



Peritumoural oedema volume as a predictor of neurological and functional outcomes in patients with gliomas

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Abstract. The purpose of the study was to evaluate the prognostic significance of the preoperative volume of peritumoural oedema according to magnetic resonance imaging in patients with gliomas. A single-centre observational study was conducted, including 60 patients aged 21 to 75 years, with predominance of high-grade diffuse gliomas grade 4 according to the World Health Organisation classification. The volume of peritumoural oedema was determined using magnetic resonance imaging in T2-weighted and fluid-attenuated inversion recovery (FLAIR) sequences by means of volumetric analysis, followed by stratification into four groups. Neurological, cognitive, and functional status were assessed using the National Institutes of Health Stroke Scale, the Mini-Mental State Examination, and the modified Rankin Scale, with final evaluation performed at 6 months. It was found that the preoperative peritumoural oedema volume significantly correlated with the severity of functional deficiency 6 months after surgery (correlation coefficient $r = 0.68$; $p < 0.001$; 95% confidence interval 0.52-0.81). It was shown that with a peritumoural oedema volume of 30 cm³ or more, the proportion of adverse outcomes on the modified Rankin Scale of more than 2 points was 60.0%, whereas with a peritumoural oedema volume of less than 30 cm³, this indicator did not exceed 26.7%. It was calculated that the presence of peritumoural oedema with a volume of 30 cm³ or more is associated with a 4.13-fold increase in the probability of an unfavourable functional outcome (odds ratio 4.13; 95% confidence interval 1.39-12.27; $p < 0.01$). It was found that after surgical resection, the average volume of peritumoural oedema decreased dynamically, but on the first day there was a temporary increase in oedema followed by regression by days 14-30. A provision has been developed that the quantitative assessment of peritumoural oedema according to preoperative magnetic resonance imaging can be used as an objective criterion for risk stratification and planning decongestant therapy in patients with gliomas

Keywords: peritumoural zone; neuroimaging; T2/FLAIR; magnetic resonance imaging; Rankin Scale; risk stratification

Introduction

The relevance of the study is conditioned by the high clinical significance of peritumoural oedema in glial brain tumours, since its severity can affect the

neurological status, functional independence of the patient, and treatment outcomes. Glial brain tumours, especially high-grade diffuse gliomas, remain one of the

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most difficult problems of contemporary neuro-oncology due to infiltrative growth, pronounced biological heterogeneity, and unfavourable prognosis.

Recommendations of M. Weller *et al.* [1] and P.Y. Wen *et al.* [2] emphasised the need for a comprehensive assessment of not only the tumour node itself, but also the surrounding peritumoural zone, since it largely determines the severity of clinical symptoms, the features of the postoperative course, and treatment outcomes. A significant role in the clinical picture of gliomas is played by peritumoural oedema, which is an important pathophysiological component of the tumour process. Its development is accompanied by impaired permeability of the blood-brain barrier; accumulation of fluid mainly in the white matter; increased mass effect, compression of adjacent structures, and deterioration of perfusion of the peritumoural zones. These changes contribute to the development of focal neurological deficits, cognitive impairments, and decreased functional independence of patients. Approaches of S.S. Ahn & J. Cha [3] to the neuroimaging assessment of primary tumours of the central nervous system also pointed to the need to analyse peritumoural changes as a clinically significant part of the tumour process.

The correct interpretation of postoperative neuroimaging changes is also important. According to A.M. Rykkje *et al.* [4], the timing of early postoperative magnetic resonance imaging can significantly affect the assessment of contrast and non-contrast changes after glioblastoma removal. In turn, the updated criteria of Response Assessment in Neuro-Oncology 2.0 and their practical neuroradiological interpretation emphasise the need for a standardised assessment of T2/FLAIR changes and residual pathological tissue in gliomas [5-6]. PET RANO positron emission criteria play an additional role in the comprehensive assessment of the tumour process, expanding the possibilities of monitoring diffuse gliomas [7]. Quantitative characterisation of the peritumoural zone is impossible without the use of standardised magnetic resonance techniques. Consensus recommendations on dynamic susceptibility contrast perfusion magnetic resonance imaging emphasise the importance of reproducible parameters in the study of high-grade gliomas [8]. In addition, advanced magnetic resonance techniques, including a multiparametric approach, spectroscopy, radiomics, and comprehensive imaging of glioblastoma patients, help to more fully characterise both the tumour itself and the surrounding oedema zone, as shown by M. Martucci *et al.* [9], O.M. Henriksen *et al.* [10] and T.C. Booth *et al.* [11].

In recent years, special attention has been paid to the quantitative assessment of peritumoural oedema as a prognostic indicator. Z. Fang *et al.* [12] have shown that the peritumoural oedema index and related mechanisms affect the prognosis in patients with glioblastoma. These data confirm that the severity of oedema can be considered not only as a radiological

characteristic, but also as a potential marker of the biological features of the tumour and the unfavourable course of the disease. Despite significant progress, there are still insufficient studies in the literature in which the peritumoural oedema volume was analysed as a quantitative indicator directly related to neurological deficits, cognitive impairments, and functional outcome after surgical treatment. The threshold values of the volume of oedema that could be used in everyday clinical practice for risk stratification have also been insufficiently studied. This determined the purpose of this study to evaluate the prognostic value of the preoperative volume of peripheral oedema according to magnetic resonance imaging in T2 and FLAIR modes for the neurological, cognitive, and functional outcome in patients with gliomas of the brain.

Materials and Methods

This study was conducted as a single-centre observational investigation at the Department of Neurosurgery of the National Hospital under the Ministry of Health of the Kyrgyz Republic between 2021 and 2025. The study included 60 patients aged 21 to 75 years with malignant glial brain tumours, in whom a pronounced peritumoural oedema zone was identified on preoperative magnetic resonance imaging. Predominance of high-grade diffuse gliomas, WHO grade 4, was observed in the morphological composition of the cohort, namely glioblastoma grade 4 in 30 patients and astrocytoma grade 4 in 30 patient. The choice of this particular category of patients was conditioned by the fact that with high-grade gliomas, peripheral oedema, as a rule, reaches the greatest severity, has a significant effect on clinical symptoms and can serve as a significant prognostic marker of the disease progression.

The inclusion criteria were the presence of an intracerebral glial tumour; confirmed by clinical, neuroimaging and morphological data, the presence of preoperative magnetic resonance imaging of the brain with mandatory T2 and FLAIR regimens, surgical treatment, and the availability of clinical assessment on the NIHSS, MMSE, and mRS scales at the main stages of follow-up. NIHSS (National Institutes of Health Stroke Scale) is a neurological deficit assessment scale; MMSE (Mini-Mental State Examination) is a brief cognitive status scale; mRS (modified Rankin Scale) is a scale for assessing functional outcome and degree of disability. Exclusion criteria were pronounced post-ischaemic or post-haemorrhagic changes in brain matter; which can independently affect neurological deficits and the volume of pathological changes on magnetic resonance imaging, severe somatic decompensation, which worsens the functional status regardless of the tumour process, and the absence of key control points for dynamic observation.

The main research materials were medical records of inpatient patients, protocols of neuroimaging studies, surgical journals, protocols of intraoperative

ultrasound examination, histological findings, and the results of dynamic clinical evaluation. The analysis of archived medical documentation was used to retrospectively clarify the anamnestic, clinical and instrumental characteristics of patients, and to compare neuroimaging parameters with clinical outcomes. The use of multiple data sources has improved the completeness of the observation and ensured comparability of neuroimaging, clinical and postoperative results. Magnetic resonance imaging of the brain was used as the main instrumental method. The study was performed in the preoperative period 1-10 days before surgery, and in the postoperative dynamics on days 1, 3, 7, 14, and 30, if there were clinical indications and the technical availability of the study. The most significant for the assessment of peritumoural oedema were T2-weighted images and the FLAIR sequence, that is, Fluid Attenuated Inversion Recovery, a mode with suppression of the signal from free fluid. The choice of FLAIR and T2 modes was conditioned by their high sensitivity to visualisation of vasogenic oedema in the cerebral white matter. Additionally, T1-weighted images were included in the standard protocol, and, if indicated, T1-weighted images with contrast enhancement, which was used to clarify the boundaries of the tumour node, necrosis zones, and the cystic component.

The volume of peritumoural oedema was determined by volumetric analysis using FLAIR-hyperintensity zones located peritumourally. During the calculation, obvious necrotic and cystic cavities were excluded, and in postoperative studies, the resection cavity was also excluded in order not to overestimate the volume of oedematous changes. For this, a morphometric image segmentation method was used, based on the sequential allocation of the area of interest on each slice, followed by the summation of the areas and conversion to volume. This approach can be performed manually or semi-automatically and is the most reasonable in neuro-oncological studies, since it allows quantifying the prevalence of pathological changes, rather than being limited only to descriptive visual characteristics. According to the results of volumetry, patients were stratified into four groups according to the volume of peritumoural oedema: less than 30 cm³, 30-60 cm³, 60-100 cm³, and more than 100 cm³. This gradation was used to compare the oedema severity with neurological deficits, cognitive impairments, and functional outcome.

An additional method of intraoperative monitoring was ultrasound examination during surgery after tumour resection. Intraoperative ultrasound examination was used to clarify the boundaries of resection, assess the residual tumour component, and visually monitor the condition of surrounding tissues. The use of this method was substantiated by its accessibility, the possibility of obtaining real-time data, and its practical significance for neurosurgical tactics. Clinical research methods included neurological examination

and standardised assessment of the patient's condition using validated scales. Neurological deficit was determined by the NIHSS scale before surgery, in the early postoperative period on days 7-14, before the start of adjuvant chemoradiotherapy on days 15-30, and after 3 and 6 months. Cognitive functions were assessed on the MMSE scale at the same control dates. Functional outcomes were analysed using a modified Rankine Scale, with the final endpoint being the mRS value 6 months after surgery. The 15-30 day interval was considered separately as a baseline before starting adjuvant treatment, since later clinical outcomes could be influenced not only by neurosurgical intervention and the dynamics of peritumoural oedema, but also by radiation therapy with temozolomide. The morphological method was used to verify the histological variant of the tumour and to confirm the diagnosis definitively. Histological findings were used to classify patients according to nosological forms and compare the morphological variant with the severity of peritumoural oedema. This was necessary to increase the diagnostic accuracy and uniformity of the sample under study.

Statistical data processing was carried out using descriptive and analytical statistical methods. Quantitative indicators were presented as the arithmetic mean and standard deviation ($M \pm SD$) with a normal distribution, or as the median and interquartile range [IQR] with an abnormal distribution, where IQR was the interquartile range. To analyse the relationship between the volume of peritumoural oedema and functional outcome indicators, Pearson or Spearman correlation analysis was used, depending on the nature of the distribution of signs. Pearson's method was used for parametric data distribution, while Spearman's method was used for deviations from normality or for the analysis of ordinal scales. For an intergroup comparison of indicators in the categories of peripheral oedema volume, appropriate criteria for comparing quantitative and qualitative signs were used. For prognostic evaluation, the odds ratio of an unfavourable outcome with mRS > 2 was calculated depending on the threshold value of the peritumoural oedema volume ≥ 0 cm³. The odds ratio was determined by the equation $OR = (a \times d) / (b \times c)$, where a and d – number of observations with matching outcomes, b and c – number of observations with alternative outcomes in the compared groups. The choice of this method was substantiated by the possibility to quantify the strength of the relationship between the volume of oedema and the risk of an unfavourable functional outcome. The differences at $p < 0.05$ were considered statistically significant. The study was conducted in accordance with the principles of biomedical ethics. The study protocol was approved by the Bioethics Committee of the National Surgical Center named after M. Mamakeev of the Ministry of Health of the Kyrgyz Republic (Protocol No. 29 dated 11 February 2021). The study was performed

in accordance with the ethical principles of the World Medical Association [13]. All patients received written informed consent to participate in the study, to process personal data, and to use the results of the examination for scientific purposes.

Results

Preoperative clinical and neurological status of patients

All patients had a pronounced zone of peritumoural oedema according to preoperative magnetic resonance imaging and were characterised by significant neurological and functional deficits at the time of admission. The volume of the tumour node in most cases ranged from 40 to 70 cm³, while the volume of peritumoural oedema was at least 30 cm³, on average about 60 cm³, and in some cases exceeded 100 cm³. The choice of the threshold value of peritumoural oedema at the level of 30 cm³ was conditioned by the fact that after exceeding this volume, oedema is usually accompanied by a significant mass effect, goes beyond the local peritumoural ring, and begins to involve the pathways and associative

networks of the brain. This leads to increased compression of brain structures, an increased risk of dislocation and secondary ischaemia of the peritumoural zones.

All patients underwent total resection of the tumour node. In the preoperative and early postoperative periods, decongestant therapy was performed, including glucocorticosteroids (dexamethasone at a dose of 12-16 mg per day), osmotic diuretics (mannitol 400-800 ml per day), and loop diuretics (furosemide 20-40 mg), which was aimed at reducing the vasogenic component of oedema and reducing intracranial hypertension. Histological examination of the surgical material confirmed the presence of grade 4 glioblastoma and astrocytoma in all patients. Upon admission, all patients underwent a comprehensive clinical and neurological assessment using standardised scales. Cognitive status was assessed using the Mini-Mental State Examination (MMSE) scale, neurological deficit was assessed using the National Institutes of Health Stroke Scale (NIHSS), and functional status was assessed using the modified Rankin Scale (mRS). Baseline assessment results are presented in Table 1.

Table 1. Cognitive, neurological, and functional status of patients depending on the histological variant of the tumour and the peritumoural oedema volum

Tumour / PTO volume	n	MMSE	NIHSS	mRS
Astrocytoma grade 4, PTO 41 cm ³ (frontal-temporal-parietal localisation)	11	19	17	3
Astrocytoma grade 4, PTO 50 cm ³ (parietal-temporal-occipital localisation)	9	23	20	3
Astrocytoma grade 4, PTO 62 cm ³ (temporal-frontal-parietal localisation)	10	20	22	4
Astrocytoma grade 4, PTO 85 cm ³ (frontal-parietal-temporal localisation)	16	16	30	4
Astrocytoma grade 4, PTO 103 cm ³ (parietal-occipital, paraventricular localisation)	8	12	36	5
Astrocytoma grade 4, PTO 112 cm ³ (deep temporal-parietal-occipital localisation)	6	8	40	5

Note: PTO – peritumoural oedema

Source: developed by the authors based on their own clinical observations

An analysis of the data presented in Table 1 showed that all patients had a pronounced neurological deficit before surgery. The values on the NIHSS scale ranged from 17 to 40 points, which corresponded to a severe neurological condition. On the mRS scale, the indicators ranged from 3 to 5 points, which indicated a significant limitation of functional independence. Cognitive scores on the MMSE scale ranged from 8 to 23 points, indicating varying degrees of cognitive impairment.

Dynamics of peritumoural oedema in glial brain tumours

In the postoperative period, the dynamics of peritumoural oedema was considered as one of the key criteria for the effectiveness of surgical treatment and the

severity of reactive changes in brain tissue. Tracking the volume of oedema allowed assessing the condition of the blood-brain barrier, the effectiveness of decongestant therapy, and determining the optimal timing of follow-up magnetic resonance imaging before starting adjuvant treatment. The volume of peritumoural oedema was assessed based on magnetic resonance imaging data in T2-weighted images and FLAIR modes, and on the results of intraoperative ultrasound examination. An example of the neuroimaging pattern of peritumoural oedema is shown in Figure 1.

As shown in Table 2, the dynamics of the peritumoural oedema volume in patients with glial brain tumours was characterised by a gradual change in indicators at different follow-up periods.

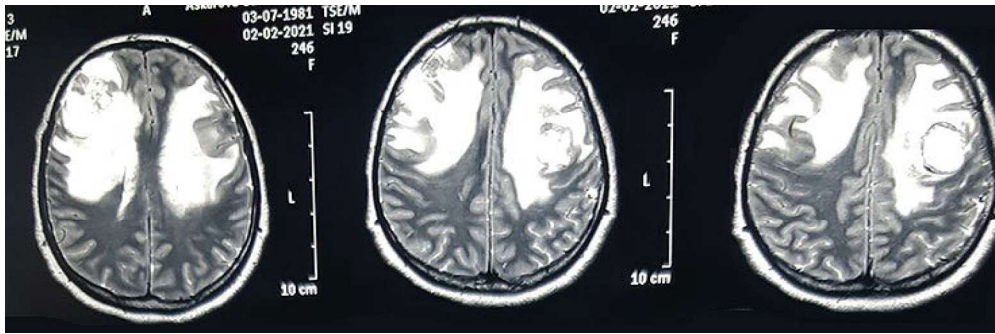


Figure 1. Magnetic resonance imaging of the brain (T2/FLAIR), showing peritumoural oedema around the glial tumour

Source: developed by the authors based on their own MRI data

Table 2. Dynamics of the peritumoural oedema volume in patients with glial brain tumours

No.	Study period	Visualisation method	n	Average PTO volume (cm ³)
1	Before surgery	MRI	60	64.3 ± 15.7
2	Before resection	Intraoperative ultrasound	60	67.1 ± 18.2
3	After removal of the tumour	Intraoperative ultrasound	60	43.7 ± 10.8
4	Day 7	MRI	60	29.4 ± 12.5
5	Days 10-14	MRI	60	18.1 ± 9.6

Note: PTO – peritumoural oedema

Source: developed by the authors based on their own clinical observations

As can be seen from the data presented in Table 2, after removal of the tumour node, there was a consistent decrease in the average volume of peritumoural oedema. The highest rate was recorded before surgery and immediately before resection according to intraoperative ultrasound examination, whereas after tumour removal there was a marked decrease in PTO volume. By days 7 and 14 of the postoperative period, there was a steady trend towards further regression of oedema,

which indicated the effectiveness of surgical decompression and ongoing decongestant therapy. To visually display the revealed dynamics, the data in Table 2 are also presented graphically in Figure 2. As can be seen in Figure 2, after a slight increase in the index at the stage of preoperative intraoperative control, there was a further marked decrease in the average volume of peritumoural oedema, especially after tumour resection and during the first two weeks after surgery.

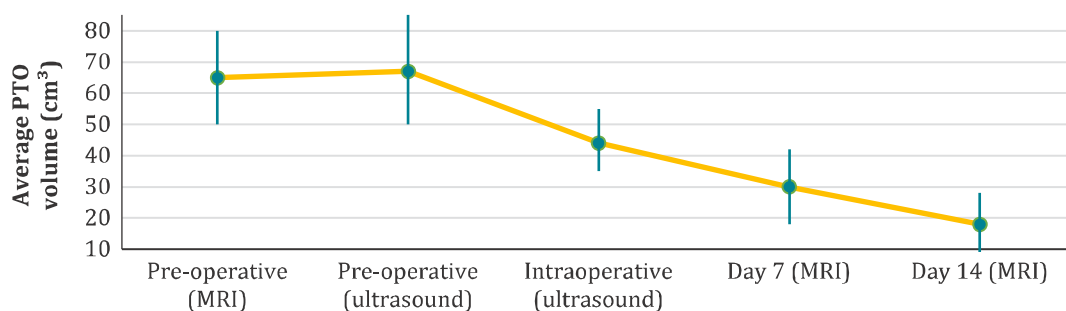


Figure 2. Dynamics of peritumoural oedema volume before and after surgical treatment

Source: developed by the authors based on the data in Table 2

A more detailed analysis of the dynamics of peritumoural oedema and clinical parameters is presented in Table 3. As the data show, changes in the peritumoural oedema volume in the postoperative period were accompanied by corresponding dynamics in the neurological and functional status of patients. The degree of oedema regression was of clinical importance, since it

was associated with a decrease in the severity of cerebral and focal symptoms, and with improved indicators of daily activity and functional independence. The results presented in the table allowed more fully assessing the relationship between neuroimaging changes and the clinical course of the disease at various stages of follow-up.

Table 3. Dynamics of the peritumoural oedema volume in patients with glial brain tumours

Reference point	PTO (cm ³)	MMSE	NIHSS	mRS
Before surgery	60.2 ± 14.8	16	> 20	4-5
Intraoperatively	45.3 ± 11.7	-	-	-
Day 1	55.1 ± 13.9	12	> 20	4-5
Day 3	40.5 ± 10.2	16	18-20	4
Day 7	30.4 ± 8.1	19	16-18	4
Day 14	25.6 ± 7.3	21	15-16	3
Day 30	20.8 ± 6.5	24	12-14	3
3 months	15-19	28	8-10	3
6 months	12-15	30	5-6	2

Note: PTO – peritumoural oedema

Source: developed by the authors based on the observation results

Analysis of the data in Table 3 showed that after surgical removal of the tumour, there was a gradual decrease in the peritumoural oedema volume. On the first day after surgery, the phenomenon of the so-called “oedema rebound” was observed, associated with a reactive inflammatory response of brain tissue. Subsequently, starting from 3-7 days, there was a steady decrease in the volume of oedema with a gradual improvement in the neurological and functional status of patients. All included patients had intracerebral glial tumours of large and gigantic sizes (linear size ≥4.0-6.0 cm; tumour volume from 60 cm³ to ≥100 cm³), accompanied by pronounced peritumoural vasogenic oedema (PTO volume, as a rule, >60-100 cm³, in some cases – more than 100 cm³)

(Table 2). There was a marked decrease in PTO intraoperatively (decompressive effect of resection), followed by a temporary increase on day 1 (“oedema rebound”), followed by a steady regression by days 7-14 and a further decrease by day 30 (Fig. 3). Such early dynamics is consistent with the fact that postoperative reactive changes and oedema may increase in the first days and then decrease; an early MRI window is critical for a correct assessment of the postoperative picture. In the long-term periods of 3 and 6 months, the volume of T2/FLAIR hyperintensity reflects the total vasogenic oedema, postoperative and postradiative changes, and possible infiltration; therefore, the term “volume of FLAIR anomalies” is used for these periods (Table 3).

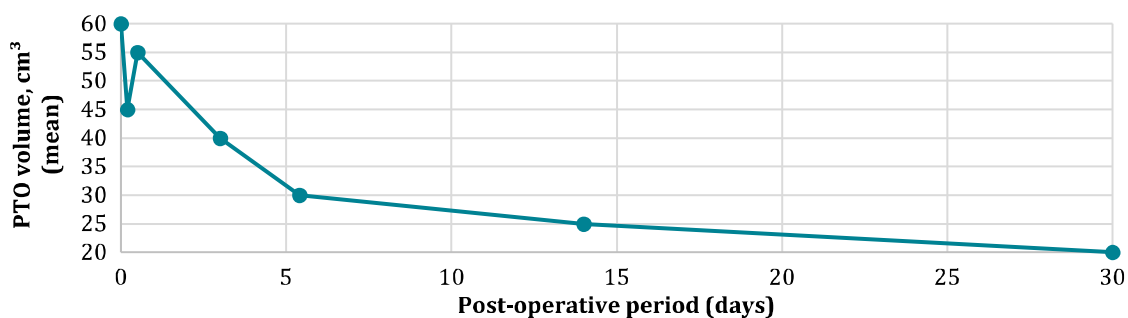


Figure 3. Linear graph of the dynamics of the average peritumoural oedema volume (cm³) at various stages of observation

Source: developed by the authors based on the data in Table 3

Thus, the results obtained indicate that pronounced peritumoural oedema is not only a neuroimaging sign, but also an important clinical and prognostic factor reflecting the degree of compression of brain tissue, microcirculation disorders, and hypoxia of the peritumoural zones. Even after radical removal of the tumour, the recovery of neurological functions is slower, since functionally significant neural networks have been under compression and ischaemia for a long time, and peritumoural tissue remains more vulnerable to intraoperative trauma and early postoperative fluctuations in perfusion.

Along with the analysis of the postoperative dynamics of peritumoural oedema, its prognostic value was assessed. The volume of peritumoural oedema of 30 cm³ was chosen as the threshold level, since it is after exceeding this value that oedema is more often accompanied by a clinically significant mass effect, goes beyond the local peritumoural ring, involves pathways and associative networks of the brain, and also increases the risk of dislocation and secondary ischaemia. It was found that the preoperative volume of peritumoural oedema significantly correlated with the severity of functional deficiency 6 months after surgery ($r = 0.68$;

$p < 0.001$; 95% CI 0.52-0.81). With a peritumoural oedema volume $\geq 30 \text{ cm}^3$, the proportion of adverse outcomes, defined as a modified Rankin Scale value of more than 2 points, was 60.0%, whereas with a peritumoural oedema volume $< 30 \text{ cm}^3$, this indicator was 26.7%. The calculation of the odds ratio showed that the presence of peritumoural oedema $\geq 30 \text{ cm}^3$ is associated with a 4.13-fold increased risk of an unfavourable functional outcome (OR = 4.13; 95% CI 1.39-12.27; $p < 0.01$).

The established patterns are of direct practical importance for the management of patients with glial brain tumours. Already at the preoperative stage, patients with a peritumoural oedema volume $\geq 30 \text{ cm}^3$ can be classified as a high-risk group for an unfavourable functional outcome according to the modified Rankine scale (mRS > 2), which should be taken into consideration when stratifying risk, planning the volume of perioperative follow-up, and choosing the intensity of decongestant therapy. The control MRI schedule is also of major importance in early postoperative follow-up; performing the examination within the recommended 24-48-hour window, but no later than 72 hours after surgery, allows for more accurate interpretation of postoperative changes, assessment of residual pathological areas, and determination of further treatment strategy.

During follow-up dynamic monitoring, particularly within 12 weeks after completion of chemoradiotherapy, the possibility of pseudoprogression should be considered when interpreting MRI findings, as an increase in FLAIR abnormalities during this period does not always indicate true tumour progression. Thus, the results obtained indicate that pronounced peritumoural oedema is not only an important neuroimaging indicator; but also a significant clinical and prognostic factor. Its severity determines the preoperative clinical condition, the characteristics of the early postoperative period, and the likelihood of an unfavourable functional outcome in long-term follow-up. A consistent decrease in the peritumoural oedema volume after surgical treatment was accompanied by an improvement in the neurological, cognitive, and functional status of patients, which confirms the practical importance of volumetric oedema assessment in the system of preoperative risk stratification and dynamic postoperative monitoring.

Discussion

The results of the study showed that the preoperative peritumoural oedema volume in highly malignant glial brain tumours has independent clinical and prognostic significance. The established relationship between an increase in the volume of PTO, the severity of neurological deficits, cognitive impairments, and an unfavourable functional outcome after 6 months allowed considering peritumoural oedema not only as a neuroimaging phenomenon, but also as an indicator of the severity of the tumour process. The data obtained are comparable

with the results of contemporary studies devoted to the quantitative assessment of the peritumoural zone. M. Gao *et al.* [14] showed that intra-tumour and peritumoural radiomic signs according to magnetic resonance imaging have prognostic value in patients with gliomas.

U. Würtemberger *et al.* [15] demonstrated that the peritumoural zone in glioblastoma is characterised not only by vasogenic oedema, but also by an altered microstructure, reflecting the infiltrative nature of tumour growth. R. Tan *et al.* [16] also showed that radiomic analysis of the tumour and peritumoural oedema can be used for preoperative prediction of glioma malignancy. Thus, the results of the study are consistent with contemporary concepts that the peritumoural zone contains clinically and prognostically significant information. Of particular interest is the interpretation of early postoperative changes. F.X. Fu *et al.* [17] argued that the diagnostic value of multiparametric radiomic models for differentiating glioma recurrence and pseudoprogression. G. Librizzi *et al.* [18] in a systematic review also emphasised the importance of perioperative neuroimaging predictors of tumour progression and pseudoprogression.

J. Lin *et al.* [19] demonstrated the value of radiomic features on multiparametric magnetic resonance imaging for distinguishing pseudoprogression and recurrence in patients with high-grade gliomas. These data confirm that the interpretation of postoperative FLAIR/T2 hyperintensity requires caution, as it may reflect both reactive changes and true tumour dynamics. The phenomenon of a temporary increase in the volume of peritumoural oedema in the early postoperative period revealed in this study can be explained by reactive tissue restructuring, impaired microcirculation, and a temporary increase in the permeability of the blood-brain barrier. In this context, the data by H. Blakstad *et al.* [20], devoted to the frequency and outcomes of pseudoprogression after radiation therapy in patients with glioblastoma, additionally emphasised the complexity of interpreting the neuroimaging picture in this category of patients. Therefore, an early postoperative increase in the area of FLAIR changes should not always be interpreted as a manifestation of unfavourable dynamics, especially in the absence of clinical and radiological signs of true progression. Molecular mechanisms also play an essential role in the development and maintenance of oedema.

L. Castañeyra-Ruiz *et al.* [21] consider aquaporin-4 as one of the key links linking impaired water transport, glymphatic dysfunction, immune evasion, and tumour resistance to treatment in glioblastoma. These ideas are in good agreement with the data obtained, according to which pronounced peritumoural oedema is associated with a more severe neurological status and a worse functional prognosis. Thus, a comparison of the results with contemporary international data showed that peritumoural oedema is not only an indicator of the

prevalence of peritumoural changes, but also a clinically significant prognostic marker. Its quantitative assessment can be considered as an accessible tool for preoperative risk stratification, and further development of this area should be associated with the integration of volumetry, multiparametric magnetic resonance imaging, radiomics, and molecular markers of the peritumoural zone.

Conclusions

The study established that peritumoural oedema in highly malignant glial brain tumours is an important clinical and pathophysiological component of the tumour process, which has a significant impact on the neurological status and functional treatment outcomes. Quantitative assessment of the volume of peritumoural oedema according to magnetic resonance imaging in T2 and FLAIR modes allows objectively characterising the degree of involvement of peritumoural tissue and assess the severity of compression-ischaemic changes in the surrounding brain structures. Analysis of the data obtained showed that an increase in the preoperative volume of peritumoural oedema is accompanied by more pronounced neurological disorders and a decrease in the functional independence of patients.

There was a significant association between the volume of peritumoural oedema and the functional outcome six months after surgical treatment. The greater the volume of oedema at the preoperative stage, the higher the probability of maintaining a pronounced neurological deficit and limited functional activity in the long-term postoperative period. Thus, peritumoural oedema can be considered as one of the objective neuroimaging indicators of the severity of the condition of patients with glial tumours. Of particular importance is the revealed threshold value of the peritumoural oedema volume. It has been shown that when a level of about 30 cm³ is exceeded, the probability of an unfavourable functional outcome increases significantly. This value can be considered as a practical guideline for clinical risk stratification. The use of this approach allows identifying a group of patients requiring more intensive perioperative follow-up, active decongestant therapy, and more careful dynamic monitoring. An important result of the study was also the investigation of the dynamics of peritumoural oedema in the early postoperative period. After removal of the tumour node, there was a marked decrease in the volume of oedema due to decompression of brain structures. However, on the first day after surgery, in some cases there was a temporary increase in the FLAIR hyperintensity zone, which may

be associated with reactive inflammatory processes, changes in microcirculation, and a temporary increase in the permeability of the blood-brain barrier.

Subsequently, starting from the first week after surgery, there was a steady decrease in the volume of peritumoural oedema, accompanied by a gradual improvement in the neurological and functional condition of patients. The results obtained confirmed the expediency of using volumetric analysis of peritumoural oedema as an accessible and informative method for assessing the severity of patients with glial tumours. Quantitative assessment of the volume of oedema can be used for preoperative risk stratification, planning treatment tactics, optimising decongestant therapy, and determining the timing of control neuroimaging studies. A promising area of further research is a more detailed investigation of the structure of the peritumoural zone using multiparametric magnetic resonance imaging, including diffusion and perfusion methods, and the analysis of molecular and immunological factors involved in the development of peritumoural oedema. Additional research may be aimed at developing comprehensive prognostic models combining neuroimaging, morphological, and clinical parameters for more accurate prediction of the course of glial tumours and individualisation of therapy.

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Conflict of Interest

None.

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