and real localization of the tip of the electrode. After electrode positioning the electrode was secured to the patient's skull using bone cement and miniplates for fixation (Figure 5). The same procedure was repeated on the other side. After all neurosurgical steps stereotactic frame was removed from the patient´s head and implantation of impulse generator (Kinetra Impulsgenerator, model 7428, Medtronic, Minneapolis) was done under general anaesthesia.

Fig. 5. Real position of the stimulation electrodes, documented by fluoroscopy

On the same or next day patients underwent postoperative MRI to rule out any surgery associated complications (Figure 6a, b). Stimulation testing and wound control took place and depending on their and the family conditions they was discharged home or to rehabilitation. In regular follow-ups, medication was checked and adjustments were made to optimise the stimulation parameters After placement of permanent electrodes, a pulse generator (Kinetra Impulsgenerator, model 7428, Medtronic, Minneapolis) was implanted in the infraclavicular fossa and connected to the electrodes. The following stimulation consisted of continuous square-wave pulses (frequency: 130 Hz, pulse duration: 120 µs, amplitude: 2.5 V). Clinical examination was performed to rule out any postoperative complications, motor, especially oculomotor and speech abnormalities. Postoperative MRI confirmed the electrode position.

2.3 Results

Planning procedure for following STN-DBS using preoperative acquired 1.5T and 3T MRI data is a reliable tool for successful stereotaxic treatment of PD. Using T1w image date after injection of contrast media an excellent visualization of anatomical details (ventricle structures, sulci and gyri) as well as passing vessels could be guaranteed. High resolution 3 Tesla MRI (T2w) allowed brilliant identification of the typical almond-shaped STN and the Nc. rubber with their typical hypointense shape. Image fusion was realized manually using
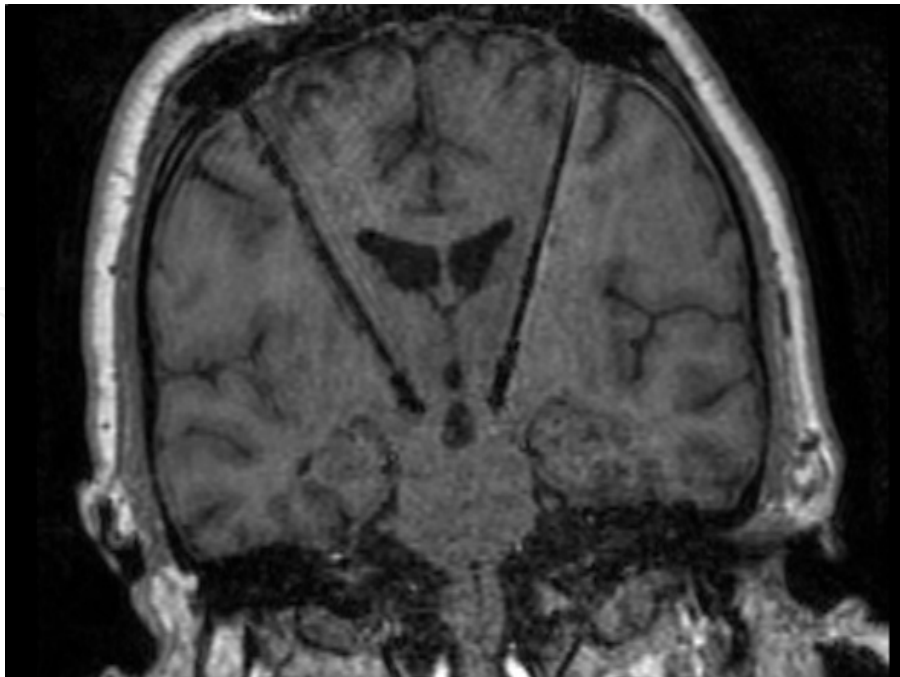
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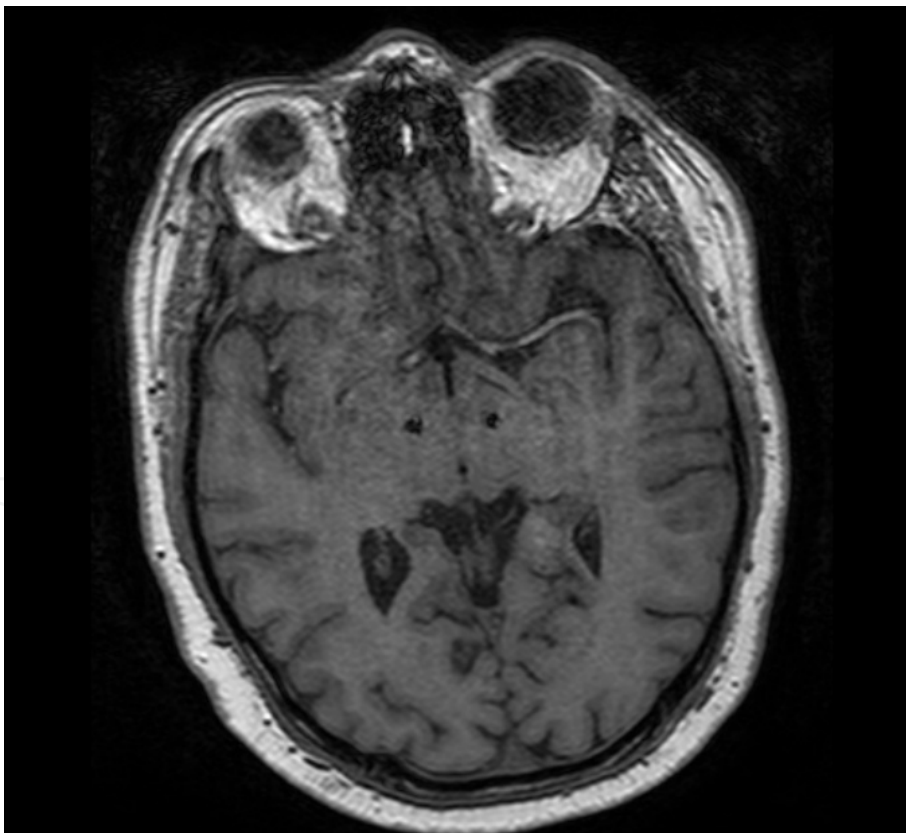
b

Fig. 6. a, b: Postoperative control of electrode positioning in different planes (a: coronar, b: axial), confirmed by small metal artefacts

anatomical landmarks with an accuracy of 0.9 mm, ranging from 0.4-1.1 mm. Corresponding to the anatomical markers and the theoretical target coordinates the STN position was superior to the substantia nigra, lateral to the anterior portion of the red nucleus and medial to the internal capsule: The longest medial-lateral and ventral-posterior diameter of STN was aimed and located immediately lateral to the anterior aspect of the Nc. rubber in the axial plane. With the help of ben gun system five electrodes were implanted simultaneously in the target region to validate target region electrophysiologically. Typical STN signature, representing neuronal activity could be documented in implanted microelectrodes. After microrecording macrostimulation was performed using electrodes with the best STN signal to confirm correct electrode placement using common stimulation parameter In both groups the image fusion accuracy was with 0.37 (group I) and 0.40 (group II) nearly the same and allowed a precise and slice identical correlation of both, T1w and T2w image series in both modalities (1.5 T, 3 T)(Table 1). The number of microelectrodes which detected a typical STN signature during MER of both sites increased from 6.7 (group I) to 7.1 (group II) averagely and showed a tendency of a safer localization of the expected target point basing on preoperative acquired image data in the second group. Further data of planning (functional coordinates) and surgical (surgical time) procedures are summarized in Table 1 and correspond with planning data of other studies (Okun et al., 2005).

radiological and surgical data	Group I (n=13) T1-w (1.5 Tesla) T2-w (1.5 Tesla)	Group II (n=14) T1-w (1.5 Tesla) T2-w (3.0 Tesla)
fusion accuracy, mean (min - max)	0.37 (0.2 – 0.6)	0.40 (0.2 – 0.7)
surgical time (min) mean (min - max)	267 (202 – 313)	247 (160 – 302)
functional coordinates x y z	± 11.25 - 1.95 - 4.15	± 10.4 - 2.05 - 4.45
active electrodes, mean (min - max)	6.7 (2 – 9)	7.1 (4 – 9)

Table 1. Summarized radiological, planning and surgical data

As a result of this, the functional coordinates have the biggest differences in the x-coordinates, but were comparable in the others. Interestingly, in group I the central track (48%) dominated as the best traject for the placement of the permanent stimulation electrode, which is followed by the medial one's (20%)(Figure 7). Contrary to this, in group II predominated the anterior track with 41.7%, compared to 37% of the central track (Figure 8).

In the comparison of both groups we found a domination of the central (group I) and anterior and central position of the active electrode (group II, Figure 9).

In the postoperative course the mean administered dose of L-dopa decreased significantly in group I from 698.1 mg/day to 200.0 mg/day twelve months later, that means 28.7 % of the initial mean dosage and in group II from 686.5 mg/day to 183.3 mg/day (24.9%)(Table 2,

Figure 10). The reduction of L-dopa dose one, two, three and twelve months postoperatively differed not significantly between both groups.
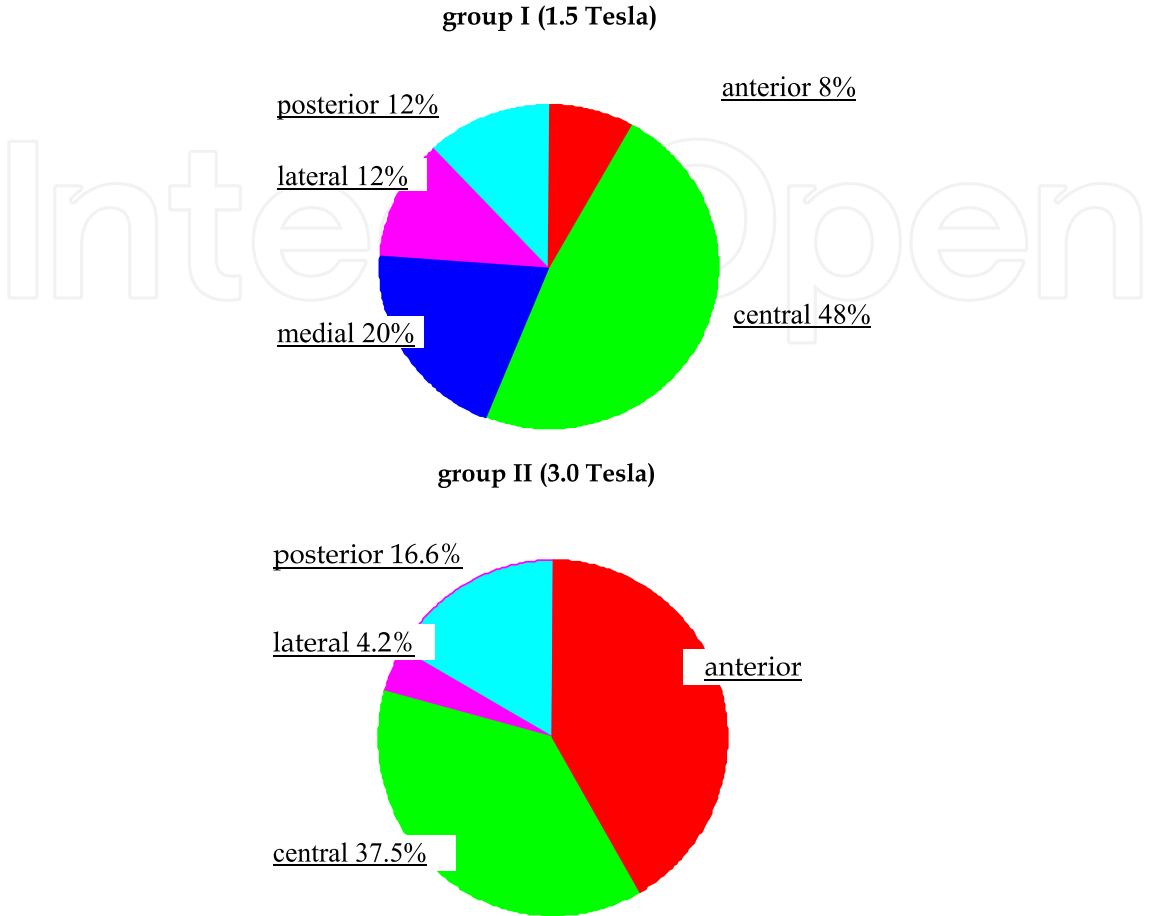
group I (1.5 Tesla)

group II (3.0 Tesla)

Fig. 8. Distribution of active electrodes in group II (3 Tesla MRI)
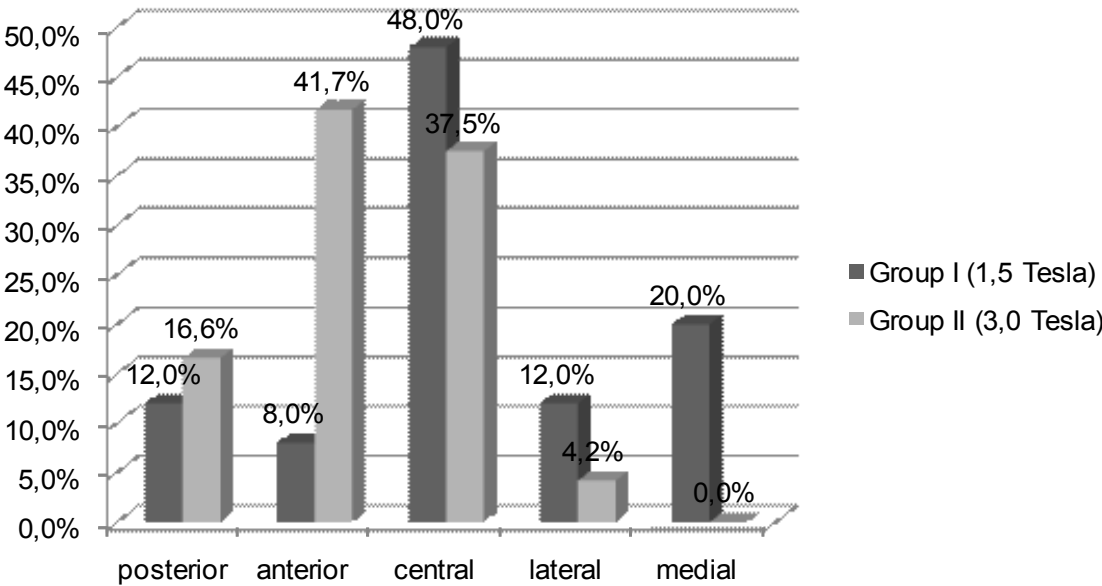

Fig. 9. Distribution of "active" electrodes with typical STN signature, detected by microrecording

L-dopa (daily dose, mg-values given as mean)	Group I (n=13) T1-w (1.5 Tesla) T2-w (1.5 Tesla)	Group II (n=14) T1-w (1.5 Tesla) T2-w (3.0 Tesla)
Preoperative	698.1 SD ± 251	686.5 SD ± 469
Postoperative - one month	170.8 SD ± 151**	170.8 SD ± 123**
Postoperative - two months	112.5 SD ± 210**	187.5 SD ± 131**
Postoperative - three months	155.5 SD ± 212**	212.5 SD ± 75**
Postoperative - twelve months	200.0 SD ± 115**	183.3 SD ± 177**

Table 2. Comparison of preoperative and postoperative L-dopa-medication in both groups. In spite of some irregularities in the course of twelve months the final dose reduction in both groups is comparable and no criteria for the used image modality. (** $p < 0.01$)
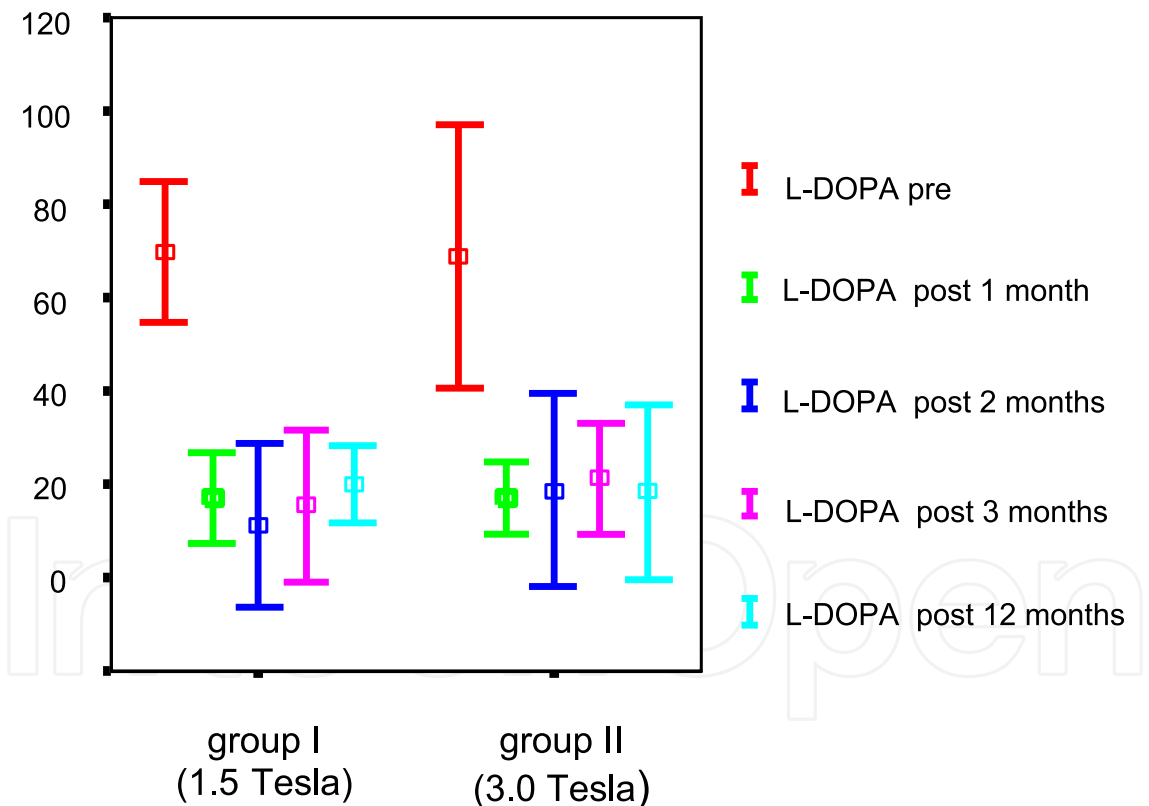

Fig. 10. Pre- and postoperative L-DOPA medication in both groups, depending on time course (preoperative, one, two, three and twelve months after STN-DBS)

The motor ratings improved significantly ($p \leq 0.01$) from the preoperative (medication-off) to the stimulator-on (medication-on) conditions in both groups (Table 3, Figure 11). Mean improvement were 70.4% (group I) and 55.4% (group II), respectively, for UPDRS, part III (Table 3, Figure 11). No significant differences between the two groups were seen.

UPDRS (III)	Group I (n=13) T1-w (1.5 Tesla) T2-w (1.5 Tesla)	Group II (n=14) T1-w (1.5 Tesla) T2-w (3.0 Tesla)
Preoperative	43.9 SD ± 20.0	42.6 SD ± 10.0
Postoperative - one month	13.4 SD ± 10.0**	13.6 SD ± 6.2**
Postoperative - twelve months	13.0 SD ± 6.3**	19.0 SD ± 4.5**

(** p < 0.01)

Table 3. Improvement of UPDRS (part III) in both groups up to one year after functional neurosurgery.
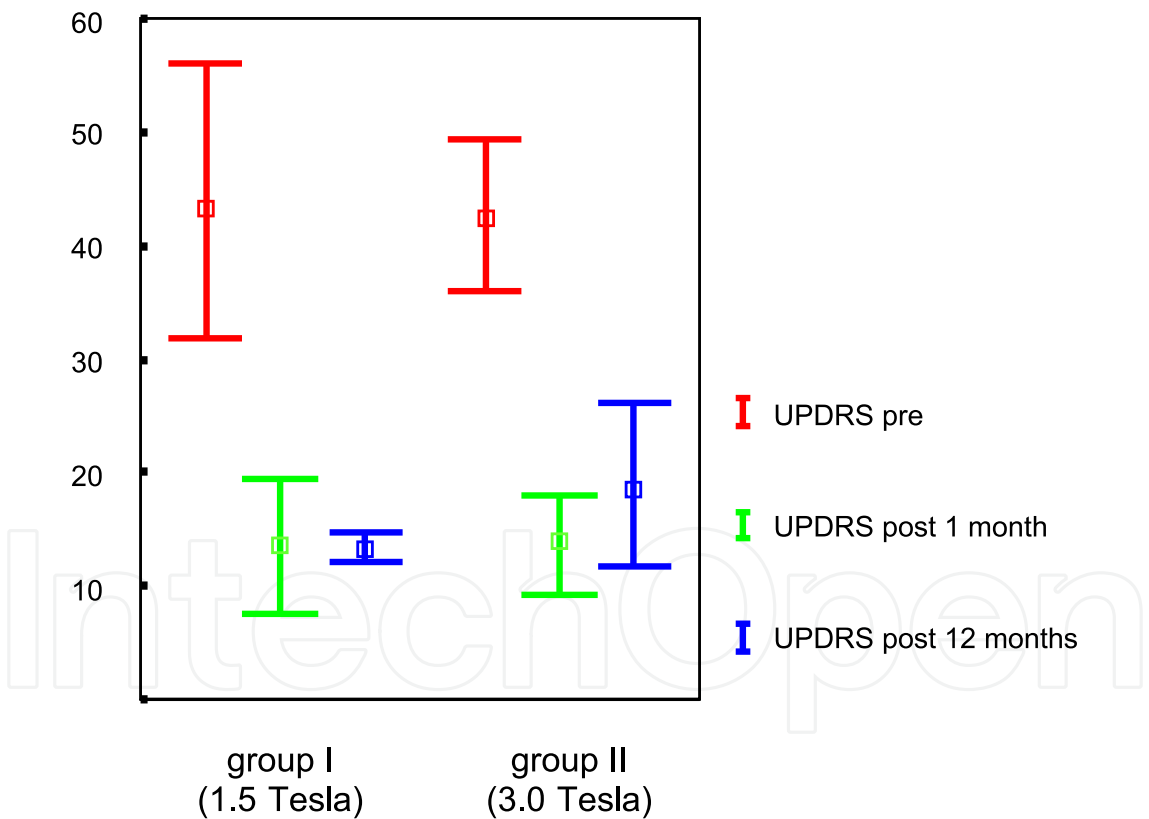

Fig. 11. Clinical effect (UPDRS (part III) up to one year after deep brain stimulation

3. Discussion

The principle of stereotaxic surgery was created by Horsley and Clarke as well as Spiegel, Wycis and Leksell. Stereotaxic surgery is a well established and accurate method and offers increasing possibilities for diagnosis and therapy. Today, stereotaxic localization based on

CT and MRI data is mostly used to guide the neurosurgeon during biopsy and functional neurosurgery with an accuracy of less than one millimetre, which is an essential advantage of used high precision stereotaxic frames. Former studies confirmed the high accuracy of stereotaxic devices despite system associated errors.

The beneficial effect of bilateral STN stimulation for neurosurgical treatment of PD is confirmed by countless studies and groups and should not be the focus of this article. At present time many neurosurgical concepts exist making the functional neurosurgery for PD via STN-DBS safe for patients and surgeons as well. The clinical results with traditional ventriculography, CT-guidance, MR-imaging and combined techniques are comparable. In this STN-DBS study for treatment of idiopathic PD we performed microrecording and macrostimulation as routinely used steps during the stereotaxic procedure, but practiced different MR planning modalities for electrode placement : 1.5 and 3 Tesla MR (T1w and T2w). Differences in both techniques and both groups as well as clinical and surgical data are the initial points for the following discussion.

In this study we used different MR modalities to define the target point and used MER and macrostimulation for electrophysiological respectively clinical validation of chosen trajectories for final electrodes.

The great appeal of 3T MRI is the improvement in image quality and an increased signal-to-noise ratio (SNR). Many are excited about the opportunity to not only use the increased SNR for clearer images, but also the chance to exchange it better resolution and contrast - a fact already well known from comparisons of images obtained at 0.5T, 1T, and 1.5T MRI. In the case of 3T MRI the SNR correlates in approximately linear fashion with field strength, it is roughly twice as great at 3T as at 1.5T. The magnetic susceptibility is exacerbated and the time necessary to acquire satisfactory images can be substantially reduced and motion artifacts can be minimized. Among other benefits, higher contrast may permit reduction of gadolinium doses and, in some cases, earlier detection of disease, a possible stimulus to use higher field systems. These possibilities makes the 3T MRI attractive especially for brain imaging.

Nevertheless, significant obstacles to 3T MRI presented by the physics at higher field strengths. 1. especially the T1 relaxation times are prolonged with increasing magnet field strength, the chemical shift is larger and the susceptibility is stronger. 2. There are safety concerns. The energy deposited in the patient's tissues is fourfold higher at 3T than at 1.5T. Especially with the use of fast spin echo and fluid attenuation inversion recovery (FLAIR), the limit on the specific absorption rate (SAR) power deposition prescribed by the FDA can easily be reached compared to 1.5T MR protocols. Scanner manufacturers are incorporating modified pulse sequences to avoid this problem, which can also be solved by restricting the volume of tissue that is studied in detail.

In our study we couldn´t observe, that the application of 3T MRI could avoid multiple passes of microelectrodes for electrophysiologic confirmation of correct target location as a possible reason to decrease the overall time of the surgical intervention and to reduce the risk of possible complications related to brain tissue trauma.

Corresponding to this surgical concept we found a sustained improvement in PD-associated motor disability (UPDRS), a reduction of postoperative L-Dopa respectively L-Dopa-equivalent medication and a minimizing of levodopa-induced motor complications, which

is confirmed by other study results. Despite of other surgical concepts of target definition, which published elsewhere, the MR-based STN localization leads to comparable results in both groups.

The STN is a biconvex lens-shaped structure, which can be visualized as a hypointense region by T2w MRI. Described by Yelnik and Percheron, 1979, STN as a relatively small region of approximately 735 mm^3 is obliquely oriented along the three anatomical axis of the space, which means approximately 20° oblique to the horizontal plane, 35° to the sagittal plane, and approximately 55° to the frontal plane (Yelnik & Percheron, 1979). As a consequence the STN has three anatomical characteristics, which make its localization difficult: it is lens shaped, relatively small, and oblique. For these reasons, the position of STN cannot be simply determined by viewing a single planar plane, but rather requires a precise and reproducible 3D reconstruction of its entire extent and a clear differentiation from the surrounding tissue. Besides the anatomical peculiarities the STN shows interindividual variations in size, shape and dimension, which complicated the positioning of electrodes basing on statistical and anatomical coordinates. In this study we used different MR modalities (T1w, T2w, 1.5mT vs. 3mT) to define the target point. Following postprocessing allowing a detailed visualization in all three sections of the space and perpendicularly along the planned trajectories, using excellent contrast between hypointense structure of STN and Nc. ruber and the hyperintense tissue in the surrounding. With the use of 3mT MRI a high resolution of basal cerebral structures, including the target area of STN and its neighbouring structures, could be achieved. Criteria for the following placement of microelectrodes were the longest medial-lateral and ventral-posterior diameter of STN and the ventral border of the red nucleus. The central trajectory was aimed and located immediately lateral to the anterior aspect of the Nc. ruber in the axial plane with regard to the patient's anatomy. MER and macrostimulation were used for electrophysiological respectively clinical validation of chosen trajectories for final electrodes. MER obtained by electrophysiological examination were consistent with other reports of bursting and non-bursting activities (Hutchison et al., 1998; Raeva & Lukashev, 1993) and correlated in the majority of tested trajectories with the typical STN signature in frequency and amplitude. Microrecording results were limited by the typical activity patterns of neighbouring structures of the zona inserta, substantia nigra and the background activity of the basal cerebral structures as well.

The image guided placement of micro- and final electrodes implicates the preoperative fixation of the stereotaxic frame just before image acquisition hours before surgery. Unfortunately most of these classic stereotaxic frames (weight: 2000 to 2500 g) are really heavy and uncomfortable during it´s fixation on the patients skull. During image acquisition, planning and surgical procedure all patients are free of L-Dopa medication to guarantee a reliable neurological testing during electrode positioning and following clinical testing. Stress, medication free interval and tremor-associated disability enforce possible motion artefacts in the acquisition of planning image data sets. This movement theoretically reduces the accuracy of image coregistration between image modalities.

Following preoperative postprocessing procedure including image fusion and definition of electrode trajectories is time consuming - to be just in time on the day of surgery is stressfull for patients and surgeons and can be a logistic problem, which is difficult to measure.

Beside the fixation of the patient´s head on the table via special head holders conventional functional neurosurgery requires the adjustment of all axis of the space corresponding to the target and entry coordinates using the microdrive and a special target arcl. A re-checking is following using by the target arch simulator, which gives additional safety, but which is time consuming. After finishing the dominant side all the equipment has to be removed, readjusted and readapted for the second side, which delay the surgery additionally and which implicates moments of inaccuracies. In the consequence, the accuracy of "static" image guided devices decreases with the time of surgery secondary to the intraoperative brain shift as a result of a) loss of cerebrospinal fluid (CSF), b) gravity, c) anaesthesiological procedure and d) brain-immanent characteristics. Confirmed by own experiences a tissue shift even in the region of STN could be documented exemplarily in the end of a hours lasting routine DBS procedure by vectorshift deformation analysis, which expressly underline the requirement of a stringent surgery. As a result of diverse shift studies it´s accepted, that long lasting procedures can dipose progressive CSF loss via burr hole trepanation and brain shift associated inaccuracies even in the middle of the brain. In the consequence, all factors, disposing shift associated inaccuracies should be prevented strictly. Microrecording and macrostimulation are relatively standardised steps and can help to compensate the mentioned inaccuracies electrophysiologically. Both neurosurgical steps are the preconditions for the following positioning of the final electrode.

In this series the mean number of active electrodes was with 6.7 (group I) and 7.1 (group II) per patient should be very good, but is confirmed by other studies. In our opinion the slight difference of the mean number of active electrodes between both groups is a possibly result of a better resolution of anatomical structures and improved signal-to-noise ratio by 3 T MRI, especially in the target region and can be the reason for a shorter surgical time. In our study intraoperative MER was an essential tool to find an optimal target point for the macrostimulation, which can reduce the surgeon's uncertainty and increases the procedure's safety. Macrostimulation was performed only in this macroelectrode, in which the cellular activity characteristics of the STN have been identified. The criteria for changing stimulation electrode were the missing motor effect of macrostimulation and persistent stimulation-induced side effects, including paresis, sensible sensations or dyskinesia. Correct anatomical and functional target – namely where the best clinical result with a partial or complete relief of symptoms – were the base for the actual placement of the permanent electrode.

As a consequence of preoperative postprocessing and following planning procedure the functional coordinates were comparable in both groups and differed only slightly, especially the x-coordinates, which were ± 11.25 in group I and ± 10.4 in group II. This correlates possibly with a changed selection of the best track for the permanent electrode placement from the central position (48%) in group I to the anterior (41.7%) and central (37.5%) position in group II. Maybe this is an indication for the phenomenon that a smaller distance from the target point to the AC-PC line correlates with a good clinical response stimulating the anterior part of the Nc. subthalamicus. However, both study groups are too small to conclude a strict and reliable tendency.

Corresponding to this surgical concept we found a sustained improvement in PD-associated motor disability (UPDRS, part III), which is confirmed by Pollo et al., 2007, and Kleiner-Fisman et al., 2006, presenting meta-analysis of outcomes from 1993 until 2004.

The medication doses could be reduced to the same extent in both groups and were in the range reported in the literature (Beric et al., 2001; Limousin et al., 1998; Minguez-Castellanos et al., 2005; Okun et al., 2005; Russmann et al., 2004). Differences in preoperative image acquisition (1.5 T, 3 T), postprocessing and defined target coordinates and chosen electrode tracks were not associated with a definite improvement of motor response and drug reduction, which would justify the use of 3 T MRI absolutely.

4. Conclusions

Acquisition of T2w 3 T MRI for following planning procedure is a useful tool to visualize the target region and anatomical landmarks with a high fidelity of detailed information. Microrecording is an excellent and reliable method to validate the target area intraoperatively by registration of typical STN signatures. Over and above that, it allows an identification of the longest segment of STN, which we preferred as the electrode position for macrostimulation and for placement of permanent STN-electrode. With the use of 3 T MRI data for image postprocessing and planning procedure the visualization of the target point – the STN – could be improved and allowed a high precision in the definition of target and entry coordinates of the virtual trajectory. Macrostimulation via macroeletrodes confirmed the target point and was used to detect any side effects for further stimulation. The macrostimulation and intraoperative testing guaranteed a proper placement of both electrodes, expecting a high rate of successful surgeries and permanent functional effects.

With our study we could confirm an encouraging response of PD-associated movement disorders. Besides the neuroradiological, physiological and neurosurgical techniques and procedures, the most important prerequisite is the optimal visualization of the target area, which can be achieved by high-resolution MRI. In the consequence using 3 T MRI series is one way to increase the surgeons and patients safety and to support an optimal electrode placement.

But, this study is not suitable to conclude, that a better visualization of the STN is also associated with a further clinical improvement of motor response and reduction of L-dopa, which is known in conventional functional neurosurgery using 1.5 T MRI. Further studies should be initiated to find a better conclusion. Up to this point, the choice of method should depend on the technical resources, preferences and experiences of each centre.

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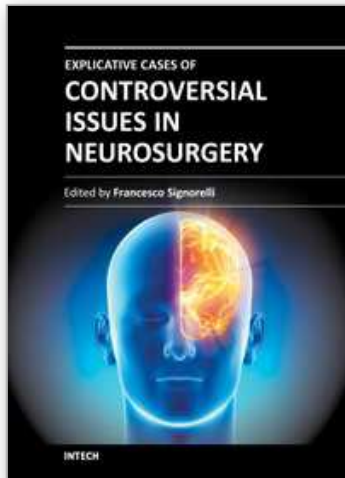
Explicative Cases of Controversial Issues in Neurosurgery

Edited by Dr. Francesco Signorelli

ISBN 978-953-51-0623-4

Hard cover, 534 pages

Publisher InTech

Published online 23, May, 2012

Published in print edition May, 2012

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