REVIEW ARTICLE

INDEX COPERNICUS INTERNATIONAL

Current strategies for the treatment of malignant gliomas – experience of the Department of Neurosurgery, Brodno Masovian Hospital in Warsaw

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Manuscript Preparation
E – Literature Search
F – Funds Collection

Grzegorz Turek[1ABCEF], Tomasz Pasterski[1,4EF], Krzysztof Bankiewicz[4,5,6AD], Sebastian Dzierzęcki[2EF], Mirosław Ząbek[1,2,3,4ABDEF]

[1]Department of Neurosurgery, Brodno Masovian Hospital, Warsaw, Poland; Head: prof. Mirosław Ząbek MD PhD
[2]Gamma Knife Centre, Warsaw, Poland
[3]Department of Neurosurgery, Postgraduate Medical Centre, Warsaw, Poland; Head: prof. Mirosław Ząbek MD PhD
[4]Interventional Neuro Center, Brodno Masovian Hospital, Warsaw, Poland
[5]Neurosurgical Clinic, Ohio State University, US
[6]Neurosurgical Clinic, University of California, San Francisco, US

Article history: Received: 24.04.2020 Accepted: 26.05.2020 Published: 27.05.2020

ABSTRACT:

Introduction: Malignant gliomas (HGG) are the most common primary malignant brain tumors arising from glial cells. From among HGG, glioblastoma is the most common and the most malignant histological subtype, with only a 27% 2-year survival rate. Current standard medical treatment of malignant gliomas is still not satisfactory and may need some development and modification. We presented and discussed the achievements of the Department of Neurosurgery at Brodno Masovian Hospital in the treatment of malignant gliomas.

Material and methods: We step by step presented and discussed the policy in the treatment of malignant gliomas. We showed all steps starting from the preparation of surgery (e.g. neuroimaging) and finishing on the presentation of the development of perioperative management – from intraoperative electrical stimulation mapping and monitoring which is nowadays already standard method to convection-enhanced delivery (CED) and gamma knife (GK) which are new and promising methods in the treatment of glioblastoma.

Results: All surgical methods described in this manuscript were introduced to achieve a maximal and safe resection of a malignant glioma. CED and GK are the last-resort methods for patients with recurrent HGG.

Discussion: Department of Neurosurgery at Brodno Masovian Hospital deals with all types of brain tumors, including all types of high-grade gliomas. As the first Department in Europe with close cooperation with the Department of Neurosurgery in San Francisco, we have started local infusions of drugs directly to the tumor in the real time of magnetic field, and we think that this technology may change all approaches to the treatment of high-grade gliomas.

KEYWORDS: Brodno Masovian Hospital, convection-enhanced delivery, gamma knife, glioblastoma, glioma, neurosurgery

ABBREVIATIONS

5-ALA – 5-aminolaevulinic acid
BJGA – Ball Joint Guide Array
CB – Cintredekin besudotox
CED – convection-enhanced delivery
CHO – choline
CRE – creatine
CRM107 – diphtheria toxin
CST – corticospinal tract
CT – computed tomography
DTI – diffusion tensor imaging
DTI-FT – diffusion tensor imaging
fMRI – functional MRI
FSRT – fractionated stereotactic radiotherapy
GA – general anesthesia
GBM – glioblastoma multiforme
GK – gamma knife
GTR – gross total resection
GW – gliadel wafers
Gy – grays
HGG – malignant gliomas
iMRI – Intraoperative Magnetic Resonance
LAC – lactate
MRI – magnetic resonance imaging
MRS – magnetic resonance spectroscopy
NAA – N-acetyl aspartate
PE – *Pseudomonas*
SRS – stereotactic radiosurgery
T2-FLAIR – T2-fluid-attenuated inversion recovery
TF – human transferrin
WHO – World Health Organization

INTRODUCTION

Malignant gliomas (HGG) are the most common primary malignant brain tumors arising from glial cells, and occurred in up to 80% of cancer patients [1]. Malignant gliomas are classified as either grade III or IV tumors and can be divided into anaplastic astrocytoma, anaplastic oligodendroglioma, anaplastic oligoastrocytoma, anaplastic ependymoma, and glioblastoma multiforme (GBM) [2]. Primary malignant gliomas are quite rare and account for 1.4% of new cancers, based on statistics from the United States, but morbidity and mortality related to that incidence are disproportionately high [2].

DOI: 10.5604/01.3001.0014.2473

Moreover, these tumors are among the most feared types of cancer, not only because of their poor prognosis but also decreased quality of life and cognitive functions in the affected individuals.

Glioblastoma is the most common and simultaneously the most malignant histological subtype with very poor prognosis. It is estimated that 17% of all primary brain tumors are GBMs, with only a 27% 2-year survival rate and a median survival of 10–11 months with standard treatment [3–5]. Survival in GBM patients depends on several factors, including age, histological tumor type, Karnofsky performance status, and location [6–8]. GBMs are found 1.5 times more commonly in men than in women and 2 times more commonly in whites than blacks.

Current standard medical treatment of malignant gliomas includes surgical resection followed by external beam radiation and chemotherapy. Despite that complex approach, the outcome of that treatment is still not satisfactory. When we compare the results of median survival in weeks between papers published between 1984 and 2018 we can find out that there is no progress in life expectancy in patients with HGG (50 vs 40 weeks, respectively). Therefore, we think that present treatment may need some development and modification. In this paper, we show the achievements of the Department of Neurosurgery at Brodno Masovian Hospital in the treatment of malignant gliomas, including safe and maximal surgical resection with state-of-the-art surgical modalities, such as intraoperative MRI, local intratumor infusions in the real time of magnetic field, and gamma knife radiosurgery.

PREPARATION FOR GLIOMA SURGERY

Preoperative neuroimaging

Nowadays there are new, fast-developing imaging techniques based on standard preoperative images to assess survival prognosis by the presence of some specific features, which is called the machine learning approach [9–11]. However, to date these have not been reliable biomarkers and therefore cannot be concurrent with surgical biopsy of the brain tumor.

Most patients with malignant glioma undergo computed tomography (CT) of the brain as the first screening examination before diagnosis. However, the final diagnosis in patients with glioma is based on magnetic resonance imaging (MRI), typically ordered with T2-weighted, T2-fluid-attenuated inversion recovery (T2-FLAIR), gradient echo, T1-weighted, and T1-weighted contrast-enhanced sequences [12, 13]. The appropriate standard preoperative imaging is obtained based on recently developed advances in imaging techniques, including functional MRI (fMRI), magnetic resonance spectroscopy (MRS), and diffusion tensor imaging (DTI).

Functional MRI is essential in preoperative surgical planning in patients when the tumor disrupts eloquent areas of the brain. The T2-weighted signal that occurs in the eloquent cortex during its activation (patients follow specific commands during imaging) provides functional mapping of the eloquent cortex. Thanks to that modality, more aggressive but still safe resection could be performed with minimal postoperative disability [14]. The sensitivity and specificity of fMRI in the localization of motor areas is high and ranges from 71% to 100% and from 68% to 100%, respectively [15–18]. Locating the language cortex with fMRI is much more complicated than the motor cortex, since there is high anatomic variability of language sites between patients. Therefore, highly variable results have been observed in papers concerning language mapping and sensitivity and specificity ranging from 59% to 100% and 0% to 97%, respectively [19, 20]. Bizzi et al. showed that presurgical fMRI mapping for the motor and language cortex may change with glioma grade: sensitivity was higher and specificity was lower in WHO grade II and III gliomas than in glioblastoma multiforme.

Functional MRI is a highly practical, advanced and noninvasive neuroimaging modality. In patients affected by brain tumor, fMRI has demonstrated to be a highly sensitive tool for localizing eloquent cortical areas within the motor and language regions [18].

MRS is a very useful neuroimaging technique which could be done simultaneously with regular magnetic resonance of the brain. By detecting some changes in metabolite levels in specific brain voxels, it allows for dedifferentiating tumors from other brain lesions, e.g. inflammatory [21, 22]. Moreover, MRS could be a good noninvasive tool for classifying and grading brain tumors. However, there are also papers suggesting that MRS could be effective as a prognostic tool for monitoring patient response to chemotherapy by localizing tumor regression or progression during oncological treatment [23–28]. In a study of 39 patients with malignant gliomas, Li et al. observed that high levels of CHO and LAC and low levels of NAA and CRE were associated with poor prognosis [23]. In another study conducted by Preul et al., in patients with malignant gliomas treated with tamoxifen, the authors found that prior to treatment, responders had higher levels of CRE and NAA compared with nonresponders but lower levels of LAC [26]. Matheus et al. [22] found increased CHO following treatment, indicating both recurrence and pyogenic infection in the tumor region in various patients.

Diffusion tensor imaging (DTI) is a commonly used technique for the visualization of subcortical white matter tracts, and the most important corticospinal tract (CST). This is not a competing technique to the fMRI, but rather complementary since fMRI only allows for the cortical localization of the eloquent areas of the brain. This method of imaging enables to plan the optimal approach to the tumor and may help critically asses the resectability of the tumor before beginning the operation. Then, during the operation thanks to close cooperation with a neuronavigation system, it allows to provide good orientation in the operating field regarding when we should expect important white matter fibers [29]. The sensitivity of DTI in localizing the CST is very high and amounts to 93-95% in different papers [30, 31]. Some papers also showed that DTI was able to localize fiber tracts which run inside the tumor with high sensitivity; this helps to decrease the risk of neurological deterioration due to surgery [32]. An important serious limitation of the intraoperative use of DTI-FT is a brain shift of more than 15 mm when using along with a neuronavigation system [33].

PERIOPERATIVE MANAGEMENT

Intraoperative Electrical Stimulation Mapping and Monitoring

Intraoperative electrical stimulation techniques allow for maximal and safe resection of the tumor with a significantly decreased risk of neurological deterioration due to surgery. Intraoperative electrical stimulation allows for both mapping for intraoperative localization of the eloquent cortex and monitoring of the integrity of CST. Motor mapping can be performed in an asleep or awake patient, but for language mapping awake surgery is required. When this technique was introduced to the neurosurgical operating room many years ago, it was doubted by most of neurosurgeons; however it has become the gold standard in tumor resection with localization in the eloquent brain. Many papers concerning this issue have been published since then. The largest analysis based on 8091 patients showed that late severe neurological deficits were observed in 3.4% of patients with intraoperative mapping and in 8.2% of patients after resections performed without mapping [34]. Moreover, GTR was 75% with and 58% without stimulation mapping [34]. The authors concluded that the use of electrical stimulation mapping has an oncological benefit for patients with eloquently located tumors [34, 35].

Fluorescein-guided resection of glioma

In patients with malignant gliomas, progression-free survival and overall survival are highly dependent on the level of resection with the best results achieved with gross total resection (GTR). Estimated GTR is achieved only in 36% of patients with malignant gliomas despite the availability of an intraoperative microscope, iMRI, or intraoperative electrical stimulation techniques. This low GTR rate in malignant gliomas is related to the major difficulty in recognizing the location of the tumor margin and where brain tissue starts. Thus, there have been many attempts to introduce some methods for improving the visualization of the tumor margin. This led to the introduction of 5-ALA (5-aminolaevulinic acid) and fluorescein sodium. Both agents accumulated in the tumor tissue and its margins, increasing the GTR rate. The 5-ALA has been proven in many papers as very effective, however at the same time its availability was low, mostly because of the high price. At the same time, fluorescein sodium has proved easily available and cheap as well as significantly increased the GTR rate in patients with malignant gliomas. Fluorescein sodium accumulates in disrupted blood-brain barrier areas and highlights tumor tissue as green in the Yellow Filter 560 nm (option modality for Zeiss Pentero 900). The GTR rate varies from paper to paper, amounting to 68.4% to 100%; however, study groups were not numerous, from 10 to 57 patients [36, 37]. The doses of fluorescein sodium used for operations varied among the studies and amounted to 3–20 mg/kg, but interestingly no difference was found in the GTR rate between these marginal values [38, 36, 37]. The authors concluded that fluorescein sodium-guided resection of malignant gliomas is safe and significantly improves the GTR rate. In their review, Waqas et al. emphasized that the usefulness of any of the available modalities is merely complementary, and depends upon several factors, especially the surgeon's experience and expertise [38].

Awake craniotomy

Awake trephination in the primitive form has been used in antiquity for removing daemons from the head to treat several conditions like severe headaches, head trauma, etc. [39]. Over the last decades, awake craniotomy has also become a very useful tool in the treatment of many neurosurgical conditions. In the era of so-called modern neurosurgery, this technique was used for the first time by Penfield to surgically treat epilepsy [40]. Since the introduction of neuro-monitoring techniques, awake craniotomy has become a very good option for neuro-oncology. It has been shown in several publications that this technique significantly decreased neurological morbidity, improved the GTR rate, and shortened the time to discharge from hospital (ref). However, there are many variables which have to be fulfilled for a patient to be qualified for this type of surgery, including a psychological test and a specific anesthesiology preparation.

The selection of patients for awake craniotomy is of the greatest importance. The first and at the same time the most important criterion is the possibility of full perioperative cooperation, therefore the capacity for and the quality of cooperation have to be carefully evaluated before final qualification for surgery. The main contraindications for AC is age younger than 11 years, tumor located in the posterior fossa, or the need for prone positioning of the patient. Another factor is highly vascularized tumor with expected large blood loss and expected very long-lasting surgery. Patients with significant co-morbidities, like obesity, sleep apnea, are not good candidates for AC either.

All hitherto published studies have shown a positive effect of awake craniotomy compared with surgery under general anesthesia (GA) on reducing iatrogenic neurological injury during tumor resection. The rate of neurological deficit related to AC varied from the studies and was 4.6–19%, whereas it was 16–64% in the GA group. All of these studies also presented a significantly higher GTR rate in the AC group. For instance, Pinsker et al. presented that AC may be related to more than a 40% increase in tumor tissue resection compared with GA.

We may conclude that awake craniotomy is an effective and versatile neurosurgical procedure with expanding applications in neuro-oncology.

Intraoperative Magnetic Resonance (iMRI)

The first attempts to visualize the brain during a neurosurgical operation took place in the mid-1990s in Boston and used a scanner with a magnetic field of 0.4 T. Technological progress and the need to obtain better image quality led to the introduction of high-tech devices into the neurosurgical operating room. The first reports were produced by a group from Erlangen in 2003. Since then, iMRI technology has become more accessible and the number of publications on this subject has been growing constantly, providing evidence of the benefits of iMRI in the treatment of gliomas.

Currently, ultra-high-field (3T) iMRI systems, located in a separate part of the operating room with the possibility of performing outpatient tests when intraoperative functionality is not used, are the most technologically advanced, and at the same time more economically advantageous. Even before the era of intraoperative examinations, the Heidelberg group showed, by performing early postoperative examinations, a significant difference in the evaluation of an unresected part of a tumor in an intraoperative assessment by a neurosurgeon and magnetic resonance imaging performed 1–5 days after surgery. In this study, the presence of a residual contrast-enhancing tumor had the greatest impact on survival [41]. A significant effect of iMRI (1.5T) on the remaining tumor volume is documented by C. Nimsky, giving a volume reduction from 21.4% to 6.9%. In the study group it allowed to increase the amount of complete resections by 41%. The application of the iMRI method changed the course of 36.2% of procedures [42].

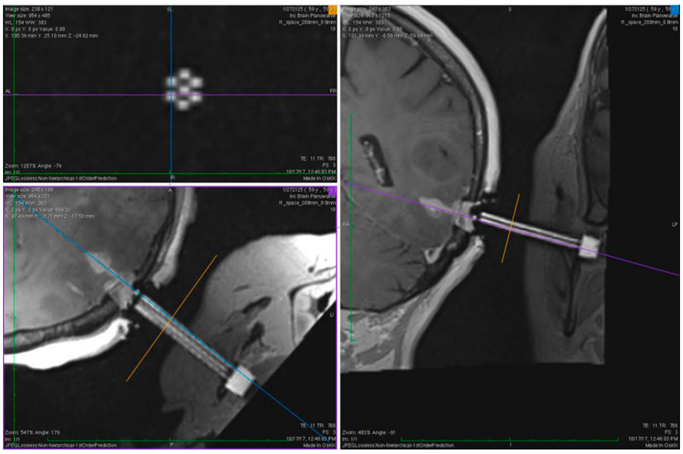

Fig. 1. IMRI enables direct confirmation of correct targeting and detection of early complications.

The HGG Knauth series from the University of Heidelberg shows that the use of iMRI increased the number of patients with GTR from 36.6% to 75.6% [43]. Despite numerous reports confirming the beneficial effect of iMRI use, only one prospective randomized trial is available. It was carried out using low-field 0.15T iMRI on a small group of patients (n = 49). An increase in GTR from 68% to 96% was demonstrated, and thus a significant increase in PFS from 98 to 226 days [44].

The combination of the iMRI method with others, supporting the scope of resection, is a hope for the future of modern neurosurgery. Although both 5 ALA and iMRI have a positive effect on increasing the extent of resection [45], a combination of iMRI and 5 ALA methods was analyzed and no additional effect on EOR was demonstrated [46].

Glioma biopsy – novel perspectives

Stereotactic brain biopsies are widely used for establishing the diagnosis of intracranial lesions. Frame-based, frameless stereotactic, and intraoperative MRI-guided brain needle biopsy techniques have a comparable diagnostic yield for patients with no prior treatments (either radiation or surgery) [47]. Intraoperative MRI-guided brain biopsy is associated with fewer serious adverse events and shorter hospital stay [47].

Especially in brain lesions involving eloquent areas, high-field iMRI contributes to lower neurological complications [48]. Stereotactic biopsy of smaller brain lesions, of less than 1 cubic centimeter (1 cc) in volume, is associated with lower (76.2% versus 94.8%) diagnostic yield and requires an experienced stereotactic neurosurgeon using advanced neurosurgical techniques [49].

To improve accuracy and minimize morbidity, we have been utilizing a new device called BJGA (Ball Joint Guide Array) for brain biopsies in real time 3T magnetic field imaging [50] (Fig. 1.). The accuracy and safety of this newly developed 3T compatible array was validated in nonhuman primates [50]. The main advantage of our surgical technique is visualization of the target and trajectory with high resolution 3T MRI scans just before inserting a biopsy needle into the brain. Trajectory adjustment can be done at any moment during the procedure. Directly after tissue sampling, we confirm correct targeting and rule out early complications.

The advanced operative technique utilizing 3T iMRI may result in higher diagnostic and accuracy rates and lower morbidity. Further investigations are necessary.

Convection-enhanced delivery in glioblastoma treatment

Lack of efficacy of chemotherapy drugs against brain tumors results partly from the inability of therapeutic agents with a molecular weight greater than 180 kDa to pass through the BBB [51]. Intraparenchymal drug delivery includes the use of implantable polymers that slowly release drugs [52] and convection-enhanced delivery (CED) through rigid cannulas and/or soft catheters [53]. CED is powered by bulk flow kinetics from pressure gradients, with the infusates moving through the interstitial space, perivascularly, para-arterially, and in axonal transport [54–57].

Conceptual development and preclinical studies of CED started in 1994 [56]. First clinical trials with CED of targeted toxin TF-CRM107, a human transferrin (TF) conjugated to diphtheria toxin (CRM107), in glioblastoma took place in 1997. In the group of the first 15 patients, 60% had a tumor size reduction. In the phase II arm only, 12 of 31 had a radiographic response. The phase III study involving TF-CRM107 was aborted because an intermediate analysis of 44 patients showed only a 39% response rate [56].

Further CED in glioblastoma studies used conjugated toxins (8), gene-bearing liposomal vectors (1) [58], or conventional chemotherapies (5) [56].

CED of IL-4(38-37)-PE38KDEL, a chimeric protein composed of a circularly permuted IL-4 and a truncated form of Pseudomonas exotoxin (PE), into recurrent malignant high-grade gliomas was investigated. No apparent systemic toxicity occurred, but seven of nine patients underwent craniotomy because of increased intracranial pressure at 16–101 days after the beginning of infusion. Histological evidence of severe tumor necrosis was found but no toxicity to the normal brain was observed [59]. Further studies are being conducted to determine the maximal tolerated concentration and volume of IL-4(38-37)-PE38KDEL.

The randomized phase III trial of CED compared to Gliadel wafers (GW) in glioblastoma, Cintredekin besudotox (CB), a chimeric protein made up of IL-13 and a truncated form of Pseudomonas exotoxin A, was delivered through 2–4 catheters inserted into the brain parenchyma during tumor resection. Infusion started 96 h afterwards. There was no survival difference between CB administered via CED and GW [60].

Preclinical studies suggest that the anatomical location determines the severity of toxicity after local delivery of therapeutic agents via CED and that caution should be used when translating data from supratentorial CED studies to treat infratentorial tumors [61].

Convection-enhanced delivery appears to represent an effective method for administering therapeutic agents in patients with malignant brain tumors [62]. Moreover, accurate catheter placement with intraoperative MRI confirmation and infusion monitoring combined with establishing a maximal tolerated concentration and volume of therapeutic agents for this route of administration will undoubtedly improve the effectiveness of CED in glioma treatment (Fig. 2.).

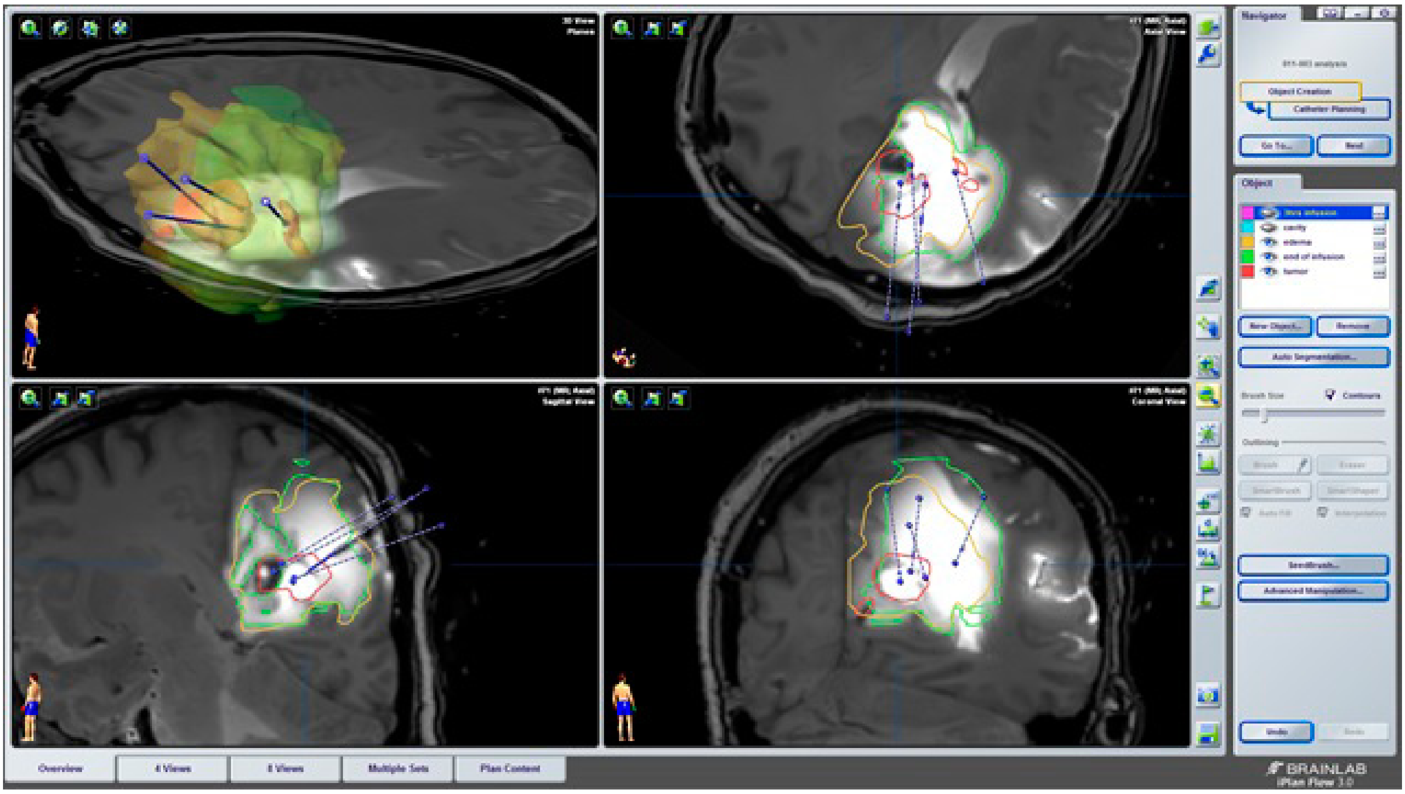

Fig. 2. Convection-enhanced delivery appears to represent an effective method for administering therapeutic agents in patients with malignant brain tumors.

Gamma knife – a novel approach in the treatment of malignant gliomas

Despite all the hitherto available treatment modalities, malignant gliomas tend to recur. Salvage treatment of patients with recurrent HGG after initial radiation therapy can include surgical re-resection, re-irradiation, systemic agent administration, and brain tumor infusions. Stereotactic radiosurgery (SRS) may be appealing because it can deliver a high dose in a small volume in one (SRS) or just a few sessions (fractionated stereotactic radiotherapy, FSRT). The strong gradient limits the dose to the edges of the irradiated area and therefore reduces the risk of complications. Therefore, SRS has been considered the last resort in patients with recurrent high-grade gliomas. Thus in our Gamma Knife Centre, we also put our attention to treat those patients, and so far 19 consecutive patients with 23 lesions were treated with gamma knife SRS (stereotactic radiosurgery) as salvage treatment for recurrent glioblastoma. The primary goal was overall survival duration from the time of the actual salvage radiosurgery. All patients included in this study received a standard course of radiotherapy after surgical resection or biopsy with a median dose of 54 grays (Gy) (range, 42–60 Gy) in conventional fractionations of 2 Gy per day. After radiotherapy, 14 patients had subsequently received temozolomide. The mean time from the initial diagnosis to salvage radiosurgery was 15.6 months (range 1–66 months). An actuarial survival analysis for all patients revealed a median overall survival duration of 32.2 months after the initial diagnosis (95% CI, 24.8–39.5 months) and 16.6 months after the date of SRS (95% CI, 12.5–20.6 months).

Conclusions

In this paper, we presented the achievements of the Department of Neurosurgery at Brodno Masovian Hospital in the treatment of high-grade gliomas. Our Department is equipped in all the possible up-to-date and state-of-the-art surgical modalities, including e.g. intraoperative MRI and gamma knife. Therefore, we can serve our patients with all types of brain tumors, including all types of high-grade gliomas. As the first Department in Europe with close cooperation with the Department of Neurosurgery in San Francisco, we have started local infusions of exotoxin A of Pseudomonas Aeruginosa directly to the tumor, and we think that technology may change all approaches to the treatment of high-grade gliomas.

REFERENCES

1. Omuro A., DeAngelis L.M.: Glioblastoma and other malignant gliomas: a clinical review. JAMA., 2013; 310: 1842–1850.
2. Leece R., Xu J., Ostrom Q.T., Chen Y., Kruchko C. et al.: Global incidence of malignant brain and other central nervous system tumors by histology, 2003–2007. Neuro. Oncol., 2017; 19: 1553–1564.
3. Ostrom Q.T., Bauchet L., Davis F.G., Deltour I., Fisher J.L. et al.: The epidemiology of glioma in adults: a „state of the science" review. Neuro Oncol., 2014; 16(7): 896–913.
4. Wrensch M.R., Barnholtz-Sloan J.S.: The epidemiology of glioma in adults: a state of the science review. Neuro Oncol., 2014; 16: 896–913.
5. Sarkar A., Chiocca E.A.: Glioblastoma and malignant astrocytoma, Brain Tumors, Kane A.H., Laws E. R. jr., Elsevier, Amsterdam, 2012: 384–407.
6. Bush N.A., Chang S.M., Berger M.S.: Current and future strategies for treatment of glioma. Neurosurg Rev., 2017; 40(1): 1–14.
7. Ostrom Q.T., Gittleman H., Ste tson L., Virk S.M., Barnholtz-Sloan J.S.: Epidemiology of gliomas. Cancer Treat Res, 2015; 163: 1–14.

8. Stupp R., Mason W.P., van den Bent M.J., Weller M., Fisher B. et al.: European Organisation for Research and Treatment of Cancer Brain Tumor and Radiotherapy Groups, National Cancer Institute of Canada Clinical Trials Group: Radiotherapy plus concomitant and adjuvant temozolomide for glioblastoma. N Engl J Med, 2005; 352: 987–996.
9. Wangaryattawanich P., Hatami M., Wang J., Thomas G., Flanders A. et al.: Multicenter imaging outcomes study of The Cancer Genome Atlas glioblastoma patient cohort: imaging predictors of overall and progression-free survival. Neuro Oncol, 2015; 17: 1525–1537.
10. Archive TCI. VASARI Research Project. Available online: https://wiki.cancerimagingarchive.net/display/Public/VASARI+Research+Project. Accessed 5/3/2017.
11. Shaver M.M., Kohanteb P.A., Chiou C., Bardis M.D., Chantaduly Ch. et al.: Optimizing Neuro-Oncology Imaging: A Review of Deep Learning Approaches for Glioma Imaging. Cancers, 2019; 11(6): 829.
12. Cha S.: Update on brain tumor imaging: from anatomy to physiology. Am J Neuroradiol, 2006; 27: 475–487.
13. Young G.S.: Advanced MRI of adult brain tumors. Neurol Clin, 2007; 25: 947–973.
14. Schulder M., Maldijian J.A., Liu W.C., Liu W.Ch., Holodny A.I. et al: Functional image-guided surgery of intracranial tumors located in or near the sensorimotor cortex. J Neurosurg, 1998; 89: 412–418.
15. Bizzi A., Blasi V., Falini A., Ferroli P., Cadioli M. et al.: Presurgical functional MR imaging of language and motor functions: validation with intraoperative electrocortical mapping. Radiology., 2008; 248(2): 579–589.
16. Bartos R., Jech R., Vymazal J., Petrovický P., Vachata P. et al: Validity of primary motor area localization with fMRI versus electric cortical stimulation: a comparative study. Acta Neurochir., 2009; 151(9): 1071–1080.
17. Meier M.P., Ilmberger J., Fesl G., Ruge M.I.: Validation of functional motor and language MRI with direct cortical stimulation. Acta Neurochir., 2013; 155(4): 675–683.
18. Castellano A., Cirillo S., Bello L., Riva M., Falini A.: Functional MRI for Surgery of Gliomas. Curr Treat Options Neurol., 2017; 19: 34.
19. Giussani C., Roux F.E., Ojemann J., Sganzerla E.P., Pirillo D. et al.: Is preoperative functional magnetic resonance imaging reliable for language areas mapping in brain tumor surgery? Review of language functional magnetic resonance imaging and direct cortical stimulation correlation studies. Neurosurgery, 2010; 113–120.
20. Kuchcinski G., Mellerio C., Pallud J., Dezamis E., Turc G. et al.: Three-tesla functional MR language mapping: comparison with direct cortical stimulation in gliomas. Neurology., 2015; 84(6): 560–568.
21. Vigneron D.B., Nelson S.J.: Magnetic resonance spectroscopy. Neuro-oncology: The Essentials, Bernstein M, Berger MS. Thieme, New York 2000: 99–113.
22. Pirzkall A., Nelson S.J., McKnight T.R., Wara W.W., Larson L.A. et al: Metabolic imaging of low-grade gliomas with three-dimensional magnetic resonance spectroscopy. Int J Radiat Oncol Biol Phys, 2002; 53: 1254–1264.
23. Li X., Jin H., Lu Y., Oh J., Chang S. et al.: Identification of MRI and 1H MRSI parameters that may predict survival for patients with malignant gliomas. NMR Biomed, 2004; 17(1): 10–20.
24. Duyn J.H., Gillen J., Sobering G., van Zijl P.C., Moonen C.T.: Multisection proton MR spectroscopic imaging of the brain, Radiology, 1993; 188(1): 277–282.
25. Gajewicz W., Papierz W., Szymczak W., Goraj B.: The use of proton MRS in the differential diagnosis of brain tumors and tumor-like processes. Med Sci Monit, 2003; 9: 97–105.
26. Preul M.C., Caramanos Z., Villemure J.G. et al.: Using proton magnetic resonance spectroscopic imaging to predict in vivo the response of recurrent malignant gliomas to tamoxifen chemotherapy. Neurosurgery, 2000; 46: 306–318.
27. Oh J., Henry R.G., Pirzkall A. et al.: Survival analysis in patients with glioblastoma multiforme: predictive value of choline-to-N-acetylaspartate index, apparent diffusion coefficient, and relative cerebral blood volume. J Magn Reson Imag, 2004; 19: 546–554.
28. Balmaceda C., Critchell D., Mao X. et al.: Multisection 1H magnetic resonance spectroscopic imaging assessment of glioma response to chemotherapy. J Neurooncol, 2006; 76: 185–191.
29. Bello L., Gambini A., Castellano A. et al: Motor and language DTI fiber tracking com-bined with intraoperative subcortical mapping for surgical removal of gliomas. Neuroimage, 2008; 39: 369–382.
30. Bello L., Riva M., Fava E. et al: Tailoring neurophysiological strategies with clinical context enhances resection and safety and expands indica-tions in gliomas involving motor pathways. Neuro Oncol, 2014; 16: 1110–1128.
31. Zhu F.P., Wu J.S., Song Y.Y. et al.: Clinical application of motor pathway mapping using diffusion tensor imaging tractography and intraoperative direct subcortical stimulation in cerebral glioma surgery: a prospective cohort study. Neurosurgery, 2012; 71: 1170–1184.
32. Ohue S., Kohno S., Inoue A. et al: Accuracy of diffusion tensor magnetic resonance imaging-based tractography for surgery of gliomas near the pyramidal tract: a significant correlation between subcortical electrical stimulation and postoperative tractography. Neuro-surgery, 2012; 70: 283–294.
33. Nimsky C., Ganslandt O., Hastreiter P. et al: Preoperative and intraoperative diffusion tensor imaging-based fiber tracking in glioma surgery. Neurosurgery, 2007; 61: 178–186.
34. De Witt Hamer P.C., Robles S.G., Zwinderman A.H., Duffau H., Berger M.S.: Impact of intraoperative stimulation brain map-ping on glioma surgery outcome: a meta-analysis. J Clin Oncol., 2012; 30: 2559–2565.
35. Ottenhausen M., Krieg S.M., Meyer B., Ringel F.: Functional preoperative and intraoperative mapping and monitoring: increasing safety and efficacy in glioma surgery. Neurosurg Focus, 2015; 38: 1–13.
36. Acerbi F., Broggi M., Schebesch K.M. et al.: Fluorescein-guided surgery for resection of high-grade gliomas: Amulticentric prospective phase II study (FLUOGLIO). Clin CancerRes, 2018; 24: 52–61.
37. Kuroiwa T., Kajimoto Y., Ohta T.: Development of a fluoresceinoperative microscope for use during malignant gliomasurgery: a technical note and preliminary report. Surg Neurol, 1998; 50: 41–49.
38. Waqas M., Shamim M.S.: Sodium fluorescein guided resection of malignant glioma. J Pak Med Assoc, 2018; 68(6): 968–970.
39. July J., Manninen P., Lai J. et al.: The history of awake craniotomy for brain tumor and its spread into Asia Surg Neurol, 2009; 71(5): 621–624.
40. Penfield W.: No Man Alone. A Neurosurgeon's Life. Little, Brown and company, MA, USA 1977.
41. Albert F.K., Forsting M., Sartor K., Adams H.P., Kunze S.: Early postoperative magnetic resonance imaging after resection of malignant glioma: objective evaluation of residual tumor and its influence on regrowth and prognosis. Neurosurgery, 1994; 34(1): 45–60.
42. Nimsky C., Ganslandt O., von Keller B., Fahlbusch R.: Preliminary experience in glioma surgery with intraoperative high-field MRI. Acta Neurochir Suppl., 2003; 88: 21–29.
43. Knauth M., Wirtz C.R., Tronnier V.M. et al.: Intraoperative MR imaging increases the extent of resection in patients with high-grade gliomas. Am J Neuroradiol, 1999; 20(9): 1642 –1646.
44. Senft C., Bink A., Franz K. et al.: Intraoperative MRI guidance and extent of resection in glioma surgery: A randomized, controlled trial. Lancet Oncol, 2011; 12(11): 997–1003.
45. Coburger J., Wirtz C.R.: Fluorescence guided surgery by 5-ALA and intraoperative MRI in high grade glioma: a systematic review. J Neurooncol, 2019; 141(3): 533–546.
46. Bassaganyas-Vancells C., Roldán P., González J.J. et al.: Combined use of 5-Aminolevulinic Acid and Low-field Intraoperative Magnetic Resonance Imaging in High-Grade Glioma surgery. World Neurosurg, 2019; 130: 206–212.
47. Sewing A.C., Lagerweij T., van Vuurden D.G. et al.: Preclinical evaluation of convection-enhanced delivery of liposomal doxorubicin to treat pediatric diffuse intrinsic pontine glioma and thalamic high-grade glioma. J Neurosurg Pediatr, 2017; 19(5): 518–530.
48. Lu Y., Yeung C., Radmanesh A., Wiemann R., Black P.M. et al.: Comparative effectiveness of frame-based, frameless, and intraoperative magnetic resonance imaging-guided brain biopsy techniques. World Neurosurg, 2015; 83(3): 261–268.
49. Zhang J.S., Qu L., Wang Q. et al.: Intraoperative visualisation of functional structures facilitates safe frameless stereotactic biopsy in the motor eloquent regions of the brain. Br J Neurosurg, 2018; 32(4): 372–380.
50. Waters J.D., Gonda D.D., Reddy H., Kasper E.M., Warnke P.C. et al.: Diagnostic yield of stereotactic needle-biopsies of sub-cubic centimeter intracranial lesions. Surg Neurol Int, 2013; 17; 4(Suppl 3): 176–181.
51. Pardridge W.M.: Blood-brain barrier delivery. Drug Discov Today, 2007; 12(1–2): 54–61.
52. Lesniak M.S., Brem H.: Targeted therapy for brain tumours. Nat Rev Drug Discov, 2004; 3(6): 499–508.

53. Bobo R.H., Laske D.W., Akbasak A., Morrison P.F., Dedrick R.L. et al.: Convection-enhanced delivery of macromolecules in the brain. Proc Natl Acad Sci, 1994; 91(6): 2076–2080.

54. Kells A.P., Forsayeth J., Bankiewicz K.S.: Glial-derived neurotrophic factor gene transfer for Parkinson's disease: anterograde distribution of AAV2 vectors in the primate brain. Neurobiol Dis, 2012; 48(2): 228–235.

55. Kells A.P., Hadaczek P., Yin D. et al.: Efficient gene therapy-based method for the delivery of therapeutics to primate cortex. Proc Natl Acad Sci, 2009; 106(7): 2407–2411.

56. Lieberman D.M., Laske D.W., Morrison P.F., Bankiewicz K.S., Oldfield E.H.: Convection-enhanced distribution of large molecules in gray matter during interstitial drug infusion. J Neurosurg, 1995; 82(6): 1021–1029.

57. Salegio E.A., Streeter H., Dube N. et al.: Distribution of nanoparticles throughout the cerebral cortex of rodents and non-human primates: Implications for gene and drug therapy. Front Neuroanat, 2014; 8: 9.

58. Samaranch L., Salegio E.A., San Sebastian W. et al.: Strong cortical and spinal cord transduction after AAV7 and AAV9 delivery into the cerebrospinal fluid of nonhuman primates. Hum Gene Ther, 2013; 24(5): 526–532.

59. Voges J., Reszka R., Gossmann A. et al.: Imaging-guided convection-enhanced delivery and gene therapy of glioblastoma. Ann Neurol, 2003; 54(4): 479–487.

60. Bruce J.N., Fine R.L., Canoll P. et al.: Regression of recurrent malignant gliomas with convection-enhanced delivery of topotecan. Neurosurgery, 2011; 69(6): 1272–1280.

61. Rand R.W., Kreitman R.J., Patronas N., Varricchio F., Pastan I. et al.: Intratumoral administration of recombinant circularly permuted interleukin-4-Pseudomonas exotoxin in patients with high-grade glioma. Clin Cancer Res, 2000; 6(6): 2157–2165.

62. Kunwar S., Chang S., Westphal M. et al.: Phase III randomized trial of CED of IL13-PE38QQR vs Gliadel wafers for recurrent glioblastoma. Neuro Oncol, 2010; 12(8): 871–881.

Word count: 3 840 Page count: 7 Tables: – Figures: 2 References: 62

DOI: 10.5604/01.3001.0014.2473 Table of content: https://ppch.pl/issue/13341

Competing interests: The authors declare that they have no competing interests.

Corresponding author: Grzegorz Turek; Department of Neurosurgery, Brodno Masovian Hospital; Kondratowicza street 8, 03-242 Warsaw, Poland; Phone.: +48 696454753; E-mail: turek.grz@gmail.com

Cite this article as: Turek G., Pasterski T., Bankiewicz K., Dzierzecki S., Zabek M.: Current strategies for the treatment of malignant gliomas – experience of the Department of Neurosurgery, Brodno Masovian Hospital in Warsaw; Pol Przegl Chir 2020: 92 (5): 50-56