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REVIEW ARTICLE

Review of current microsurgical management of insular gliomas

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Abstract The insular lobe is a functionally complex structure, harbouring peculiar anatomical and vascular features and specific neuronal connectivity with surrounding cerebral structures. It is situated in the depth of the Sylvian fissure and can be affected by either low-grade or high-grade gliomas. Because of its complexity, surgery of insular tumours has been traditionally regarded as hazardous. Nonetheless, currently improved diagnostic, neurophysiological and surgical tools allow the neurosurgeon to perform surgery of insular gliomas in a safer way, thus bringing forward the pioneering work performed by neurosurgeons in the past two decades.The aim of this paper is to provide the reader with an updated review of the anatomy, the clinical picture, diagnosis and surgical management of insular gliomas.

Keywords High-grade glioma · Insula · Low-grade glioma · Tumour

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Introduction

The island or insula of Reil is named after the German anatomist, physiologist and psychiatrist, Johann Christian Reil (1759–1813), who in 1809 first described this anatomically and functionally complex structure situated in the depth of the Sylvian fissure and hidden by the opercula of the frontal, parietal and temporal lobes (Figs. 1, 2). The convolutional anatomy of the area presents an overt challenge for the surgeon, while its diverse functional associations further compound fears of disability. Moreover, the insula is adjacent to perisylvian essential language areas, the primary auditory area, both the primary motor (PMA) and sensory (PSA) areas of the lower face in addition to subcortical pathways subserving these sites. It is involved with gustatory, olfactory, auditory and vestibular senses, motor integration and the motor planning of speech. Cardioregulatory and vasomotor functions as well as pain perception suggest a further integrative role in association with proximate limbic structures. In fact, the insula is thought to be critically involved in the bio-behavioural dysfunction characteristic of schizophrenia [19].

Tumours affecting the insula and the adjacent opercular region may therefore present with a variety of ill-defined symptoms dominated perhaps by a single entity such as a motor dysphasia with or without lower facial paresis [13, 15] and may, on occasion, do so only after reaching a considerable size. They are often managed conservatively regardless of their nature and clinical evolution even with impending invasion of nearby eloquent areas. Some authors [4, 14, 18, 34, 38, 42, 43] have demonstrated that resection of these lesions is nonetheless feasible arguing that tumour burden often displaces the surrounding cerebral tissue [4, 18], while compensatory mechanisms allow for some adaptation of function lost by infiltrated tissues. Two open

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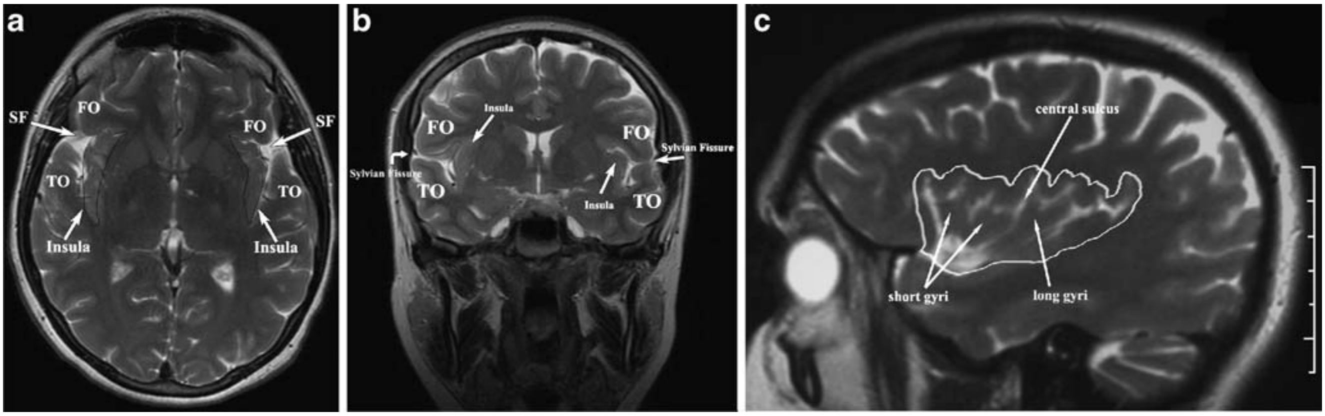

Fig. 1 Axial (**a**) and coronal (**b**) T2-weighted, magnetic resonance (MR) images showing the insula (*areas outlined by black lines* in **a**) surrounded by the frontal (*FO*) and temporal (*TO*) opercula. The Sylvian fissure (*SF*) is indicated by *white arrows*. **c** Sagittal T2-weighted MR image demonstrating the insular lobe with the short gyri, the insular central sulcus and the long gyri

surgical approaches are possible: (1) trans-sylvian and (2) transcortical [4, 8, 14, 18, 34, 38, 42, 43]. In either, an appreciation of the cortical, subcortical and vascular anatomy of the deep perisylvian region is required.

Surgical anatomy

The insula is a well-defined cerebral cortical surface with an ellipsoidal outline but flattened superiorly (Fig. 1c). Its topology is pyramidal rising from its base medially with its three sides skewed towards an anteroinferiorly situated insular apex, the most lateral projection of the insula. The central sulcus separates the larger anterior lobule from the posterior. Three short gyri dominate the lateral surface of the anterior lobule, the anterior, middle and posterior short insular gyri. The middle gyrus, at times, may not be distinguished [23]. The transverse and accessory gyri comprise the remainder of the anterior lobule. The former extends from the fronto-orbital surface to the most

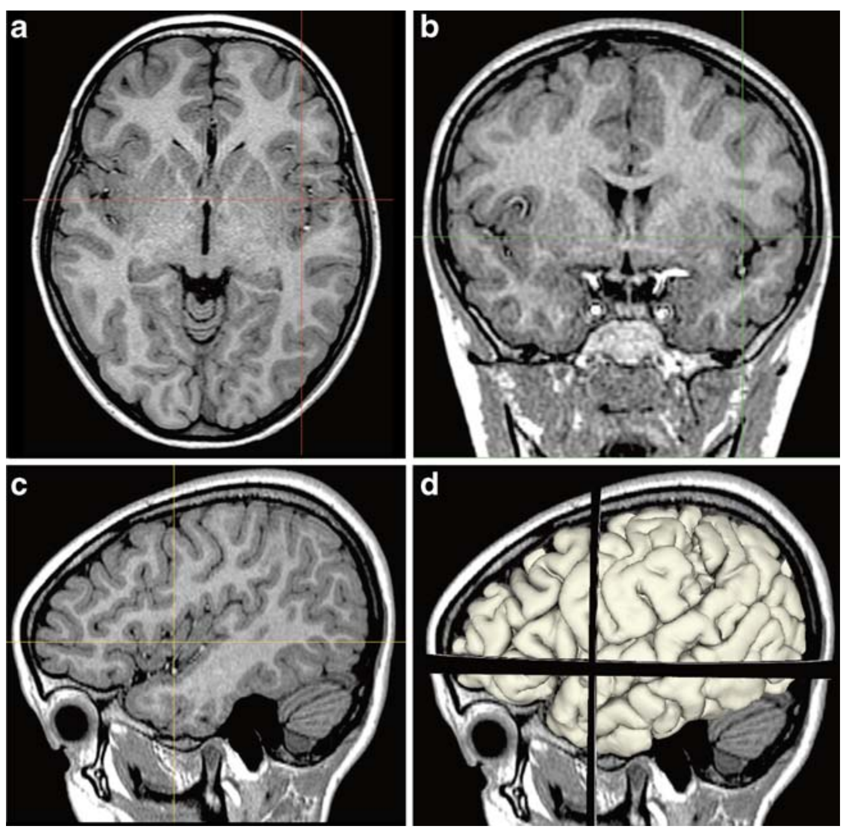

Fig. 2 Axial (**a**), coronal (**b**) and sagittal (**c**) fluid attenuated inversion recovery (FLAIR) MR imaging (MRI) showing the left insula. The *red, green and yellow crosses*, respectively, mark the site in the corresponding three-dimensional reconstruction of the lateral insular surface (**d**)

anteroinferior point of the insula or the pole and so is the inferiormost structure of the anterior lobule. The accessory gyrus is typically small but may be, at times, a prominent anteriorly placed entity on the lateral surface. The limen insulae (threshold to the insula) is the white matter structure extending from the anterior perforated substance medially to the insular pole along what is known as the sylvian stem and situated in parallel with the lateral olfactory stria [40]. The smaller posterior lobule consists of an anterior and a posterior long insular gyrus. These converge anteroinferiorly to form the pole of the posterior lobule situated behind the limen insulae. The perimeter of the insula is provided by anterior, superior and inferior peri-insular sulci. The anterior and posterior insular points are identified as the meeting points of anterior with the superior sulcus and the superior with the inferior sulcus, respectively [40].

Deep to the central portion of the insula in a lateral-to-medial direction lie the extreme capsule, claustrum, external capsule and putamen with its subjacent globus pallidus. Superiorly, at the level of the peri-insular sulcus, is the corticospinal tract, anteroinferiorly, the uncinate fasciculus and posteriorly, along the same sulcus, the arcuate fasciculus.

The blood supply of the insula is largely derived from the second (M2) segment of the middle cerebral artery (MCA) through its short and medium-sized perforating vessels. Long perforators overlying the posterior lobule are larger in diameter and may supply the corona radiata, particularly the corticospinal and thalamocortical fibers [14]. The primary trunk of the MCA (M1) or the sphenoidal segment courses laterally from the carotid bifurcation, parallel and 1 cm behind the lesser sphenoid ridge to lie under the anterior perforated substance where it commonly bifurcates (88%). Most of the lenticulostriate branches originate in the vicinity of the bifurcation and arise in a nearly even distribution from before and after the bifurcation, although the number arising from M1 increases commensurate with its length [28]. At a length of 2.5 cm or more, all lenticulostriate branches will arise from M1. The mean distance from the insular apex to the lateralmost lenticulostriate artery, the length of M1 notwithstanding, is less than 1.5 cm. The peri-insular sulcus marks the transition from M2 to M3, whereas the convexity surface of the opercula defines the M4 segment of the MCA.

Clinical presentation and diagnosis

Study of the clinical presentation of gliomas reveals some association with grade. Insular low-grade gliomas (LGGs) give rise to a medically intractable epilepsy in 58% of cases with little or no neurological impairment [5]. High-grade gliomas (HGGs) tend to present with mass effect and headache. A sensorimotor or language impairment reflects either tissue injury or surrounding vasogenic edema. Cognitive ability often declines ostensibly from regional edema, electrophysiological disturbance and adverse effects brought about by anti-epileptic drugs (AEDs) [16, 21]. When imaging declares the likelihood of a LGG, a formal cognitive assessment before and after treatment would aid in the recognition of any decline. Language assessment in the case of dominant insular LGG would also define more objectively issues of communication. Such studies often reveal impairment of motoric speed, visual memory, attention and executive function, all of which will impact a patient's quality-of-life, specifically their interactions with those close to them [8, 16].

The semiology of insular epilepsy reflects the heterogeneity of the region's functional anatomy [32]. It may mimic that of temporal lobe epilepsy [2, 15, 25, 32] or nocturnal hypermotor epilepsy of frontal lobe origin [3, 32] and may also present with certain features that recommend it to its rightful place. The latter commonly manifest as a simple partial epilepsy with respiratory, viscerosensitive or oroalimenatry features [13, 24]. Spread to the suprasylvian opercular cortex may produce facial paresthesia or tonic-clonic action laryngeal constriction, gustatory illusions and hypersalivation with postictal facial paresis [15, 26]. Infrasylvian opercular spread may produce auditory hallucinations or a sensory aphasia [1]. Further spread of activity over the central convexity gives rise to contralateral hemisensory or hemimotor manifestations.

MRI defines tumour location and the surrounding structural distortion. Tumour volume may be estimated along with some appreciation of gross margination. Contrast enhancement provides some intrinsic detail of neovascularity and necrosis and both T2-weighted and FLAIR images declare the extent of territorial infiltration by tumour element (Fig. 3). Based upon these imaging features, Yasargil et al. [44] proposed a classification in which type 3a tumours were purely insular, whereas type 3b tumours infiltrated the perisylvian opercula. Type 5 tumours extended to other paralimbic areas, namely the orbitofrontal and temporopolar regions, with or without involvement of primary limbic sites. The proximity to highly functionally relevant cerebral cortex and white matter tracts has confounded the surgical approach to the insular region for fear of serious clinical impairment. The advent of functional imaging, however, has provided much needed preoperative detail in the regard. Functional MRI [31, 35] magnetoencephalography [20] and positron emission tomography [37] provide useful estimates of cerebrocortical activation that help to define regional language, auditory, sensory and motor function. Moreover, diffusion tensor imaging (DTI) and, in particular, tractography has provided a much needed picture of the major interconnecting

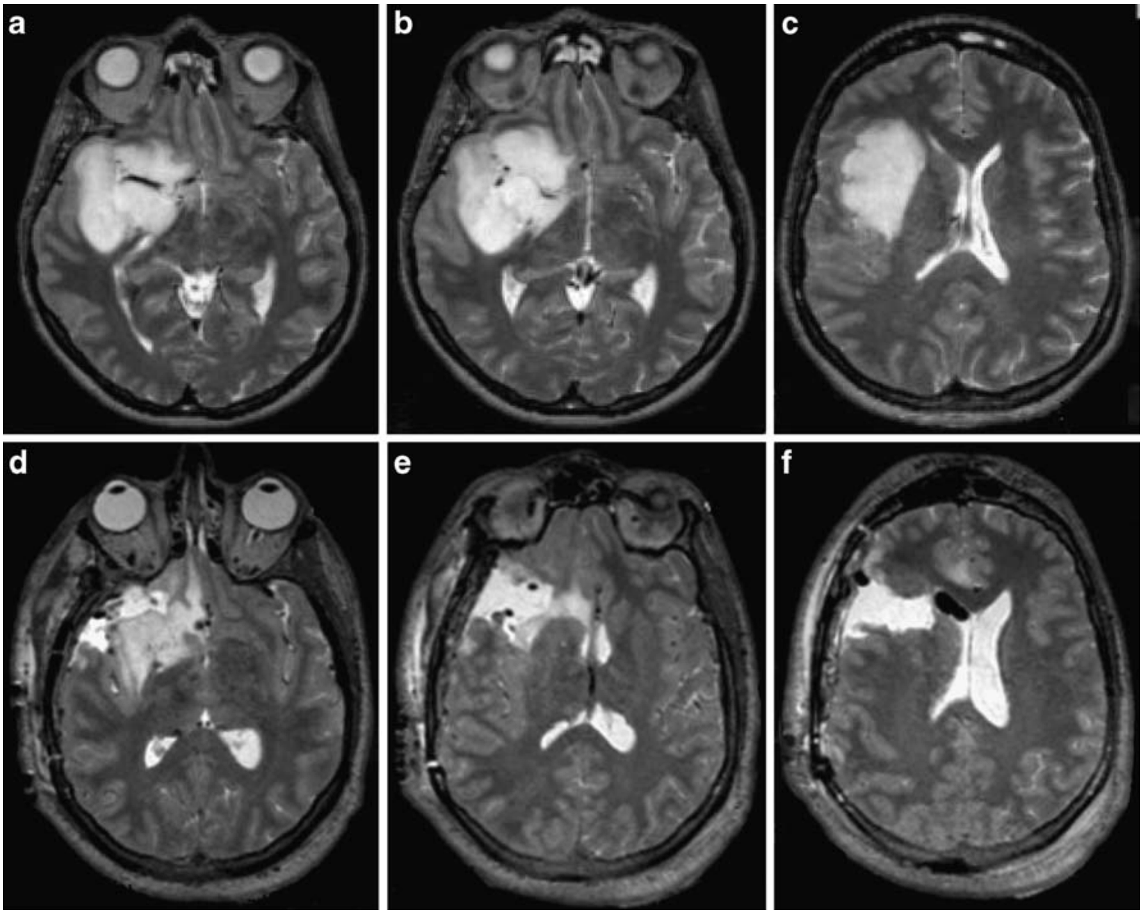

Fig. 3 **a–c** Axial, T2-weighted, MRI of a patient harbouring a right-sided low-grade glioma involving the insula, the opercular, fronto-temporopolar region and the limbic lobe (type 5B of Yasargil's classification [44]). **d–f** Early (24 h) postoperative, axial, T2-weighted MRI. Note that one reliable marker of the resection's depth is the frontal horn of the lateral ventricle, which has been opened, as shown by the presence of air inside it. In this case, the infiltration of the anterior perforated substance limited the resection of the tumour medially to the limen insulae

tracts in the vicinity, interruption of which would be detrimental [19]. Taken together, cortical and subcortical structural features coupled with an appreciation of regional functionality provides highly relevant information for surgical planning. Ultimately, such information is supplemented by intraoperative cortical and subcortical stimulation as the final measure to optimize tumour removal while preserving local function [4, 7–9].

Surgical procedure

The patient is turned obliquely with a rest pad under the ipsilateral shoulder and the head turned 60° or more controlaterally (Fig. 4). This allows the opercula to separate more easily when the Sylvian fissure is opened and provides the surgeon a better orientation towards the posterior insular lobule. The latter is hidden by both the pre- and postcentral gyri [14]. For dominant hemispheric tumours, surgery under awake conditions are undertaken in order to assess the extent of the cortex subserving language and to identify subcortical pathways interconnecting cortical sites critical for language. A wide frontotemporoparietal craniotomy (Fig. 4b) exposes the Sylvian fissure from the pars orbitalis of the inferior frontal gyrus (IFG) to the postcentral sulcus, in order to directly visualize its anterior and middle parts. It is important to have a frontobasal exposure in cases of infiltration of the orbitofrontal region towards the anterior perforated substance. After the identification of the primary motor area (PMA) of the face and hand and, in the case of dominant-sided tumours, of the perisylvian language sites (Fig. 5a), a resection of non-functional frontotemporal opercula allows exposure of the lateral surface of the insula with retraction minimized (Fig. 5b). In particular, the apex is generally found under the pars triangularis of IFG [30], while the limen insulae and the MCA bifurcation are located somewhat more deeply and anteriorly. Subpial resection of cortical tissue

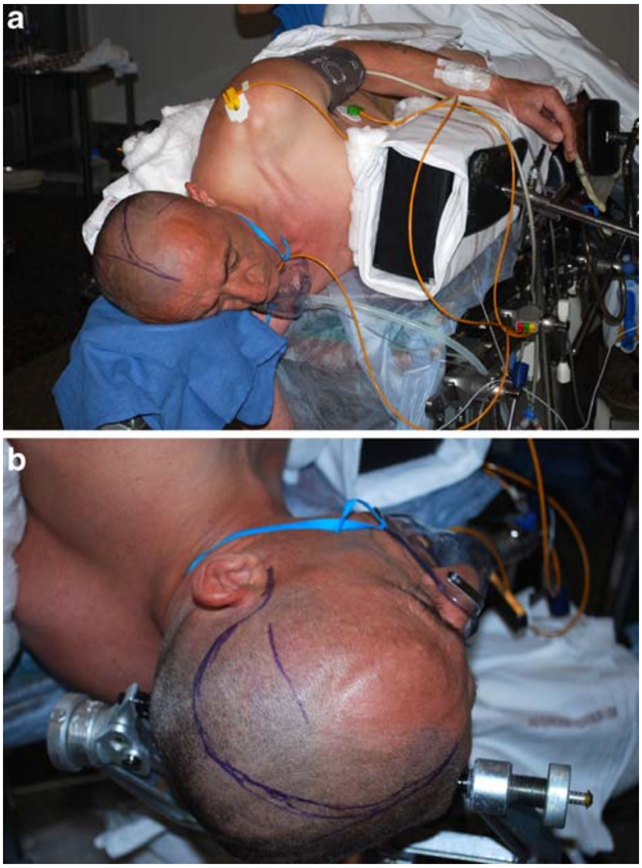

Fig. 4 **a** Intra-operative patient's position for a left-sided, awake craniotomy. **b** The *blue line* marks the wide frontotemporoparietal flap

behind the ascending ramus of the Sylvian fissure exposes the anterior peri-insular sulcus and thus the anterior aspect of the insula behind the posterior orbitofrontal gyrus [30]. The superior sulcus lies under the frontoparietal operculum and the inferior sulcus under the temporal operculum [29]. A transcortical approach respecting a subpial plane of dissection avoids any injury or iatrogenic spasm of the MCA and its branches [33] and remains most suitable when opercular extension of the tumour has occurred. Alternatively, a wide trans-sylvian approach [14] may expose a larger insular surface for a more direct approach to a tumour confined to the insular structure.

The greatest difficulty resides with the resection of tumour infiltrating the posterior lobule, which is hidden by the subcentral gyrus or the U-shaped convolution connecting the pre- and postcentral gyri and otherwise termed the subrolandic gyrus [30]. It is generally possible to resect part of the frontoparietal operculum without incurring a deficit, as in most cases the tumour displaces eloquent cortex at its periphery [4]. Once entered, the debulking of tumour mass reduced the need for surrounding retraction of eloquent tissues. The medial boundaries of the resection are confirmed by neuronavigation and/or intraoperative ultrasound. Subcortical electrical stimulation mapping (ESM) (Fig. 5c) refines the definition of these boundaries and ensures the integrity of the functional white matter in the immediate vicinity [7]. The anterior extremity of the frontal horn of the lateral ventricle coincides with the anterior peri-insular sulcus and provides a useful landmark to judge the anterior extent of a tumour occupying the anterior insular lobule (Fig. 3g). On the dominant side, subcortical ESM just lateral to the frontal horn is likely to impair the initiation of spontaneous speech, mimicking a transcortical motor aphasia. This is a consequence of electrical disruption of the subcallosal fasciculus connecting the supplementary motor area (SMA) with the head of caudate nucleus [9, 19]. Entry into the ventricle in this location would incur a language deficit. Superiorly and still anterior to the striatum, stimulation of the external capsule will result in semantic paraphasias as a result of interference with the ventral semantic stream between the frontal and temporooccipital areas conducted through the inferior occipitofrontal fasciculus [9, 10]. The temporal portion of the same fasciculus will underlie the inferior boundary of any resection at the level of the temporal stem. As a consequence, entry into the temporal horn of the lateral ventricle immediately anterior to the optic radiations [9] again will incur a language deficit. More posteriorly, the striatum becomes the medial limit for resection. Stimulation in the vicinity of the putamen may result in anarthria [12].

Motion of the contralateral limbs can be initiated by subcortical stimulation of the internal capsule posterior to the genu. When resection is carried above the superior limiting sulcus care must be taken to avoid injury of motor fibers traversing the corona radiata as these are devoid of the protection of the lenticulate nucleus provided inferiorly at the level of the posterior limb of the internal capsule. In the corona radiata, the motor fibres have a somatotopic distribution with those subserving the upper limb and face more laterally situated and those for the lower limb more medially [8]. Moreover, the second component of the superior longitudinal fasciculus (SLF) and the horizontal part of the arcuate fasciculus (AF) run above the superior insular sulcus deep to the extreme and external capsules and just lateral to corona radiata to join, respectively, the middle frontal gyrus (MFG) and the pars opercularis of IFG and the MFG and the dorsal part of the superior frontal gyrus (SFG) [19]. When disrupted during tumour removal above the superior limiting sulcus, permanent language (i.e. impaired perception and conduction aphasia) and short term memory difficulties arise [9].

Upon completion of resection, thorough hemostasis is mandatory to avoid secondary compromise of peri-insular tissues. An early postoperative MRI is desired to confirm the extent of resection and rule out iatrogenic complications such as ischemia or hematoma (Fig. 3d–f).

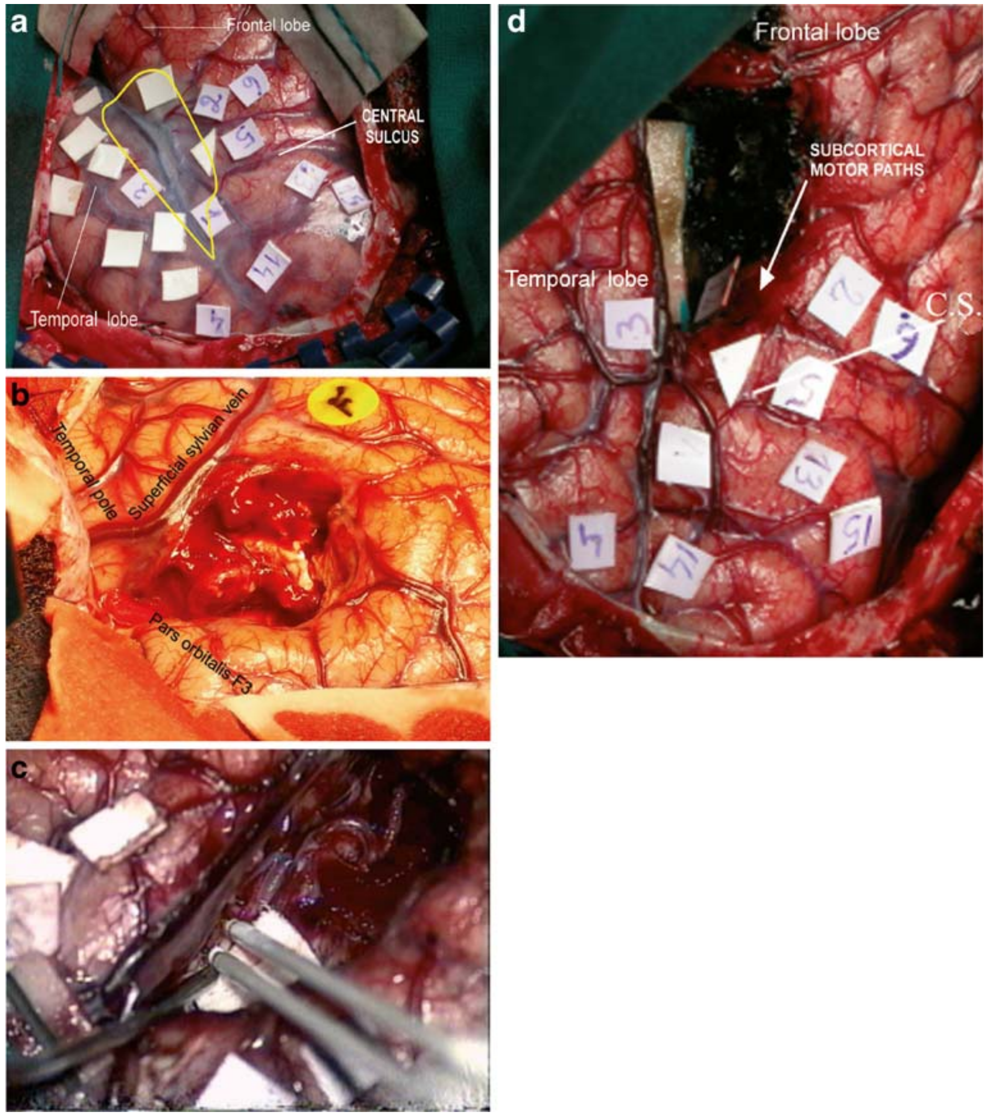

Fig. 5 **a** Intraoperative picture showing the left frontotemporoparietal cerebral cortex after ESM. The *yellow area* represents the projection of the insula over the brain surface. The Sylvian fissure with the superficial middle cerebral vein is recognised within the *yellow area*. **b** The first stage of the surgical procedure: the resection of pars triangularis of F3, which exposes the insular lateral surface with no need to retract the sylvian opercula. Note the respect of a subpial plane of resection. *F* marks the primary motor area of the face. **c** A bipolar, fine-tipped probe is used for ESM. **d** Intra-operative picture demonstrating the tumour resection at the end of the procedure

Discussion

Surgical series have supported the notion that optimal resection of both LGG [27] and HGG [17, 38] extend median survival. A significant percentage of LGGs, up to 25% in one series [6], invade the insula, raising doubt regarding their resectability. Both tumour volume and involvement of functionally eloquent regions are significant predictive factors for incomplete resection [39]. Several LGGs, however, are operated on 2.5–10 years from the time of diagnosis [11, 43] raising questions regarding the advisability of delay. Aggressive resection of HGGs in eloquent regions has also been shown not only to advance survival but to improve the quality of life [36].

The first large surgical series of insular tumours was that of Yasargil et al. [44] and addressed both low- and high-grade tumours. A few other series have followed [14, 18, 22, 34, 38, 41, 45], including that of Duffau et al. [4, 8] which dealt solely with LGGs. A number of reports have emphasized the importance of functional mapping because of the critical nature of both insular and peri-insular structures. Mapping of the sensorimotor cortex either by sensory and/or motor evoked potentials [24, 43] or by ESM [4–10, 41] is often applied here. Dominant hemisphere cortical language localization is advisable, although language interference seldom results from direct stimulation of the insular cortex [4, 8, 11, 14], particularly when infiltrated by tumour. The patient may be engaged in conversation during the stage of tumour removal [4, 8, 14, 18] and the course of resection altered when interference of speech production occurs. Resection is stopped altogether when impairment cannot be reversed despite release of opercular retraction [4, 8, 11, 14, 18]. When reporting upon total or near complete removals of greater than 80% to 90% of the insular tumour volume, results vary between 40% and 90% [4, 8, 18, 38, 41, 43] without notable differences between dominant and non-dominant sides. The incidence of immediate postoperative clinical impairment is 21–63% of cases, whereas permanent morbidity occurs in 3.6–9% of cases [4, 8, 18, 43]. Without language mapping, a postoperative permanent aphasia in cases of dominant-sided insular LGG is reported to be as high as 14% [43].

Language function has been variably interrupted by ESM applied to the insular cortex with speech arrest at times reported in patients with LGG infiltrating the insula along with the perisylvian opercular structure (type 3b) and paralimbic regions (type 5), whereas no speech arrest could be elicited in cases where tumours were confined to the insula itself (type 3a) or in cases of insulo-opercular tumours when patients presented initially with a language impairment [4, 8]. A complete or near-complete tumour resection is achieved in 55.5–74% in the latter case [4, 8, 18, 43]. Immediate postoperative language impairment was evident in 92–100% of cases but regressed completely in 1–3 months [4, 8, 18, 43]. In one series, patients who had presented with phasic language disturbances preoperatively showed improvement following surgery [8]. Motor impairment predominated as a lasting disability in 7% of cases [8].

It therefore appears necessary to undertake ESM of the insular cortex for language function particularly for the patient without apparent clinical impairment but harbouring a tumour that extends through the dominant opercular region. One might speculate that the insula acquires some capacity for compensatory language function in such circumstances.

Conclusions

Insular tumours present a surgical challenge because of the highly functional nature of the insula and surrounding brain as well as its accessibility with its hidden surface underlying the cerebral operculum. The advent of improved structural and functional imaging supplemented by intraoperative ESM has provided the surgeon the ability to plan and carry out an approach with acceptable risk in most circumstances. Moreover, the optimization of tumour removal coupled with ultimate return of function assures an improved quality of life and improved survival.

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References

1. Bancaud J (1987) Clinical symptomatology of epileptic seizures of temporal origin. Rev Neurol 43:392–400
2. Barba C, Barbati G, Minotti L, Hoffmann D, Kahane P (2007) Ictal clinical and scalp-EEG findings differentiating temporal lobe epilepsies from temporal 'plus' epilepsies. Brain 130(Pt 7):1957–1967
3. Dobesberger J, Ortler M, Unterberger I, Walser G, Falkenstetter T, Bodner T, Benke T, Bale R, Fiegele T, Donnemiller E, Gotwald T, Trinka E (2008) Successful surgical treatment ofinsular epilepsy with nocturnal hypermotor seizures. Epilepsia 49:159–162
4. Duffau H, Capelle L, Lopes M, Faillot T, Sichez JP, Fohanno D (2000) The insular lobe: physiopathological and surgical considerations. Neurosurgery 47:801–810
5. Duffau H, Capelle I, Lopes M, Bitar A, Sichez JP, van Effenterre R (2002) Medically intractable epilepsy from insular low-grade gliomas: improvement after an extended lesionectomy. Acta Neurochir (Wien) 144:563–573
6. Duffau H, Capelle L (2004) Preferential brain locations of low-grade gliomas. Cancer 100(12):2622–2626
7. Duffau H, Gatignol P, Mandonnet E, Peruzzi P, Tzourio-Mazoyer N, Capelle L (2005) New insights into the anatomo-functional connectivity of the semantic system: a study using cortico-subcortical electrostimulations. Brain 128:797–810
8. Duffau H, Taillandier L, Gatignol P, Capelle L (2006) The insular lobe and brain plasticity: lessons from tumor surgery. Clin Neurol Neurosurg 108(6):543–548
9. Duffau H, Gatignol P, Mandonnet E, Capelle L, Taillandier L (2008) Intraoperative subcortical stimulation mapping of language pathways in a consecutive series of 115 patients with Grade II glioma in the left dominant hemisphere. J Neurosurg 109:461–471
10. Duffau H, Thiebaut de Schotten M, Mandonnet E (2008) White matter functional connectivity as an additional landmark for dominant temporal lobectomy. J Neurol Neurosurg Psychiatry 79:492–495
11. Ebeling U, Kothbauer K (1995) Circumscribed low grade astrocytomas in the dominant opercular and insular region: A pilot study. Acta Neurochir (Wien) 132:66–74
12. Gil Robles S, Gatignol P, Capelle L, Mithcell M-C, Duffau H (2005) The role of dominant striatum in language: a study using intraoperative electrical stimulations. J Neurol Neurosurg Psychiatry 76:940–946
13. Guénot M, Isnard J (2008) Epilepsy and insula. Neurochirurgie 54:374–381
14. Hentschel SJ, Lang FF (2005) Surgical resection of intrinsic insular tumors. Neurosurgery 57(ONS Suppl 1):176–183
15. Isnard J, Guénot M, Sindou M, Mauguière F (2004) Clinical manifestations of insular lobe seizures: a stereo-electroencephalographic study. Epilepsia 45:1079–1090
16. Klein M, Engelberts NH, van der Ploeg HM, Kasteleijn-Nolst Trenité DG, Aaronson NK, Taphoorn MJ, Baaijen H, Vandertop WP, Muller M, Postma TJ, Heimans JJ (2003) Epilepsy in low-grade gliomas: the impact on cognitive function and quality of life. Ann Neurol 54:514–520
17. Lacroix M, Abi-Said D, Fourney DR, Gokaslan ZL, Shi W, DeMonte F, Lang FF, McCutcheon IE, Hassenbusch SJ, Holland E, Hess K, Michael C, Miller D, Sawaya RA (2001) Multivariate analysis of 416 patients with glioblastoma multiforme: prognosis, extent of resection, and survival. J Neurosurg 95:190–198
18. Lang FF, Olansen NE, DeMonte F, Gokaslan ZL, Holland EC, Kalhorn C, Sawaya R (2001) Surgical resection of intrinsic insular tumors: complication avoidance. J Neurosurg 95:638–650
19. Makris N, Goldstein J, Kennedy D, Hodge S, Caviness V, Faraone S, Tsuang M, Seidman L (2006) Decreased volume of left and total anterior insular lobule in schizophrenia. Schizophrenia Res 83:155–171
20. Makela JP et al (2006) Magnetoencefalography in neurosurgery. Neurosurgery 59:493–510
21. Meyers C, Hess KR (2003) Multifaceted endpoints in brain tumor clinical trials: cognitive deterioration precedes MRI progression. Neuro-oncology 5:89–95

22. Moshel YA, Marcus JD, Parker EC, Kelly PJ (2008) Resection of insular gliomas: the importance of lenticulostriate artery position. J Neurosurg 109:825–834
23. Naidich TP, Kang E, Fatterpekar GM, Delman BN, Gultekin SH, Wolfe D, Ortiz O, Yousry I, Weismann M, Yousry TA (2004) The insula: anatomic study and MR imaging display at 1.5T. AJNR Am J Neuroradiol 25:222–232
24. Neuloh G, Pechstein U, Schramm J (2007) Motor tract monitoring during insular glioma surgery. J Neurosurg 106(4):582–92
25. Ostrowsky K, Isnard J, Ryvlin P, Guénot M, Fischer C, Mauguière F (2000) Functional mapping of the insular cortex: clinical implication in temporal lobe epilepsy. Epilepsia 41:681–686
26. Penfield W, Faulk M (1955) The insula: further observations on its function. Brain 78:445–470
27. Prats JM, Garaizar C, Garcia-Nieto ML et al (1999) Opercular epileptic syndrome: an unusual form of benign partial epilepsy in childhood. Rev Neurol 29:375–380
28. Pignatti F, van den Bent M, Curran D, Debruyne C, Sylvester R, Therasse P, Afra D, Cornu P, Bolla M, Vecht C, Karim AB, European Organization for Research and Treatment of Cancer, Brain Tumor Cooperative Group, European Organization for Research and Treatment of Cancer, Radiotherapy Cooperative Group (2002) Prognostic factors for survival in adult patients with cerebral low-grade glioma. J Clin Oncol 20:2176–2084
29. Rhoton AL Jr (2002) The supratentorial arteries. Neurosurgery 51: S53–S120
30. Rhoton AL Jr (2007) The cerebrum. Anatomy. Neurosurgery 61(1 Suppl):37–118
31. Ribas GC, Ribas EC, Rodrigues CJ (2005) The anterior sylvian point and the suprasylvian operculum. Neurosurg Focus 18(6B): E2
32. Roux FE, Ibarrola D, Tremoulet M, Lazorthes Y, Henry P, Sol JC, Berry I (2001) Methodological and technical issues for integrating functional magnetic resonance imaging data in a neuronavigational system. Neurosurgery 49:1145–1156
33. Ryvlin P, Minotti L, Demarquay G, Hirsch E, Arzimanoglou A, Hoffman D, Guénot M, Picard F, Rheims S, Kahane P (2006) Nocturnal hypermotor seizures, suggesting frontal lobe epilepsy, can originate in the insula. Epilepsia 47:755–765
34. Schaller C, Klemm E, Haun D, Schramm J, Meyer B (2002) The transsylvian approach is “minimally invasive” but not “atraumatic”. Neurosurgery 51:971–976
35. Schramm J, Aliashkevich A (2008) Temporal mediobasal tumours: a proposal for classification according to surgical anatomy. Acta Neurochir (Wien) 150:857–864
36. Signorelli F, Guyotat J, Schneider F, Isnard J, Bret P (2003) Technical refinements for validating functional MRI-based neuronavigation data by electrical stimulation during cortical language mapping. Minim Invasive Neurosurg 46:265–268
37. Signorelli F, Guyotat J, Isnard J, Schneider F, Mohammedi R, Bret P (2001) The value of cortical stimulation applied to the surgery of malignant gliomas in language areas. Neurol Sci 22:3–10
38. Simon M, Neuloh G, von Lehe M, Meyer B, Schramm J (2008) Insular gliomas: the case for surgical management. J Neurosurg 110(4):685–695
39. Sobottka SB, Bredow J, Beuthien-Baumann B, Reiss G, Schackert G, Steinmeier R (2002) Comparison of functional brain PET images and intraoperative brain mapping data using image-guided surgery. Comput Aided Surg 7:317–325
40. Stummer W, Reulen HJ, Meinel T, Pichlmeier U, Schumacher W, Tonn JC, Rohde V, Oppel F, Turowski B, Woiciechowsky C, Franz K, Pietsch T, ALA-Glioma Study Group (2008) Extent of resection and survival in glioblastoma multiforme: identification of and adjustment for bias. Neurosurgery 62:564–576
41. Talos IF, Zou KH, Ohno-Machado L, Bhagwat JG, Kikinis R, Black PM, Jolesz FA (2006) Supratentorial low-grade glioma resectability: statistical predictive analysis based on anatomic MR features and tumor characteristics. Radiology 239:506–513
42. Türe U, Yasargil MG, Al-Mefty O, Yasargil DCH (2000) Arteries of the insula. J Neurosurg 92:676–687
43. Vanaclocha V, Saiz-Sapena N, Garcia-Casasola C (1997) Surgical treatment of insular gliomas. Acta Neurochir (Wien) 139:1126–1134
44. Yasargil MG, von Ammon K, Cavazos E, Doczi T, Reeves JD, Roth P (1992) Tumors of the limbic and paralimbic systems. Acta Neruochir (Wien) 118:40–52
45. Zentner J, Meyer B, Stangl A, Schramm J (1996) Intrinsic tumors of the insula: a prospective surgical study of 30 patients. J Neurosurg 85:263–271