ORIGINAL PAPER/*ARTYKUł ORYGINALNY*

Surgical treatment of insular tumours with tractography, functional magnetic resonance imaging, transcranial electrical stimulation and direct subcortical stimulation support

Chirurgiczne leczenie guzów wyspy z wykorzystaniem traktografii, czynnościowego rezonansu magnetycznego, przezczaszkowej stymulacji elektrycznej oraz bezpośredniej stymulacji istoty białej podkorowej

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Neurologia i Neurochirurgia Polska 2011; 45, 4: 351–362

Abstract

Background and purpose: Surgical treatment of insular tumours carries significant risks of limb paresis or speech disturbances due to their localization. The development of intraoperative neuromonitoring techniques that involve evoked motor potentials induced via both direct and transcranial cortical electrical stimulation as well as direct subcortical white matter stimulation, intraoperative application of preoperative tractography and functional magnetic resonanceimaging (fMRI) in conjunction with neuronavigation resulted in significant reduction of postoperative disabilities that enabled widening of indications for surgical treatment. The aim of this study was to present the authors' own experience with surgical treatment of insular gliomas.
Material and methods: Our cohort comprises 30 patients with insular gliomas treated at the Department of Neurosurgery in Sosnowiec. Clinical symptoms included sensorimotor partial seizures in 86.6%; generalized seizures in 23.3%; persistent headaches in 16.6% and hemiparesis in 6.6%. All the patients were operated on with intraoperative neuromonitoring that included transcranial cortical stimulation, direct subcortical white matter stimulation as well as tractography and fMRI concurrently with neuronavigation. The analysis in - cluded postoperative neurological evaluation along with the

Streszczenie

Wstęp i cel pracy: Ze względu na lokalizację chirurgia guzów wyspy obarczona jest ryzykiem wystąpienia niedowładów w zakresie kończyn oraz zaburzeń mowy. Postęp w ograniczeniu inwalidztwa pooperacyjnego, a tym samym rozszerzeniu wskazań do leczenia chirurgicznego wynika ze śródoperacyjnego zastosowania neuromonitorowania, w tym badania potencjałów ruchowych, obejmujących bezpośrednią lub przezczaszkową stymulację elektryczną kory mózgu oraz bezpośrednią stymulację istoty białej podkorowej, a także śródoperacyjne zastosowanie traktografii i czynnościowego rezonansu magnetycznego (fMRI) w połączeniu z systemem neuronawigacji. Celem pracy było przedstawienie własnych doświadczeń w chirurgicznym leczeniu glejaków wyspy.
Materiał i metody: Materiał obejmował 30 chorych z guzami wyspy, operowanych w Klinice Neurochirurgii w Sosnowcu. Objawy kliniczne guzów wyspy obejmowały napady padaczkowe częściowe czuciowo-ruchowe w 86,6%; uogólnione napady drgawkowe w 23,3%; uporczywe bóle głowy w 16,6% oraz niedowłady połowicze w 6,6%. Wszyscy chorzy byli operowani z wykorzystaniem śródoperacyjnego neuromonitorowania, obejmującego przezczaszkową stymulację elektryczną kory mózgu, bezpośrednią stymulację istoty białej podkorowej, a także traktografię i fMRI w połączeniu z systemem neuronawigacji.

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Received: 4.06.2010; accepted: 14.02.2011

assessment of the radicalism of resection evaluated based on postoperative MRI.
Results: Postoperatively, four patients had permanent hemiparesis (13.3%); importantly, two out of those patients had preoperative deficits (6.6%). Persistent speech disturbances were present in four patients (13.3%). Partial sensorimotor seizures were noted in two patients (6.6%). Seizures in the other patients receded. Intraoperative transcranial electrical stimulation as well as direct subcortical white matter stimulation along with tractography (DTI) and fMRI facilitated gross total resection of insular gliomas in 53.5%, subtotal in 13.3% and partial resection in 33.1%.
Conclusions: Implementation of TES, direct subcortical white master stimulation, DTI and fMRI into the management protocol of the surgical treatment of insular tumours resulted in total and subtotal resections in 66% of cases with permanent motor disability in 6.6% of patients. Poor prognosis for independent living after surgery mainly affects patients with WHO grade III or IV.

Key words: insular gliomas, surgery, DTI, fMRI, transcranial electrical stimulation, subcortical stimulation.

W opracowaniu wyników ocenie poddano stan neurologiczny chorych po operacji oraz doszczętność resekcji określoną na podstawie kontrolnego badania rezonansu magnetycznego.
Wyniki: Po leczeniu operacyjnym u 4 pacjentów stwierdzono utrwalone niedowłady połowicze (13,3%), w tym u 2 (6,6%), u których występowały przed operacją. Utrwalone zaburzenia mowy wystąpiły u 4 pacjentów (13,3%). Po operacji napady padaczkowe częściowe czuciowo-ruchowe spostrzegano tylko u 2 pacjentów (6,6%). U pozostałych chorych napady padaczkowe ustąpiły. Zastosowanie w trakcie operacji guza wyspy przezczaszkowej stymulacji elektrycznej, bezpośredniej stymulacji istoty białej podkorowej, wykorzystanie traktografii oraz fMRI umożliwiło całkowite wycięcie guza w 53,3%, prawie całkowite w 13,3% i częściowe w 33,1%.
Wnioski: Zastosowanie w trakcie operacji guzów wyspy przezczaszkowej stymulacji elektrycznej, bezpośredniej stymulacji istoty białej podkorowej, traktografii oraz fMRI umożliwiło całkowitą i subtotalną resekcję w 66% przypadków, z wystąpieniem trwałych niedowładów u 6,6% chorych. Złe rokowanie odnośnie do możliwości samodzielnego życia dotyczyło głównie chorych z guzami wyspy w III lub IV stopniu złośliwości wg WHO.

Słowa kluczowe: guzy wyspy, leczenie chirurgiczne, DTI, fMRI, stymulacja elektryczna przezczaszkowa, stymulacja istoty białej.

Introduction

Due to their location deep in the cerebral hemisphere, within the lateral sulcus, surgical treatment of insular tumours carries a risk of postoperative paresis or paralysis of the limbs along with speech disturbances in cases with dominant hemisphere localization. Both high- and low-grade gliomas might arise within the insula with significant predominance of the latter [1]. A paradigm that favoured conservative treatment of insular tumours dominated for many years. It was not until the beginning of the 1990s that Yasargil's studies on surgical treatment of insular tumours were published [2]. It has led to the gradual change of the view on surgical treatment of neoplastic lesions within the insula. The progress in the field of surgical management of insular tumours has resulted from studies that provided detailed information on vascularisation of the insula and adjacent structures, particularly the internal capsule and corona radiata [3-7]. Further reduction of the perioperative disability and, along with it, further extension of indications for surgical treatment occurred after introduction of intraoperative motor evoked potentials (MEP) monitoring [8-9]. This examination encompasses both direct and transcranial electrical stimulation of the cortex or subcortical white matter tracts during insular tumour surgery. Intraoperative implementation of tractography (DTI) in combination with neuronavigation brought further limitation of adverse sequelae of the surgery. With their implementation, a surgeon gains the ability of intraoperative verification of the resection extent in relation to the internal capsule, which facilitates mechanical injury evasion [10,11]. Neuronavigation also helps, in a limited range, to assess the extent of the resection. This method is limited, however, by the intraoperative subcortical white matter shift. Conversely, this variable might be counteracted with intraoperative magnetic resonance imaging (MRI) or ultrasound imaging [10,11]. Taking into account the facts that surgery within the insula is rare and only radical resection ensures maximum benefits for the patient, we decided to share our own experience in this field.

Material and methods

A retrospective analysis of 30 cases of tumours that involved the insula, treated in the Clinical Department of Neurosurgery in Sosnowiec between 2006 and 2009, was performed. The study group included 12 women aged 31 to 68 years (mean age 43.1 years) and 18 men aged 20 to 79 years (mean age 44.2 years). On admission full catamnesis and neurological examination were performed with particular attention to the possibility of seizures or speech disturbances and limb paresis. Prior to surgery, all the patients underwent extensive MRI imaging performed in the Department of Radiodiagnostics of the Gliwice Branch of the Maria Skłodowska-Curie Memorial Cancer Centre and Institute of Oncology. On top of regular sequences, the examination encompassed cortical mapping with fMRI BOLD technique, diffusion-tensor imaging (DTI), perfusion-weighted imaging (PWI), diffusion-weighted imaging (DWI) and MR spectroscopy (MRS).

Examinations were performed with a 1.5 T (Avanto, Siemens) or 3 T (Achieva, Philips) system with a standard head coil. White matter tract changes resulting from the tumour presence were classified according to criteria proposed by Jellison *et al.* [12].

Based on preoperative MRI and tumour localization, patients were classified according to the Yasargil classification [2] into the following groups: 3A – patients with tumours within the insula alone; 3B – patients with tumours localized within the insula and operculum; 5A – insular tumours that infiltrate the orbital gyri of the frontal lobe and temporal lobe pole; 5B – insular tumours that infiltrate the orbital gyri of the frontal lobe, temporal lobe pole and limbic structures within the mesial part of the temporal lobe.

Intraoperative monitoring included: fMRI for localization of the cortical motor and speech centres and tractography in conjunction with the BrainLab neuronavigation system; MEP – transcranial electrical stimulation (TES) and direct electrical stimulation of the subcortical white matter tracts (DSCS). In order to enable MEP monitoring, anaesthesia involved continuous infusion of propofol and opioids. No anaesthetic gases, barbiturates or myorelaxants were used since they interfere with evoked responses to the transcranial or direct stimulation. Constant temperature and blood pressure parameters were maintained. MEP examination was performed with 5-channel apparatus (Oxford Instrument, Medelec) with 'Synergy' software. An external AC stimulator (Digitimer) was coupled with Medelec apparatus. Inomed electrodes were used. A bipolar Galanda electrode was used as a stimulatory electrode for direct subcortical stimulation; for transcranial stimulation 'corkscrew' electrodes screwed into the scalp at C3 and C4 points according to a 10/20 scheme were used. Monopolar needle electrodes were used as receiving electrodes. Two electrodes (a receiver and reference electrode) were introduced into each muscle examined. The receiving electrode was inserted into the muscle's head while the reference electrode was introduced into the muscle's tendon or its vicinity. The standard registration protocol included evoked responses from the following muscles: for the upper limb, the small finger abductor and one of the thenar prominence muscles, most commonly the abductor pollicisbrevis muscle; for the lower limb, the anterior tibial muscle and gastrocnemius were monitored. The responses from these muscles were registered as a standard, independent of the tumour location or size, even in other types of surgery with MEP implemented. In order to verify transcranial stimulation efficacy, a response from the thenar prominence muscle ipsilateral to the insular tumour localization was recorded. The 'train' patterns of stimulation for cortical (TES) or motor fibres of the internal capsule (DSCS) stimulations were applied. The stimulatory impulse consisted of 4-6 short bursts that lasted 0.5 ms with 3-4 ms intervals. Voltage for transcranial stimulation varied from 300 to 700 V, usually within the range of 300-400 V. Voltage for direct subcortical stimulation averaged 100-120 V. TES was performed prior to resection in order to acquire initial (referent) muscle response recordings. Upon the approach to the region where the surgeon expected to find internal capsule fibres, a control TES stimulation was performed prior to each direct subcortical white matter stimulation and every several seconds in order to monitor conductivity of corticospinal tracts. We accepted a decrease in the amplitude of electrical response from monitored muscles that exceeded 50% in relation to the preoperative recording (reference recording) or when latency of the electric muscular response increased at least by 10% as threshold values in intraoperative monitoring with MAP that indicated significant deterioration of corticospinal tract conductivity. Importantly, to define universal, proper, absolute values of referral amplitude and latency (ms) was virtually impossible. Various factors, such as body temperature, arterial blood pressure, the surface of contact between an electrode and a muscle (impedance value), the intensity of electrical stimulation, length of corticospinal tracts, anaesthetics, etc., affected the efficacy of stimulation and reception of responses from muscles. In order to counteract the aforementioned obstacles, we analysed percentage changes between the final recording after resection and the initial recording that had preceded the resection.

Surgical technique

Prior to surgery all the patients gave written consent for the surgery after receiving extensive information about the type of surgery that had been planned, the necessity of implementation of invasive, intraoperative neuromonitoring techniques as well as all the possible complications that might have resulted from the proposed therapeutic scheme. We also obtained the approval of the Bioethics Committee of the Silesian Medical University.

Patients were positioned supine with head rotated 30° contralaterally to the lesion. The surgery was performed via a lateral fissure approach. Initially fronto-temporal craniotomy was performed. Subsequent to dural opening, the location of functional areas according to preoperative fMRI mapping was identified on the cerebral cortex with neuronavigation that allowed an 'in vivo' assessment of its localization in relation to the tumour. Verification of speech centres' localization via direct cortical stimulation in relation to the fMRI mapping was not feasible due to the general anaesthesia used for surgery. Eloquent areas of the cerebral cortex relevant to the activity fields in the fMRI mapping were protected with wet cottonoids during the whole procedure.

In the next stage, the lateral fissure was dissected. In cases where tumours were limited to the insula (3A type), the frontal, fronto-parietal and temporal opercula were dissected from the insula. Thick, rolled cottonoids were subsequently used in order to ensure stable fixation of the opercula, which facilitated unbound surgery within the insula. Upon visualization of the insular surface, M1, M2 and M3 segments of the middle cerebral artery were dissected. As soon as the lateral lentostriatal arteries had been identified, their initial part was visualized with concomitant localization of the middle cerebral artery segment they originated from. Particular attention was paid to the last lateral lentostriatal artery that originates at the very edge of the insula from the M1 segment of the middle cerebral artery in order to confirm whether a single or double trunk is present. The distal segment was not dissected in order to avoid injury to the internal capsule vascularisation.

Then, insular boundaries were localized – limen insulae in front, inferior periinsular sulcus caudally and superior peri-insular sulcus rostrally. Upon delineation of insular limits, we proceeded with tumour removal with either the dissector or ultrasound aspirator. The neoplastic lesion was dissected subarachnoidally. As a rule, resection began with limen insulae removal followed by tumour removal between short, insular branches of the middle cerebral artery. Meticulous attention was paid to their preservation but it was not successful in all of the cases. Short branches usually originated from the M2, less often from the M3 segment on the posterior surface of the middle cerebral artery. Particular attention was also paid to preservation of long branches in the posterior part of the insula for they are responsible for corona radiata vascularisation. During dissection of the superior part of the tumour, in the lead of the superior periinsular sulcus, attention was paidto preservation of adjacent corona radiata. All the cases with involvement of polar and mesial parts of the temporal lobe (5A and 5B types) required that tumour resection began with temporal lobe neoplastic lesion removal followed by insular tumour dissection. The tumour part that infiltrated the orbital gyri of the frontal lobe (5A type) on top of insular and temporal (polar) involvement was dissected at the very end of the procedure following lesion dissection from the temporal lobe and the insula. Localization of the internal capsule was continuously verified with neuronavigation during insular dissection. Simultaneously, transcranial electrical stimulation was performed and whenever the internal capsule was approached, multidirectional direct subcortical white matter stimulation was performed in order to localize it. Each time the tumour encompassed eloquent areas, i.e. cortical speech centres, or invaded corticospinal tracts, the lesion remained in situ.

The extent of resection was assessed based on postoperative T2-weighted FLAIR images with subsequent volumetric analysis performed within 3 days from surgery according to the classification of Berger *et al.* [13] and was stratified as: total resection, subtotal resection whenever less than 10 ml of the tumour tissue remained, and partial resection when the remaining part of the tumour exceeded 10 ml. Final diagnosis was based on histopathology. All of the patients were reexamined between six months and two years after surgery; at the same time they underwent control MRI. Pre- and postoperative Karnofsky performance scale assessment was performed as well [14].

Results

Clinical signs and symptoms of insular tumours included: sensorimotor partial seizures in 86.6%, generalized seizures in 23.3%, persistent headaches in 16.6% and hemiparesis in 6.6% of cases. Lesions were found in the left hemisphere in 18 cases (60%) and in the right hemisphere in 12 cases (40%). Patients were diagnosed based on T2-weighted MRI images with FLAIR. Corticospinal tract location within the hemisphere along with its tumour dependent dislocation, fibre loss or coexisting oedema was defined based on tractography (Fig. 1).

Based on tumour site, patients were classified according to the Yasargil [2] scale. Type 3A was found in 9 patients (30%), type 3B in 8 patients (26.6%), type 5A in 9 patients (30%) and type 5B in 4 patients (13.4%). We managed to identify proximal segments of lateral lentostriatal arteries that originated from the M1 segment of the middle cerebral artery in 18 cases (60%). The lentostriatal artery 'closest to the surgeon', i.e. the last one that originates from the M1 segment of the middle cerebral artery at the limen insulae, always appeared as a single trunk that immediately divided into two branches (Fig. 2).

Gross total resection was achieved in 16 cases (53%), subtotal in 4 (13.3%) and partial in 10 cases (33.7%) (Fig. 3).

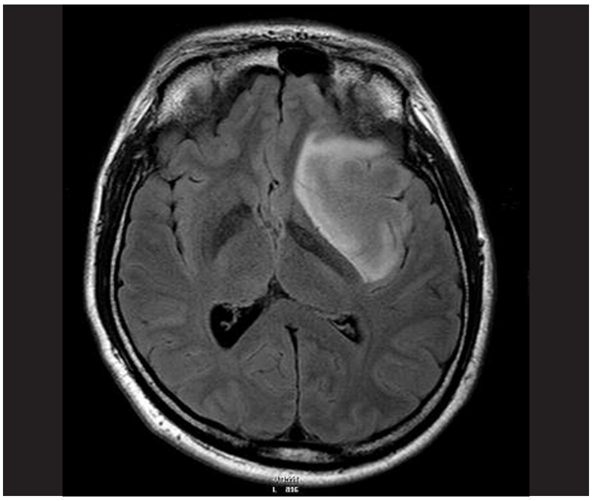


Fig. 1A. Patient FJ. T2-weighted FLAIR axial MRI image; left-sided, high intensity tumour clearly seen in the insula.Medial aspect of the tumour adjacent to the internal capsule

Only 2 patients presented with preoperative hemiparesis (6.6%). In the early postoperative period, hemiparesis was found in 17 (56.6%), including 2 patients

B-1

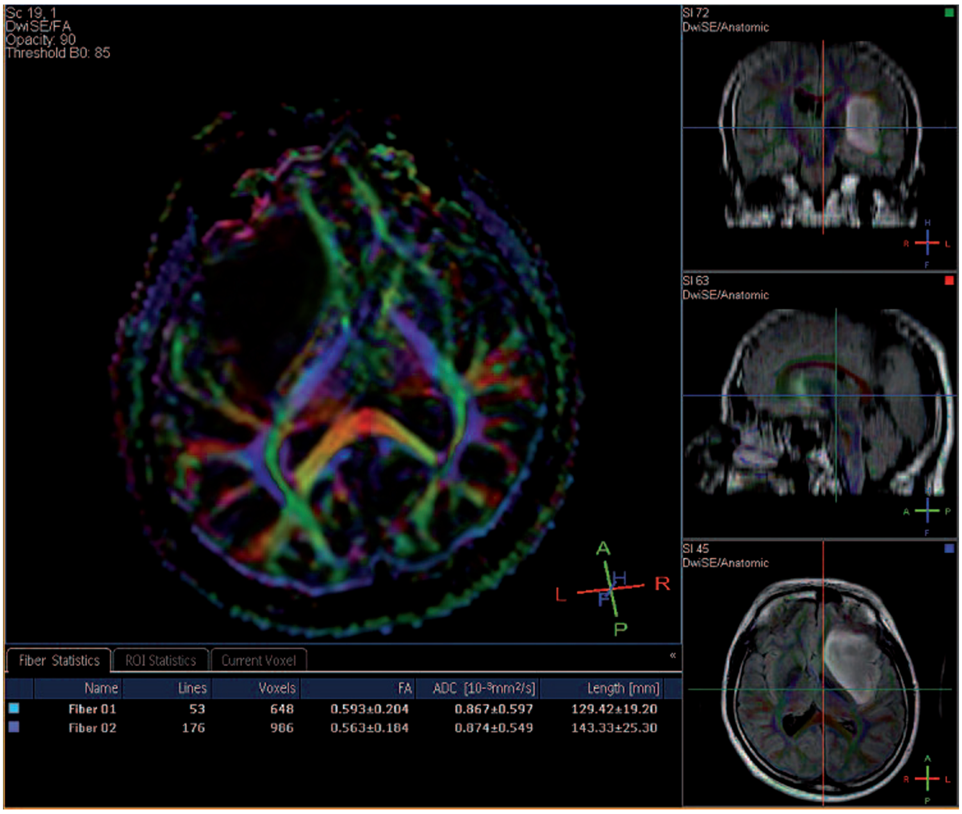
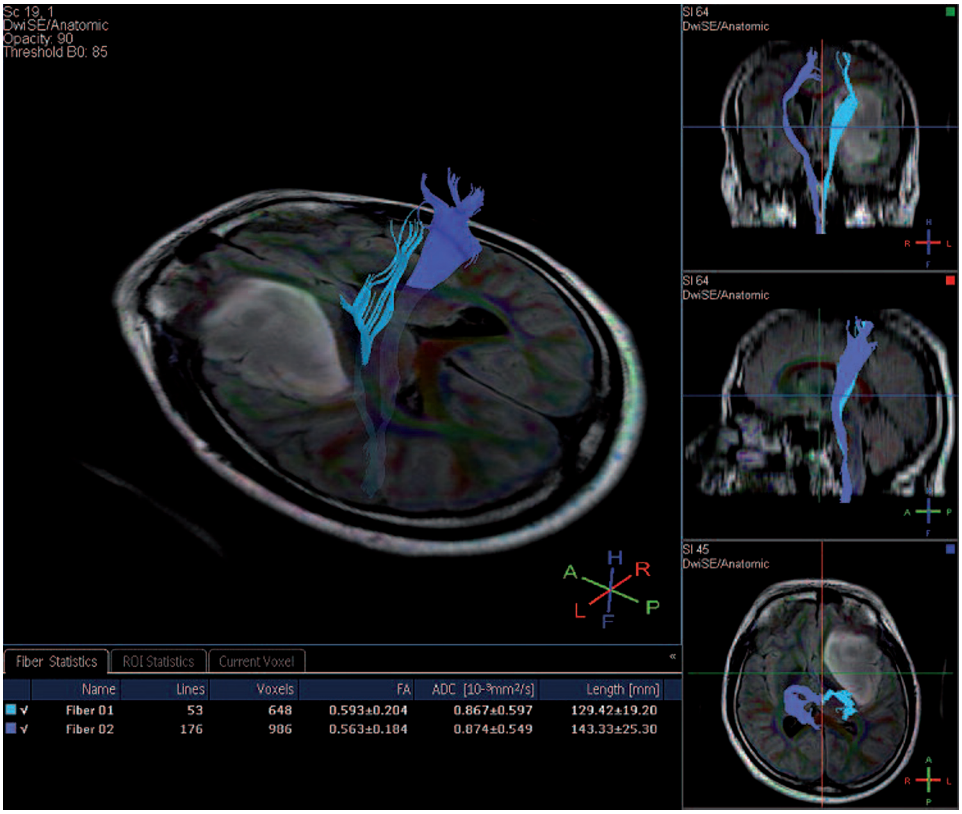


Fig. 1B-1. Patient FJ. Colour-coded fractionated anisotropy map. A given colour is defined by the direction of the maximal component of diffusion tensor: blue – rostral/caudal; red – left/right; green – anterior/posterior. Colour intensity depends on FA value

B-2



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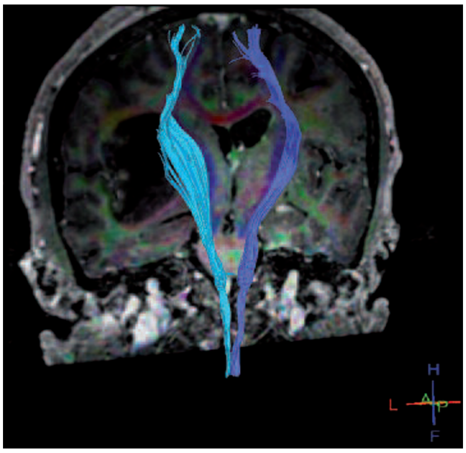

Fig. 1B-2; 1B-3. Patient FJ. MR tractography 1B-2 axial; 1B-3 coronal. White matter tract reconstructions superimposed on T1-weighted 3D images fused with a colour-coded fractionated anisotropy map. Corticospinal tracts and corticopontine tracts in the posterior limb of the internal capsule are symmetrical; no reduction in the number of tracts in the posterior limb of the internal capsule on the tumour side. Patient had no motor deficits

with preoperative deficit – these patients deteriorated in comparison to their preoperative status (Figs. 4 and 5).

Follow-up examination was performed between 6 months and 2 years after surgery; the average follow-up time was 1.3 years. At the time of examination, 4 patients presented with established hemiparesis (13.3%); this group included 2 patients (6.6%) who presented with preoperative hemiparesis (Fig. 6).

Importantly, established hemiparesis was found in patients with WHO grade III or IV gliomas. Three patients suffered from glioblastoma, and one patient had histopathological diagnosis of anaplastic astrocytoma. All the patients who developed permanent hemiparesis after surgery had shown amplitude reductions exceeding 50% in relation to the initial recordings (prior to tumour resection) in their intraoperative MAP recordings along with a minimum of 10% increase in the latency of the electrical muscular response during TES. On the other hand, they showed comparable (sometimes even higher) response amplitudes from upper and lower limbs in relation to the initial recordings when direct subcortical stimulation in the internal capsule vicinity was performed. The distance from the stimulatory electrode to the internal capsule judged based on DTI studies and neuronavigation averaged 5 mm (Fig. 7).

None of the patients presented with speech disturbances in the initial examination. In the early postoperative period, all 18 patients (100%) whose tumours were located in the left, dominant hemisphere devel-

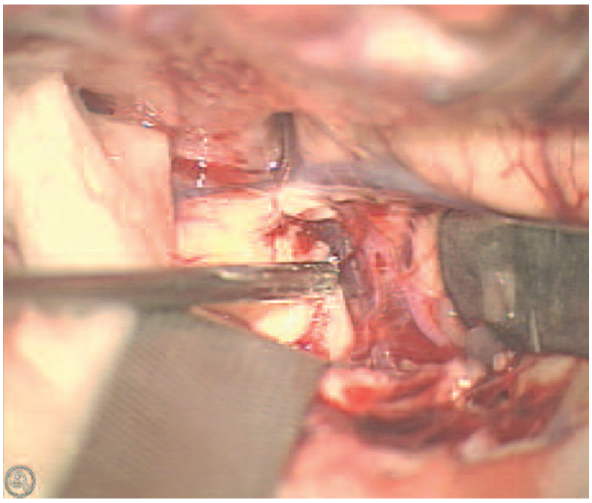

Fig. 2. Patient FJ. Intraoperative microscopic view: main stem of a lentostriatal artery distal to its origin from middle cerebral artery divides into two branches

Fig. 3. Patient FJ. Follow-up MRI images one year after surgery. A) and B) T2-weighted FLAIR images, C) T1-weighted, contrast-enhanced image. Complete tumour resection; hyperintense areas in T2-weighted FLAIR images (2A) delineate minor ischaemic lesions. Patient had no motor deficits

oped dysphasia. Thanks to the gradual improvement seen during the convalescence period, only 4 patients (13.3%) presented with persistent speech disturbances on their follow-up visit. None of them underwent detailed neuropsychological examination, though.

Prior to the surgery, 20 patients presented with Karnofsky performance scores of 80 to 100 points (66.6%). Ten patients achieved 50 to 70 points (33.3%) when assessed preoperatively. In the latter group, three patients had WHO grade IV tumours, four patients WHO grade III, two patientsWHO grade II and one person WHO grade I tumour. Conversely, 70% of patients who required support (50-70 points) had a high-grade glioma (grade III or IV).

During follow-up, 22 patients presented with Karnofsky performance scores of 80 to 100 points (73.3%), six patients achieved 50 to 70 points (20%) and two patients scored below 50 points (6.6%). All of the patients who scored below 50 points had glioblastoma.

Six out of 30 patients who underwent surgery resumed their previous professional career (20%), all of them with a final diagnosis of WHO grade I or II glioma. During follow-up only two patients (6.6%) reported partial sensorimotor seizures; all the other patients were seizure-free. The whole cohort has received antiepileptic drugs since the surgery.

The final pathological diagnosis is presented in Table 1. Based on the WHO classification 3.3% of tumours were grade I, 53.3% grade II, 30% grade III and 13.3% grade IV.

A

B

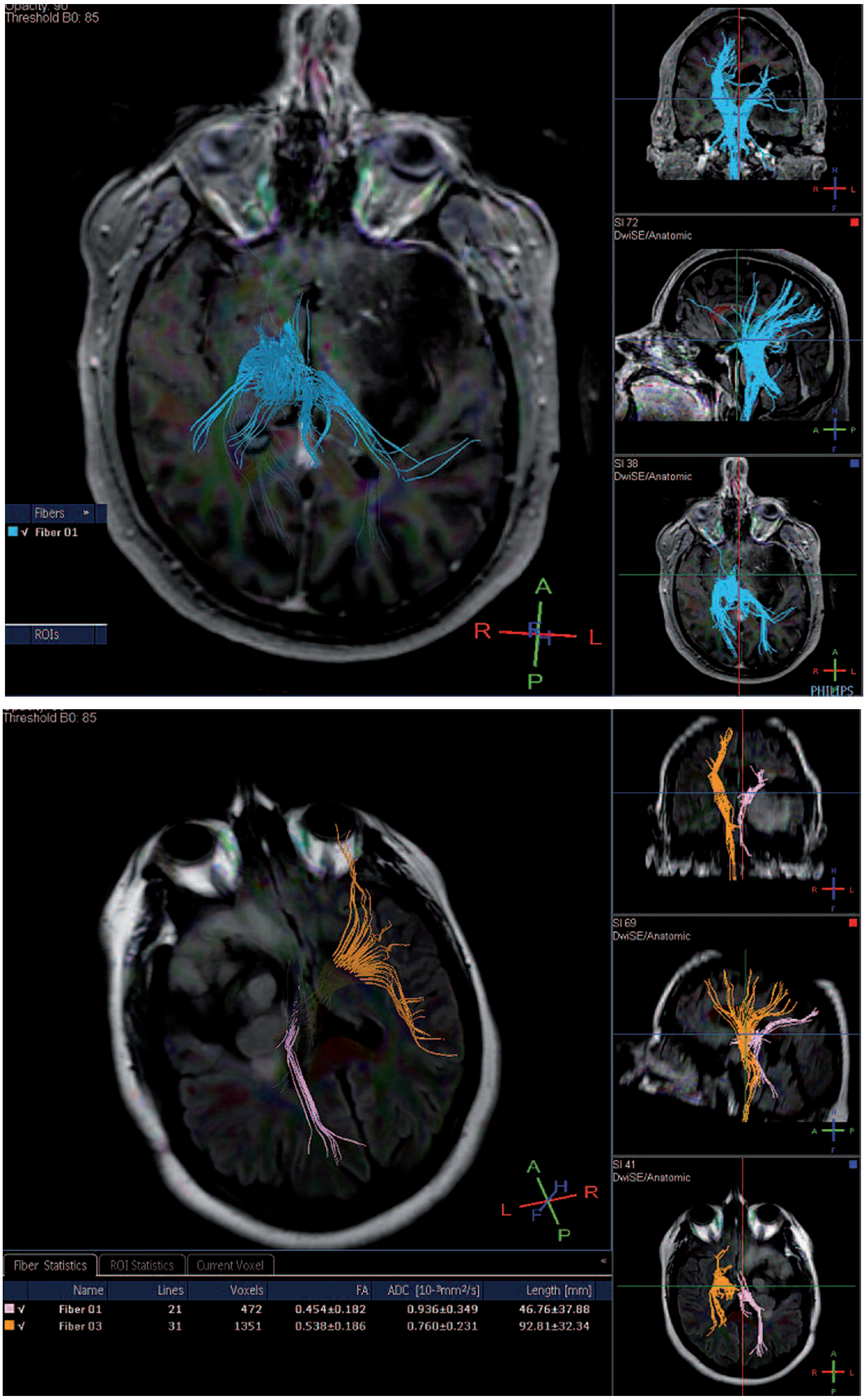

Fig. 4. Patient KK with left-sided insular tumour that infiltrated pole of the temporal lobe and orbital gyri of the frontal lobe – type 5A according to Yasargil classification. MR tractography superimposed on morphological images (T1-weighted 3D) fused with colour-coded fractionated anisotropy map. Loss of fibres in corticospinal and corticopontine tracts on the left. Dislocation of corticospinal and corticopontine tracts on the left incurred by tumour of temporal lobe and insula is present. Patient with mild right-sided hemiparesis (grade IV according to Lovett scale)

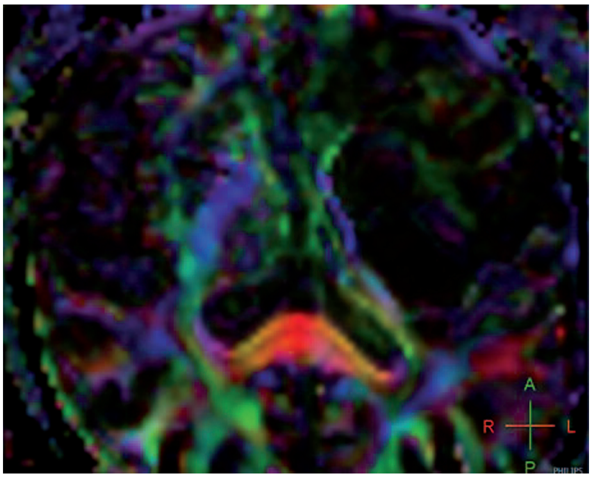

Fig. 5. Patient KK. Colour-coded fractionated anisotropy map. Colour intensity depends on FA value. Left-sided insular tumour that infiltrates lenticular nucleus compresses white matter tracts in the anterior and posterior limb of the internal capsule. Preserved colour and slightly altered colour intensity (FA reduction by approx. 25-30%) of the posterior limb of the internal capsule suggest dislocation and oedema of the posterior limb tracts (type I/II according to Jellison)

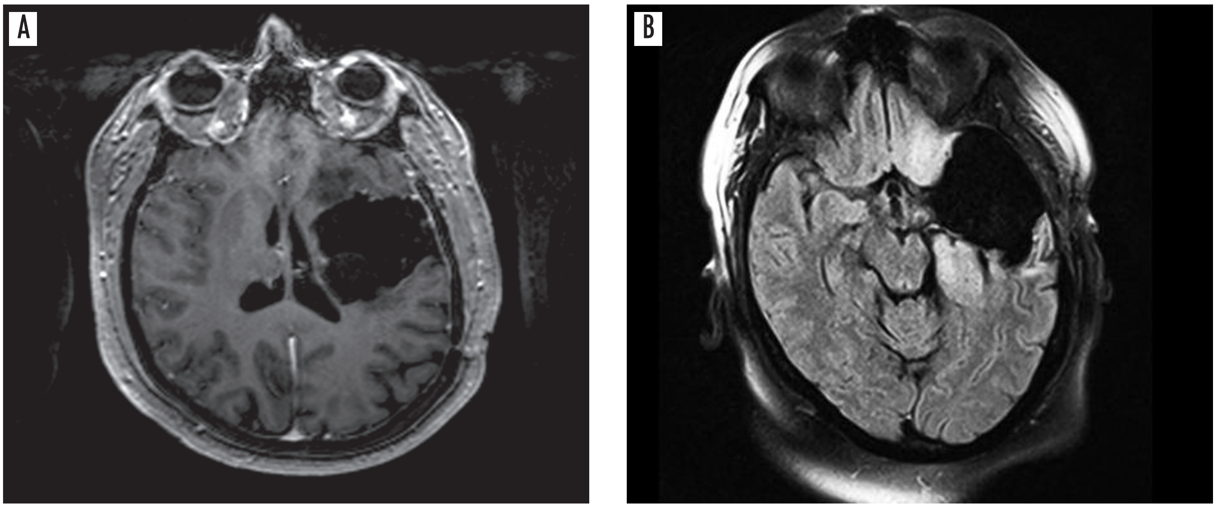

Fig. 6. Patient KK. A) T2-weighted FLAIR image. B) T1-weighted contrast-enhanced image. Follow-up MRI one year after surgery. Subtotal tumour resection, small residual tumour in the anterior part of the orbital gyri

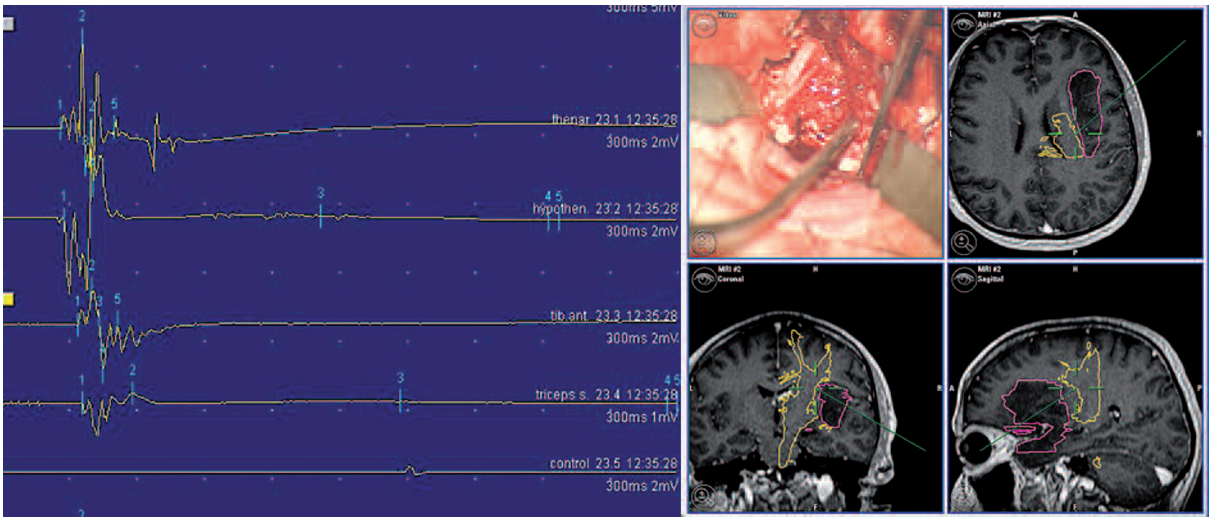

Fig. 7. Corticospinal tract fibres' localization within internal capsule via direct electrical stimulation with Galanda electrode. Upper (thenar and hypothenar muscles) and lower (tibialis anterior and gastrocnemius muscles) limb response suggests direct contact of the probe with the internal capsule

Table 1. Final histopathological diagnosis in patients with insular tumours

Pilocytic astrocytoma	1
Fibrillary astrocytoma	5
Mixed astrocytoma – fibrillary, partial protoplasmic	2
Mixed astrocytoma – fibrillary, partial gemistocytic	1
Gemistocytic astrocytoma	1
Diffuse mixed astrocytoma – fibrillary and gemistocytic	1
Diffuse mixed astrocytoma – fibrillary, partial protoplasmic and gemistocytic	1
Isomorphic oligodendroglioma	2
Mixed oligoastrocytoma	3
Fibrillary astrocytoma, partial gemistocytic and undifferentiated	1
Anaplastic astrocytoma	6
Glioblastoma	3
Gliomatosis cerebri	2
Primary neuroectodermal tumour	1

Discussion

Despite the risks of permanent hemiparesis and speech disturbances, a constant increase in the number of patients treated for insular tumours has been reported over the last several years, thanks to the introduction of neurophysiological monitoring [1,7,9,15-17]. It is of interest that in our study 60% of patients with insular gliomas presented with left-sided tumours; moreover 56.6% of them were low-grade. A similar proportion (60%) of low-grade gliomas in their group of 104 patients treated for insular tumours was reported Sanai *et al.* [17]. Lang *et al.* reported even higher frequency of the lesions on the left side (70%) as well as low-grade gliomas of the insula (75%) [15].

During surgery, the proximal segment of lentostriatal arteries that originated from the middle cerebral artery at the limen insulae was dissected. In our cohort we managed to identify the initial segment of the lentostriatal arteries in 18 cases (60%). All of them originated from the M1 segment of the middle cerebral artery. In 12 cases we were unable to unequivocally identify the initial segment of these arteries. Ture *et al*., based on their sectional material analysis, proved that 78% of lentostriatal arteries originate from the M1 segment, 18% from the frontal or temporal branch of the middle cerebral artery, and 4% from the upper or lower trunk of the M2 segment [6]. In all our cases, we noticed the presence of two main vascular branches at the origin of the last lentostriatal artery that originates from the M1 segment. Yasargil *et al*. suggest that all the patients, prior to insular tumour surgery, should have angiography of the internal carotid arteries in order to visualize the two main arterial branches, i.e. the internal and external lentostriatal arteries,which would have allowed the surgeon to become familiar with their course so as to avoid intraoperative injury [2]. Following the suggestions of Yasargil *et al*. and Ebeling *et al*. we did not dissect distal segments of lentostriatal arteries on their route toward the anterior perforated substance due to the risk of their injury [2,18].

An important part of the operation involved control over the internal capsule localization based on DTI imaging, neuronavigation and direct electrical stimulation of the tumour cavity walls. Despite the hemisphere shift during surgery that has been described by various authors [10,11] and resultant inadequacy of the internal capsule localization based on DTI and neuronavigation, in our experience direct stimulation performed during surgery confirmed capsule localization appraised according to tractography and neuronavigation. We attained muscular response recordings comparable to initial ones during direct subcortical stimulation when the stimulatory electrode was within 5 mm of the internal capsule. Others have confirmed our data [19,20]. Preservation of lateral lentostriatal arteries, internal capsule and corona radiata prevented hemiparesis after surgery.

Surgical removal of the tumour located within the posterior part of the insula posed a risk of injury to the long insular arteries that provide blood supply for the corona radiata as well as mechanical injury of the corona radiata itself. Although Ture *et al*. [6] state that only 3 to 5% of the insular arteries are long branches that supply the corona radiata, the possibility of this injury should not be neglected. It is well known that the internal capsule makes the blood supply watershed zone between lateral lentostriatal arteries medially and insular arteries laterally that originate from the middle cerebral artery. There are no anastomoses between these two systems. We observed transient hemiparesis in 56.6% of patients after surgery. Duffau reported a similar percentage (59%) of patients with neurological deterioration immediately after surgery [1]. Lang *et al*. observed transient neurological deficits in 36% of cases [15]. Finally, we observed permanent hemiparesis in 2 cases without preoperative deficits (6.6%) during follow-up. It resulted from ischaemic changes within the posterior arm of the internal capsule, whose presence was confirmed by postoperative MR. Duffau reported permanent neurological deficits in 4% of cases, while Sanai *et al*. did so in 6% of cases [1,17], in their groups of patients with low-grade gliomas. Describing motor tract monitoring with MEP during insular tumour surgery Neuloch *et al*. found deterioration (decrease of the amplitude) or disappearance of electrical, muscular responses to stimulation in 44% of patients, while permanent paresis that results in significant disability applied to no more than 4% of patients [9].

We found permanent hemiparesis in two other patients in our group; these patients, however, had suffered from hemiparesis prior to surgery and it had resulted from tumour infiltration that had been confirmed by DTI study. Intraoperatively, these patients presented with a decrease of over 50% in the amplitude of the electrical response to stimulation and an increase in the latency of the electrical muscular response that exceeded 10% relative to the initial recordings (registered prior to the tumour resection) during transcranial electrical stimulation (TES); simultaneously they retained comparable (sometimes even higher) amplitudes of responses from upper and lower limbs when compared to the initial recordings during direct subcortical stimulation of the internal capsule vicinity.

We attempted to preserve cortical speech centres localized during the preoperative fMRI study during the surgery; still, it was not successful in all of the cases. During follow-up we found speech disturbances in 13.3% of cases. Lang *et al*. reported transient speech deficits in 46% of patients after insular tumour resection that usually subsided during the first 3 months postoperatively [14]. French authors reported speech deficits in 23.8% of patients after surgery for WHO grade II gliomas of the insula [21]. The extent of resection we achieved – 66.6% of total or subtotal resections – was comparable to that reported by others. Lang *et al*., based on volumetric measurements, reported that they achieved an extent of resection over 90% in 45% of cases and 70 to 90% in 27.2% [15]. Duffau showed, based on preoperative MRI, that the extent of resection in WHO grade II gliomas (total or subtotal resection) amounted to 77% [1]. Conversely, Brell *et al*. estimated the extent of insular tumour resection (total or subtotal resection) at 64% [22]. Simon *et al*. in 2009, based on their analysis of 94 patients with tumours of the insula who underwent surgery between 1995 and 2005, reported 42% of tumour resections exceeding 90% and 51% of cases with the resection range between 70 and 90% [16].

Karnofsky performance scores in our cohort proved that the lowest quality of life was seen in the patients with anaplastic astrocytoma, glioblastoma and WHO grade III gliomatosis cerebri. Similarly, Simon *et al*. report that patients with glioblastoma in the insula and low Karnofsky score preoperatively have poor prognosis [16]. Zenter *et al*. also suggest that resection of an insular glioblastoma in older people provides very little benefit for the patient while surgical removal of a low-grade glioma has a significant impact on prognosis [7]. Our data confirmed low effectiveness of the surgical treatment of patients with WHO grade III and grade IV gliomas of the insula, which resulted from the fact that radical resection was not feasible; moreover, these patients had higher incidence of postoperative hemiparesis and more often became dependent. Taken together, our study supports the notion that insular glioma cases, particularly low-grade ones, should be operated on with the contemporary neuromonitoring methods implemented, i.e. with cortical mapping of motor and speech areas along with direct subcortical stimulation in combination with tractography (DTI). Duffau strongly supports early surgical treatment of WHO grade II glioma patients, with resection as extensive as possible [23].

Sanai *et al*. in their recent paper proved that overall survival of patients with low-grade gliomas depends on the extent of resection [17]. Furthermore, they found evidence that low-grade insular gliomas have a lower tendency for malignant transformation [17].

Conclusions

1. Implementation of TES, direct subcortical white matter stimulation, DTI and fMRI into the management protocol of the surgical treatment of insular tumours resulted in total resections in 53.3% of cases, subtotal in 13.3% and partial in 33.1% of cases. Permanent disability in the form of stable, postoperative hemiparesis in patients without previous deficits was found in two patients (6.6%).
2. Six months after surgery 13.3% of right-handed patients had speech deficits despite the application of fMRI imaging techniques during surgery of all left-sided tumours.
3. After insular tumour resection 93.3% of patients with seizures preoperatively were seizure-free.
4. Poor prognosis for independent living after surgery mainly affects patients with WHO grade III or IV insular tumours.
5. Progression of malignant disease, higher incidence of permanent neurological deficits as well as lack of self-dependence of the patients with WHO grade III and IV gliomas after surgery should prompt the surgeon to consider a biopsy and, upon confirmation of the diagnosis, cessation of surgical treatment of the lesion within the insula.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

This study was supported by the Ministry of Science and Higher Education grant no. NN 403278933.

References

1. Duffau H. A personal consecutive series of surgically treated 51 cases of insular WHO grade II glioma: advances and limitations. *J Neurosurg* 2009; 110: 696-708.
2. Yasargil M.G., Von Ammon K., Cavazos E., et al. Tumours of the limbic and paralimbic systems. *ActaNeurochir* (*Wien*) 1992; 118: 40-52.
3. Duret H. Recherches anatomiques sur la circulation de l'encephale. *Arch Physiol Norm Pathol* 1864; 1: 60-91.
4. Marinkovic S.V., Kavacevic M.S., Marinkovic J.M. Perforating braches of the middle cerebral artery. Microsurgical anatomy of their extracerebral segments. *J Neurosurg* 1985; 63: 266-271.
5. Marinkovic S.V., Milisavljevic M.M., Kovacevic M.S., et al. Perforating branches of the middle cerebral artery. Microanatomy and clinical significance of their intracerebral semgents. *Stroke* 1985; 16: 1022-1029.
6. Türe U., Yasargil M.G., Al-Mefty O., et al. Arteries of the insula. *J Neurosurg* 2000; 92: 676-687.
7. Zentner J., Meyer B., Stangi A., et al. Intrinsic tumors of the insula: A prospective surgical study of 30 patients. *J Neurosurg* 1996; 85: 263-271.
8. Duffau H., Capelle L., Lopes M., et al. The insular lobe: physiopathological and surgical considerations. *Neurosurgery* 2000; 47: 801-811.
9. Neuloh G., Pechstein U., Schramm J. Motor tract monitoring during insular glioma surgery. *J Neurosurg* 2007; 106: 582-592.
10. Nimsky C., Ganslandt C., Hastreiter P., et al. Intraoperative diffusion-tensor MR imaging: Shifting of white matter tracts during neurosurgical procedures – initial experience. *Radiology* 2005; 234: 218-225.
11. Nimsky C., Ganslandt C., Hastreiter P., et al. Preoperative and intraoperative diffusion tensor imaging fiber tracking in glioma surgery. *Neurosurgery* 2005; 56: 130-138.
12. Jellison B.J., Field A.S., Medow J., et al. Diffusion Tensor Imaging of cerebral white matter: a pictorial review of physics, fiber tract anatomy, and tumor imaging patterns. *AJNR* 2004; 25: 356-369.
13. Berger M.S., Deliganis A.V., Dobbins J.D., et al. The effect of extent of resection on recurrence in patients with low grade cerebral hemisopheregliomas. *Cancer* 1994; 74: 1784-1791.
14. Schag C.C., Heinrich R.L., Ganz P.A. Karnofsky performance status revisited: reliability, validity and guidliness. *J Clin Oncology* 1984; 2: 187-193.
15. Lang F.F., Olansen N.E., DeMonte F., et al. Surgical resection of intrinsic insular tumors: complications avoidance. *J Neurosurg* 2001; 95: 638-650.
16. Simon M., Neuloh G., von Lehe M., et al. Insular gliomas: the case for surgical management. *J Neurosurg* 2009; 110: 685-695.
17. Sanai N., Polley M.Y., Berger M.S. Insular glioma resection: assessment of patient morbidity, survival, and tumor progression. *J Neurosurg* 2010; 112: 1-9.
18. Ebeling U., Kothbauer K. Circumscribed low grade astrocytomas in the dominant opercular and insular region: a pilot study. *Acta Neurochir* (*Wien*) 1995; 132: 66-74.
19. Berman J.I., Berger M.S., Chung S.W., et al. Accuracy of diffusion tensor magnertic resonance imaging tractography assessed using intraoperative subcortical stimulation mapping and magnetic source imaging. *J Neurosurg* 2007; 107: 488-494.
20. Ozawa N., Muragaki Y., Nakamura R., et al. Identification of the pyramidal tract by neuronavigation based on intraoperative diffusion-weighted imaging combined with subcortical stimulation. *Sterotac Funct Neurosurg* 2009; 51: 67-71.
21. Duffau H., Taillandier L., Gatignol P., et al. The insular lobe and brain plasticity: lessons from tumor surgery. *Clin Neurol Neurosurg* 2006; 108: 543-548.
22. Brell M., Conesa G., Acebes J. Intraoperative cortical mapping in the surgical resection of low grade gliomas located in eloquent areas. *Neurocirugia* 2003; 14: 491-503.
23. Duffau H. Surgery of low grade gliomas: towards a "functional neurooncology". *Curr Opin Oncol* 2009; 21: 543-549.