Arq Neuropsiquiatr 2006;64(4):963-970

STRATEGIES FOR RESECTION OF LESIONS IN THE MOTOR AREA

Preliminary results in 42 surgical patients

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ABSTRACT - In recent years considerable technological advances have been made with the purpose of improving the surgical results in the treatment of eloquent lesions. The overall aim of this study is to evaluate the postoperative surgical outcome in 42 patients who underwent surgery to remove lesions around the motor cortex, in which preoperative planning by using neuroimaging exams, anatomical study, appropriate microsurgery technique and auxiliary methods such as cortical stimulation were performed. Twenty-two patients (52.3%) presented a normal motor function in the preoperative period. Of these, six developed transitory deficit. Twenty patients (47.6%) had a motor deficit preoperatively, nevertheless 90% of these improved postoperatively. Surgery in the motor area becomes safer and more effective with preoperative localization exams, anatomical knowledge and appropriate microsurgery technique. Cortical stimulation is important because it made possible to maximize the resection reducing the risk of a motor deficit. Stereotaxy method was useful in the location of subcortical lesions.

KEY WORDS: motor cortex, mapping, stimulation, stereotaxic techniques, preoperative planning.

Estratégias para ressecção de lesões em área motora: resultados preliminares em 42 pacientes operados

RESUMO - Nos últimos anos, consideráveis avanços tecnológicos, principalmente métodos de localização funcional do córtex cerebral, têm surgido no sentido de melhorar os resultados cirúrgicos no tratamento de lesões em áreas eloqüentes. O objetivo deste estudo é avaliar os resultados pós-operatórios em 42 pacientes submetidos à ressecção de lesões em área motora, utilizando-se de planejamento com exames de neuroimagem, conhecimento anatômico, técnica microcirúrgica adequada e métodos auxiliares a exemplo do estimulador cortical. Vinte e dois pacientes (52,3%) apresentavam força muscular normal no pré-operatório. Destes, seis apresentaram déficit motor transitório. Vinte pacientes (47,6%) tinham déficit motor no pré-operatório, mas 90% destes apresentaram melhora no pós-operatório. A cirurgia em área motora se torna mais segura e eficaz com a utilização de planejamento pré-operatório baseado nos exames de imagem, conhecimento anatômico e técnica microcirúrgica adequada. A utilização de estimulador cortical é importante para maximizar a ressecção minimizando o risco de déficit motor. A estereotaxia foi útil na localização de lesões subcorticais.

PALAVRAS-CHAVE: córtex motor, mapeamento, estimulação, técnicas estereotáxicas, planejamento pré-operatório.

The resection of brain lesions located in or adjacent to the motor cortex (central lobe) remains a challenge for the neurosurgeon, because the high risk of a neurological deficit. In recent years, advances have occurred, allowing for a more accurate identification not only of the cortex and motor pathways, but also of many other eloquent brain areas, such as the language cortex, and their relationship to the lesion to be removed. A number of studies have been published in which the use, isolated or not, of cortical stimulation[1-5], motor evoked potentials[3,6,7], functional magnetic resonance (fMRI)[4,8,9], neuronavigation system[10-13], and other methods[14-16] allowed, in addition to the satisfactory preoperative planning, an identification of the functional cortex, including the rolandic cortex during surgical treatment, making it possible for the surgeon to avoid these areas when formulating surgical strategies.

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Received 10 April 2006, received in final form 8 June 2006. Accepted 14 August 2006.

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In addition to the preservation of cerebral function during surgery, it is also possible with these techniques to achieve a greater extent of resection of the lesion or epileptic regions in the brain with increased safety. Anatomical knowledge and the use of an improved neurosurgical technique in compliance with the principles of Yasargil is particularly important, in order to preserve the integrity of vascular structures and perilesional cortex[17] (Fig 1D-E, 2B-C).

In this no-randomized prospective study we evaluate the strategies needed, the results and complications in the treatment of motor cortex lesions, according to the histological classification and methods of identification of the cortex motor available, always considering that the main goal of surgical treatment in patients with intracranial lesions in or around the sensorimotor cortex is to achieve a complete resection of the lesion while preserving normal brain tissue and function.

METHOD

Patient selection – A total of 42 patients with supratentorial lesions located in or around the motor cortex, seen by the authors during the period between January 2002 and March 2005, aged from 3 to 77 years, were selected for this no randomized prospective study, whether or not they presented motor deficit preoperatively. The surgeries were performed by the same neurosurgeon. The cases which were of reoperation and those with a Karnofsky score lower than 70 were excluded from this study. The topographic relationship between the lesion and the motor area was evaluated preoperatively in all of the patients by computerized tomography (CT) and magnetic resonance image (MRI). MRI was used to identify the anatomic relation between the brain lesion and the central lobe, using coronal, axial and sagittal plans. The T1-weighted sequences after the intravenous administration of gadolin was used, permitting the central sulcus, cortical vessels and their relationship with the lesion to be identified. The patients had been evaluated for lesion location and depth, histological diagnosis, degree of resection, the presence or not of a motor deficit preoperatively and early and late postoperatively. Approval of the Ethics Committee and informed consent from each patient or their closest relative was obtained.

Surgical technique – The craniotomy planning was based on the topographic relationships and neuroimaging information available of the sutures and craniometric points, especially by the identification of the coronal suture. The central sulcus and the lesion to be removed can be projected perfectly onto the scalp based on MRI data; these permit that the surgeon marks the site and shape of the incision correctly (Fig 1A-C).

All patients were subject to craniotomy for resection of the lesion. The patient's head was fixed in a Mayfield head holder. The tricotomy was performed just on the planned surgical incision and craniotomy site before the procedure began. Those patients whom cortical stimulation was necessary, the side of body part including the face where we expected the response was left exposed.

Prophylactic antibiotics (1 gm IV 6/6h Oxacilin), dexamethasone (10 mg IV Decadron) and anticonvulsive drug (300-500 mg IV Fenitoin) were routinely given preoperatively. Most patients could be safely sedated during the procedure using propofol (75 mcg/kg/min) and fentanyl (0.15 mcg/kg/min) drips. Both drugs being adjusted when cortical stimulation was necessary. In order to evaluate the motor response, muscle relaxants were avoided and used only during endotracheal intubation.

Local anesthesia with lidocaine 0.25% was injected into the area for the skin incision. The skin flap had accommodated the optimal exposure for the craniotomy planned. The shape of the skin incision depended on the particular patient. An C-shaped or a small horseshoe-shaped incision was usually appropriate.

After the identification of the coronal suture it was possible to estimate the location of the central gyrus and sulcus on the skull. A high-speed drill was used to perform an initial burr hole, which was extended with a footplate to turnthe craniotomy flap and expose the duramater. The opening of the dura was tailored for each patient, but normally the dura was opened and turned medially to protect the sagital sinus and draining veins (Fig 1D-E).

Cortical stimulation was performed using a constant-current biphasic square wave 60-Hz, bipolar stimulator (Ojemann stimulator, Radionic sales corp, Burlington, mA; 5 mm between electrodes) (Fig 1D-E). The electrode was put in contact with the cortical surface corresponding to the anatomical location of the motor area. The current used to elicit movement ranging between 2 to 10 mA.

RESULTS

The clinical and surgical characteristics of the 42 patients are summarized in the Table. In this group there were 19 male and 23 female patients with an age range of 3 to 77 years (mean 47.2 years). Glioma was the most frequent histopathological diagnosis, followed by meningioma and metastasis. Nine patients (21.4%) had a meningioma, seven (16.6%) patients had metastasis, seven (16.6%) patients had an anaplastic astrocytoma and five (11.9%) patients harbored an astrocytoma WHO grade II. As regards to the cases with metastases, the lung was the primary site in three patients, the breast in two, melanoma in one, and in one patient the primary site of the tumor was unknown. Twenty-four (57.1%) lesions were located on the left hemisphere and 18 (42.8%) on the right hemisphere. In relation to the distribution of the lesions according to the lobe, 29 (69%) of the lesions were located in the frontal lobe, seven (16.6%) in parietal lobe, five (11.9%) in the insula and one

(2.3%) was frontoparietal. Left frontal lobe was the most common place of the lesions and in 23 (54.7%) of the patients it were sited subcortically. The surgical resection was total in 38 (90.4%) of the cases and subtotal in four (9.5%).

Of the 42 patients, 22 presented normal motor function in the preoperative period. Of these, four had a grade 4 motor deficit in the immediate postoperative period, although they presented a complete recovery of the motor function within up to 3 months of surgery. One patient experienced a grade 3 motor deficit and another one grade 2, but both recovered their muscular strength (grade 5).

Thirteen patients presented a grade 4 motor deficit preoperatively. Of these, eight patients maintained the same deficit, four presented motor deterioration and one experienced an improvement in the motor function. Nevertheless, within 3 months, of the eight patients that maintened the grade 4 deficit postoperatively, six had a complete regression of the paresis (grade 5) and two continued with the previous deficit. All patients with grade 4 motor

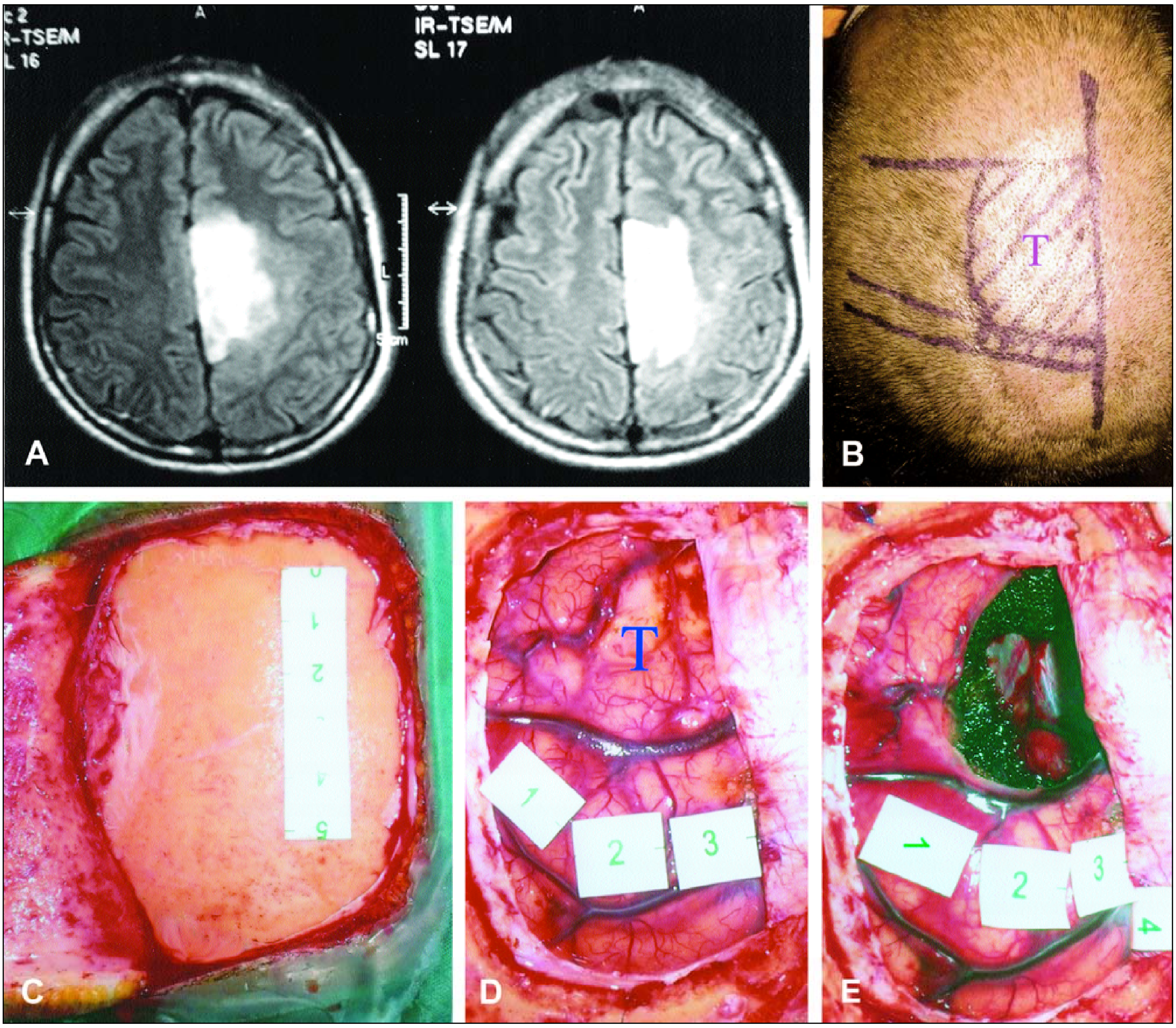

Fig 1. Astrocitoma grade III in the left superior frontal gyrus displacing the motor cortex in a 38 years old patient. (A) pre-operative axial MRI. (B) markings on the scalp estimate the location of the tumor (T), planned surgical incision, and pre-central gyrus based on MRI data. (C) the coronal suture is identified and about 5 cm behind it the central sulcus begins. The craniotomy site was planned. (D) after duramater opening the brain surface was exposed and the cortical stimulation begun: movements on the right hand (point 1) and movements on the right arm (point 2 and 3) could be elicited. The location of the tumor (T) was confirmed. (E) localization of the motor function on the right leg and foot (point 4) and complete resection of the lesion with preservation of motor function was performed.

Table. Summary of clinical and surgical characteristics and auxiliary method of motor cortex identification in 42 patients.

Case	Age (yrs)/Sex	Auxiliary method of motor cortex identification	Lesion location & Depth	Degree of resection	Diagnosis	Motor deficit		
						Pre-op	Post-op	3 months follow-up
1	67/F	–	R parietal - cortical	total	metastasis	4/5	4/5	5/5
2	64/M	cortical stimulation	R parietal - subcort	total	glioblastoma	5/5	4/5	5/5
3	14/M	cortical stimulation.	L frontal - subcort	total	dysplasia	5/5	5/5	5/5
4	63/M	cortical stimulation	L parietal - cortical	total	metastasis	4/5	1/5	5/5
5	55/F	–	L frontal - cortical	total	meningioma	5/5	3/5	5/5
6	45/M	cortical stimulation	L frontal - subcort	total	metastasis	3/5	2/5	4/5
7	60/F	–	L frontal - subcort	total	meningioma	5/5	5/5	5/5
8	59/F	–	L frontal - cortical	total	meningioma	4/5	2/5	5/5
9	27/M	cortical stimulation	L parietal - subcort	total	primary lymphoma	5/5	4/5	5/5
10	52/F	–	L frontal - subcort	total	glioblastoma	4/5	4/5	4/5
11	3/F	neuronav + cort stimul	R insula	total	dysplasia	4/5	4/5	5/5
12	58/M	cortical stimulation	L frontal - cortical	total	anaplastic astroc	3/5	4/5	5/5
13	30/F	–	R frontal - subcort	total	anaplastic astroc	5/5	5/5	5/5
14	26/F	stereotactic	R parietal - subcort	total	cavernoma	5/5	5/5	5/5
15	42/F	–	L frontal - subcort	total	metastasis	4/5	4/5	4/5
16	68/M	–	L frontal - subcort	total	anaplastic astroc	3/5	3/5	5/5
17	65/M	cortical stimulation	R frontal - subcort	total	metastasis	2/5	2/5	5/5
18	77/F	cortical stimulation	R frontal - subcort	total	anaplastic astroc	3/5	3/5	4/5
19	51/F	–	L frontal - cortical	total	metastasis	5/5	5/5	5/5
20	48/M	–	R frontal - cortical	total	metastasis	5/5	5/5	5/5
21	25/F	–	R frontopariet - subcort	total	encephalitis	5/5	5/5	5/5
22	38/F	stereotactic	R frontal - subcort	total	cysticercosis	5/5	5/5	5/5
23	68/F	–	L parietal - subcort	total	anaplastic astroc	4/5	3/5	5/5
24	33/M	–	L insula	total	cavernoma	4/5	4/5	5/5
25	68/M	–	LR frontal - subcort	total	meningioma	5/5	5/5	5/5
26	21/F	stereotactic	L frontal - subcort	total	cavernoma	5/5	5/5	5/5
27	41/F	–	L frontopariet - cort	total	meningioma	3/5	4/5	5/5
28	40//M	cortical stimulation	L parietal - subortc	subtotal	anaplastic astroc	4/5	4/5	5/5
29	54/F	–	L frontal - subcort	total	encephalitis	4/5	4/5	5/5
30	49/M	–	R frontal - cortical	total	meningioma	4/5	5/5	5/5
31	65/M	–	R frontal - cortical	total	meningioma	5/5	5/5	5/5
32	44/M	stereotactic	R insula	total	cavernoma	5/5	4/5	5/5
33	38/F	–	R frontal - subcort	total	anaplastic astroc	5/5	5/5	5/5
34	40/M	–	R insula	total	astrocytoma II	5/5	5/5	5/5
35	55/F	–	L frontal - cortical	total	meningioma	2/5	4/5	5/5
36	28/F	–	R frontal - subcort	subtotal	astrocytoma II	5/5	4/5	5/5
37	29/M	neuronavigation	R frontal - cortical	total	astrocytoma II	5/5	5/5	5/5
38	69/M	cortical stimulation	R frontopariet - subcort	subtotal	astrocytoma II	4/5	4/5	5/5
39	47/F	cortical stimulation	L frontal - subcort	total	glioblastoma	4/5	3/5	5/5
40	35/M	stereotactic	R insula	subtotal	astrocytoma II	5/5	5/5	5/5
41	70/F	–	L frontal - subcort	total	oligodendroglioma	5/5	5/5	5/5
42	53/F	–	L frontal - cortical	total	meningioma	5/5	1/5	4/5

neuronav, neuronavigation system; cort stimul, cortical stimulation; R, right; L, left; RL, right and left; cort, cortical; subcort, subcortical; frontopariet, frontoparietal; total, no residual tumor; subtotal, residual tumor; anaplastic astroc, anaplastic astrocytoma.

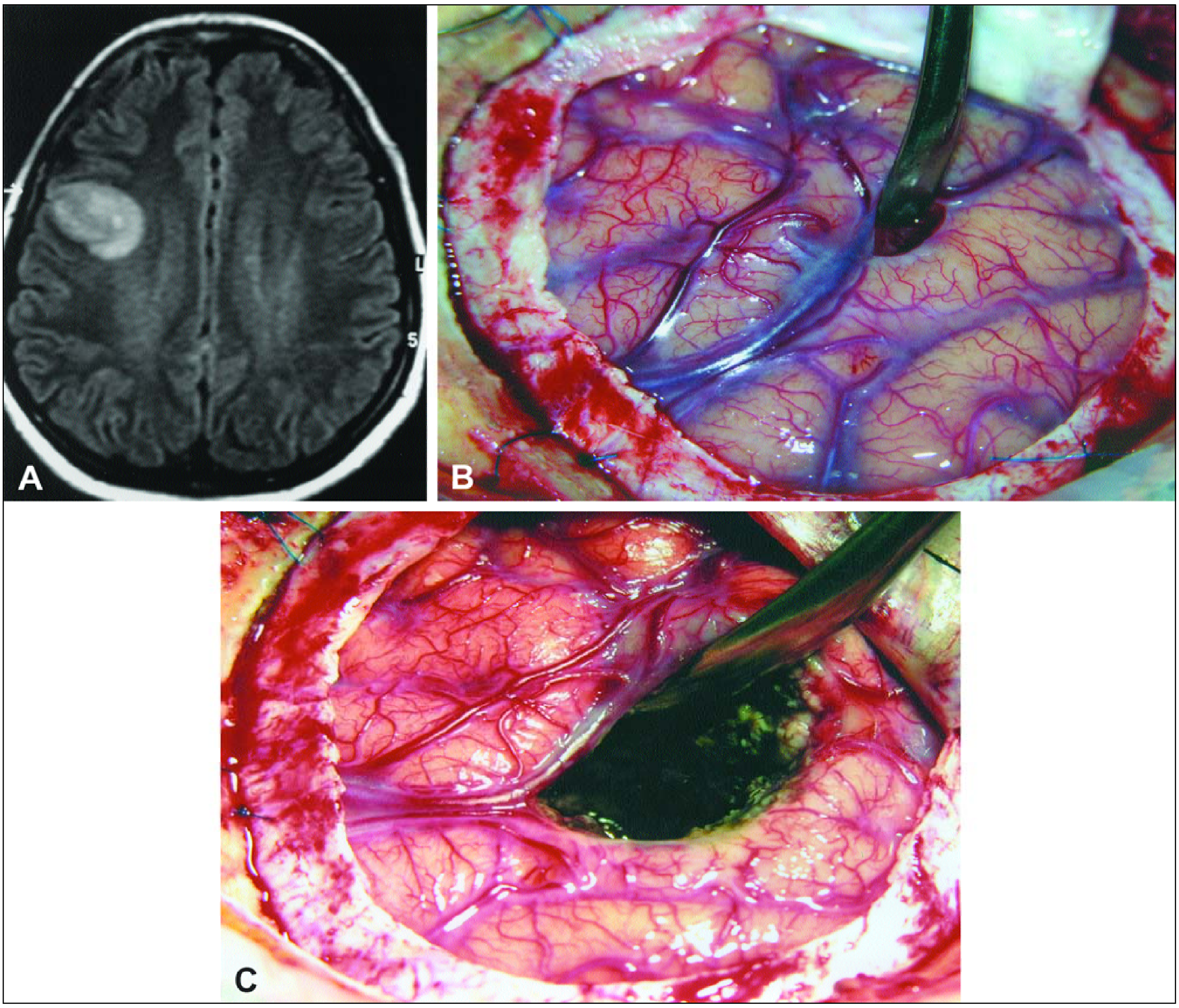

Fig 2. Astrocytoma grade III in a 38 years old patient. (A) MRI showing the lesion. (B) careful dissection and opening of the sulcus. (C) complete resection of the lesion with preservation of the adjacent cortex and vein.

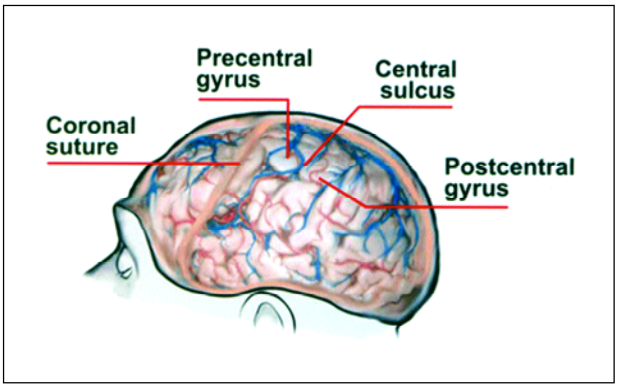

Fig 3. Anatomy of the central lobe: The coronal sutures crosses the posterior part of the superior, middle, and inferior frontal gyrus in front of the precentral sulcus. The central sulcus has a more posterior slope than the coronal suture, thus placing the coronal suture nearer the lower end of the central sulcus than the upper end.

deficit and those who presented deterioration in the immediate postoperative phase made a complete recovery in their muscular strength.

Of the five patients with grade 3 deficit preoperatively, two were unchanged in the immediate postoperative phase, one got worse and two improved. At the 3 months follow-up, two patients had recovered completely and two had a mild deficit (grade 4). In the two patients who had a severe pre-operative motor deficit (grade 2), this deficit was completely disappeared by surgery.

We performed cortical stimulation in 12 patients, stereotaxic surgery in five patients and the neuronavigation system in two patients. In one patient both neuronavigation system and cortical stimulation were used.

There was no operative mortality in this series of 42 patients. Complications occurred in three patients (7.1%) and included one patient with glioblastoma multiforme who was found to have a large hematoma in the tumor bed, which was treated surgically, and two cases of cerebrospinal fistula were treated clinically. There were no deep venous thrombosis, no wound complications and no infection.

DISCUSSION

Paul Broca (1824-1880) was the first neurosurgeon to perform a craniotomy based on cerebral localization[18]. Craniotomy planning is an essential point in the approach to perirolandic lesions. MRI, especially with contrast-enhanced T1 image, allows a good visualization of the cerebral veins and their relationship with the lesions to be removed. The projected image of the lesion on the scalp (Fig 1B) based on radiological findings and anatomical landmarks, influences the position of the patient, the size and conformation of the surgical incision and principally the location and extent of the craniotomy. This must be large enough to allow for the identification of the structures and safe resection of the lesion, but sufficiently small to avoid unnecessary exposure. In some cases during the opening of the dura it was necessary to perform a careful dissection of the veins and sometime multiple cuts parallel to the draining veins to avoid their disruption through dural flap elevation. In only one case there was a partial lesion of the superior anastomotic vein next to the sagittal sinus, however the correction using Prolene 6-0 was performed. Although the correction was performed promptly, the patient developed postoperative cerebral edema and a severe motor deficit (grade 1), but in this case the patient presented an improvement of the deficit at the 3 months follow-up (grade 4). No other patient presented edema postoperatively. The preservation of these veins and the debulking of the lesion with diminished manipulation of peri-tumor tissue contributed to minimize the motor deficit and reduced postoperative complications (Fig 2A-C).

The second step, following the exposure of brain surface, is to identify the motor gyrus and its relationship with the lesion, as well as the relationship of the lesion with the veins and arteries. The motor and sensory areas are separated by the central sulcus which begins at the superior border of the lateral surface, 5 cm behind the coronal suture, and extends, in almost 90% of cases, onto the medial surface of the hemisphere[19] (Fig 3).

When the lesion distorts the anatomy of brain surface or it has a subcortical location, we have to determine the best approach, considering that is safer for the surgeon to remove a lesion being sure of the correct localization of the functional cortex. The employment of identification methods takes in to account not only the real necessity for its use but also which of these methods were available.

Fritsch and Hitzig (1870) have been given credit for the first experimentally controlled direct electrical stimulation of the mammalian cerebral cortex, when they applied galvanic current through bipolar electrodes to the anterior half of the canine cerebral hemisphere; direct electrical stimulation of the human brain to produce sensory or motor responses was first performed by Roberts Bartholow (1874) who inserted wires through an abscess in the left cerebral convexity and observed contractions of musculature in the contralateral arm and leg. Functional localization by cortical stimulation mapping has been performed for over 40 year[20,21]. Stimulation mapping of the somatosensory cortex requires the patient to be awake; however, the motor cortex can be stimulated with the patient under general anesthesia. It is important to bear in mind during cortical stimulation that repetitive stimulation at or near the same site, or with high currents, can elicit local or generalized seizure activity. Therefore, it is important to make sure that the patient has adequate serum anticonvulsivant levels preoperatively[22]. According to Ebeling et al. the use of microsurgery combined with cortical mapping has been revealed to be an effective and safe technique, permitting a complete and large resection in these areas. Although this technique is reliable, it is often difficult to elicit responses in children or under general anesthesia[2]. Higher current settings may be necessary in younger children, in patients under general anesthesia or when stimulated through the dura. The technique can also be used to identify descending subcortical motor fibers when resection extends below the cortical surface, such as during supplementary motor area and insular resections. When performing subcortical motor mapping, the current needed to elicit movement is the same as or lower than the current needed at the cortical surface. When the resection is very close to the functional cortex it is helpful to periodically repeat the stimulation mapping procedure to verify that cortical and subcortical functional regions are not damaged. In this study, the cortical stimulation was used in 12 cases to maximize the resection safely (Table), although we did not obtain response in two cases, despite the fact that we knew the stimulation was being performed at the correct points. In these two cases, the resections were performed based on anatomical parameters. Three patients, on whom cortical stimulation was used, suffered partial motor seizures postoperatively, but they had a previous history of epilepsy.

Neuronavigation system was used in only two patients. However, its contribution was only useful for confirm the positioning of the craniotomy. In relation to the boundary of the lesion attached to adjacent structures, the use of the neuronavigation system was not of great value in these two cases specifically, especially due to the dislocation of structures during surgery. Reithmeier et al. compared the surgical results and quality of resection between one patient group that used the neuronavigation system and electrophysiological monitoring with another group that did not, concluding that it is possible reduce the size of the craniotomy using a combination of these two methods[11]. In our study, the definition of the size and craniotomy conformation was possible in all of the cases bases on knowledge of topographic anatomy of the skull.

In the treatment of cavernomas we used a craniotomy guided stereotaxically. This method permitted the formulation of the surgical trajectory, correct localization and resection of the lesion in all of cases. The utility of craniotomy guided by stereotaxic has already been defined in literature[23].

As shown in the Table, infiltrative lesions such as gliomas the use of mapping becomes essential for two reasons: to preserve the functional cortex and to maximize the resection. According to Ammirati et al. and Berger et al. the long-term survival of the patients is associated with the degree of resection, not only in low-grade gliomas but also in high-grade ones[1,6,24,25]. Those patients in which the extent of resection include the supplementary motor area (SMA) may evolve with complete acinesia predominating in contralateral members to the lesion, although this kind of deficit may not permament[26]. In our study, we had two patients who presented acinesia as a result of the resection of tumors which involved the SMA. In both cases, a complete recovery occurred within 4 weeks of surgery.

Intrinsic brain tumors might invade cortical and subcortical structures without impairment of the function, even the grossly abnormal appearance of tissue is not a guarantee that such tissue can be safely removed without a risk of a new deficit. In gliomas, mainly low grade ones, some studies have shown, applying MSI, the possibility of function existing in the tumor or on the edges of it[27,28]. This information according to those studies has been important to guide surgical routine. In our study, the pre-operative demonstration of functional activity was not possible. We performed stimulation during surgery such as an instrument to verify how far we might proceed with the extent of resection. It is hard to demonstrate that the immediate post-operative deficits were associated with a probable intratumoral cortical function, a closer manipulation of the motor area or both.

Another question is the role of neuroplasticity in these situations. The anatomic location of function may be altered by plasticity, in which neurons in normal regions of the brain take over the function of the damaged or diseased part of the brain. The reorganization of the functional cortex has been shown in acquired brain disorders using positron emission tomography, magnetoencephalography, and electromyographic recording[29]. Yoshiura et al. found increased activity in the contra lateral motor area on functional MR images obtained during a hand-motor task on patients with brain tumors[30]. Some studies suggest the possibility that a dynamic functional reorganization in the peri-tumor brain occurs[27,31]. The recruitment of compensatory areas with long term peri-lesion functional reshaping would explain why before surgery there is no clinical deficit (despite the tumor growth in eloquent regions), and immediately after surgery the occurrence of a deficit which could be due to the resection of invaded areas participating, (but not essentially) in the function, and why three months after surgery, almost complete recovery had occurred[32].

In conclusion, the resection of lesions in motor areas is difficult, but feasible. Careful surgical planning, anatomical knowledge and improved technique using microsurgery, minimize the post-operative complication and are enough to deal with the greater part of the lesions in the central region. The use of cortical stimulation in addition to contributing to the identification of functional cortex became safer and easier for the surgeon to enlarge the resection especially in the gliomas. Those patients with subcortical lesions need an additional method of localization such as stereotaxy for a better definition of the cortical approach, although the study of the sulcus in MRI and its relationship with the lesion gives important clues to the best approach.

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