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MODERN SURGICAL TECHNOLOGIES IN THE TREATMENT OF MENINGEAL AND NEUROEPITHELIAL BRAIN TUMORS: A COMPARATIVE CLINICAL STUDY

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Abstract:

Background. Surgical treatment remains the primary modality for meningeal and neuroepithelial brain tumors; however, traditional techniques are often associated with significant intraoperative blood loss, prolonged operative time, and a high risk of neurological deficits. **Objective.** To compare the outcomes of surgical treatment of meningeal and neuroepithelial brain tumors using standard techniques and modern technologies aimed at reducing surgical trauma. **Materials and Methods.** A retrospective analysis of 70 patients operated on for brain tumors was performed. Patients were divided into two groups: a comparison group treated with standard surgical methods and a main group treated using modern technologies, including ultrasonic disintegration, neuronavigation, intraoperative ultrasound, cortical mapping, and plasma-based coagulation. Intraoperative blood loss, duration of surgery, and safety of surgical access were assessed.

Results. The use of modern technologies significantly reduced intraoperative blood loss and operative time compared with standard techniques ($p < 0.05$). Improved hemostasis reliability and safer surgical trajectories contributed to a lower risk of postoperative neurological deterioration. **Conclusion.** The integration of modern microsurgical, ultrasonic, and plasma technologies significantly improves the safety and efficiency of surgical treatment of meningeal and neuroepithelial brain tumors.

Keywords: brain tumors, meningiomas, gliomas, modern neurosurgery, intraoperative hemostasis

СОВРЕМЕННЫЕ ХИРУРГИЧЕСКИЕ ТЕХНОЛОГИИ В ЛЕЧЕНИИ ОБОЛОЧЕЧНЫХ И НЕЙРОЭПИТЕЛИАЛЬНЫХ ОПУХОЛЕЙ ГОЛОВНОГО МОЗГА: СРАВНИТЕЛЬНОЕ КЛИНИЧЕСКОЕ ИССЛЕДОВАНИЕ

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Аннотация:

Введение. Хирургическое лечение оболочечных и нейроэпителиальных опухолей головного мозга остаётся основным методом терапии, однако стандартные методы часто сопровождаются значительной интраоперационной кровопотерей и риском неврологических осложнений.
Цель исследования. Сравнить результаты хирургического лечения оболочечных и нейроэпителиальных опухолей головного мозга при использовании стандартных методов и современных технологий.
Материалы и методы. Проведён ретроспективный анализ 70 пациентов, оперированных по поводу опухолей головного мозга. Сформированы две группы: группа сравнения, оперированная стандартными методами, и основная группа, в которой применялись

современные технологии (ультразвуковая дезинтеграция, интраоперационное УЗИ, кортикальное картирование, аргон-плазменная и холодная плазменная коагуляция). Оценивались объём интраоперационной кровопотери, продолжительность операции и безопасность хирургического доступа.

Результаты. Применение современных технологий позволило достоверно снизить объём кровопотери и длительность оперативного вмешательства ($p < 0,05$), повысить надёжность гемостаза и уменьшить риск неврологического дефицита.

Заключение. Использование современных хирургических технологий значительно повышает эффективность и безопасность оперативного лечения оболочечных и нейроэпителиальных опухолей головного мозга.

Ключевые слова: опухоли головного мозга, менингиомы, глиомы, нейрохирургия, интраоперационный гемостаз

MIYA QOBIQ VA NEYROEPITELIAL O‘SMALARINI DAVOLASHDA ZAMONAVIY JARROHLIK TEXNOLOGIYALARI: QIYOSIY KLINIK TADQIQOT,

Mamadaliyev Abdurahmon Mamatkulovich
Samarqand davlat tibbiyot universiteti huzuridagi Neyroxirurgiya va neyroreabilitatsiya ixtisoslashtirilgan ilmiy-amaliy markazi

Annotatsiya:

Kirish. Miya qobiq va neyroepitelial o‘smalarini jarrohlik yo‘li bilan davolash asosiy usul bo‘lib qolmoqda, biroq an’anaviy texnikalar katta qon yo‘qotish va nevrologik asoratlar xavfi bilan kechadi.

Tadqiqot maqsadi. Miya qobiq va neyroepitelial o‘smalarini standart va zamonaviy jarrohlik texnologiyalari yordamida davolash natijalarini solishtirish.

Materiallar va usullar. Miya o‘smalari bo‘yicha operatsiya qilingan 70 bemorning retrospektiv tahlili o‘tkazildi. Bemorlar standart usullar qo‘llanilgan solishtirma guruh va zamonaviy texnologiyalar (ultratovushli disintegratsiya, intraoperatsion UTT, kortikal xaritalash, argon-plazmali va sovuq plazmali koagulyatsiya) qo‘llanilgan asosiy guruhga bo‘lindi.

Natijalar. Zamonaviy texnologiyalar qo‘llanilganda operatsiya davomiyligi va intraoperatsion qon yo‘qotish hajmi sezilarli darajada kamaydi ($p < 0,05$).

Xulosa. Zamonaviy jarrohlik texnologiyalarini qo‘llash miya qobiq va neyroepitelial o‘smalarini davolashda samaradorlik va xavfsizlikni sezilarli darajada oshiradi.

Kalit so‘zlar: miya o‘smalari, meningiomalar, gliomalar, zamonaviy neyroxirurgiya, gemostaz

INTRODUCTION

An important issue in modern neuro-oncology is the desire to improve the quality of life of patients after surgery. The low effectiveness of radiation and drug therapy for tumor lesions of the brain and its membranes determines the relevance of the problem of surgical treatment of this pathology [1-4]. Surgical interventions for neuroepithelial and meningeal tumors of the brain are quite complex not only in terms of technical execution, possible damage to the brain tissue, the occurrence of bleeding, but also the initial condition of patients, who, as a rule, exhibit pronounced neurological symptoms at the time of surgery [5-7, 12, 13]. Surgical interventions previously performed on such patients were often accompanied by significant intraoperative blood loss, trauma to the brain tissue, which aggravated not only the neurological status, but also the general condition of the patient [8-11]. The aim of the study was to compare the results of surgical treatment of meningeal and neuroepithelial tumors of the brain using standard methods and new technologies, the advantages of which are reduced intraoperative blood loss, increased reliability of hemostasis, reduced duration of surgery, and a reduced risk of developing or worsening neurological deficit. Materials and methods of the study. The analysis was based on 70 patients operated on at the Khanty-Mansiysk Regional Clinical Hospital using standard treatment methods and new technologies. Depending on the used methods of surgical treatment of neuroepithelial and meningeal tumors of the brain, we formed 2 groups of patients. To ensure representativeness of the observation results, the groups were comparable in tumor location, size, and histological structure. Group 1 included 30 (42.9%) patients, who were diagnosed with neuroepithelial tumors (15 (50%)) and meningeal tumors (15 (50%)), which were removed using a standard technique. Group 2 included 40 patients (57.1%), 19 of whom were diagnosed with neuroepithelial and 21 with meningeal tumors, which were removed using modern technologies. Surgical tactics in each specific situation were determined taking into account MRI and CT data. CT was performed using CT-MAX (GE, USA), CT-LX (Phillips, Holland) with 256x256 and 512x512 matrices using step and spiral scanning. MRI was performed using Magnetom 42 SP (Siemens, Germany) at a magnetic field strength of 1.0 T. The standard modes for all patients were T1- and T2-weighted tomograms. In the early postoperative period, CT was performed in all patients to determine the radicality of the surgical intervention, as well as to identify postoperative complications. Results and discussion. Standard methods for removing neuroepithelial and meningeal tumors of the brain included the following steps.Patient positioning and surgical site preparation followed generally accepted principles. The patient's head was firmly fixed with a Mayfield clamp. Standard access was used, depending on the tumor location. Layer-by-layer skin and subcutaneous tissue dissection was performed after preliminary hydropreparation of soft tissues with 0.25% novocaine solution, which helped reduce blood loss at this stage. Hemostasis was achieved by applying plastic skin clips and monopolar coagulation.

MAIN PART

Osteoperforation and craniotomy were performed manually. Hemostasis from the diploic veins was achieved by rubbing wax into the bone cut. The dura mater of the brain was opened in a horseshoe shape, after preliminary electrocoagulation or ligation of the vessels, typically at a distance of 0.5 cm from the bone. Taking into account the tumor topography based on preoperative CT and MRI data, the approach trajectory and transcortical approach to the neuroepithelial tumor were calculated for all patients, based on the topography of functionally significant areas and vascular structures of the brain. However, intraoperative mapping based on ultrasound data was not performed. During neuroepithelial tumor removal, cerebral cortex traction was achieved using brain spatulas. Although the brain wound was demarcated with cotton wool to reduce trauma to the brain tissue, manual traction often resulted in additional trauma to the brain tissue, leading to the development or worsening of neurological deficits.

Meningeal and neuroepithelial tumors were removed by cutting, under magnification, using standard instruments (spatulas, spoons, loops, an electric suction device, and a coagulator). Hemostasis was achieved using hydrogen peroxide-soaked turundas, bipolar and monopolar coagulation, as well as TachoComb, Surgical, and Spongostan plates and a hemostatic sponge as the final stage of hemostasis. Upon completion of the surgery, the dura mater was closed, using interrupted or continuous sutures whenever possible. The bone flap was repositioned and secured with an aponeurosis suture or wire suture. To improve hemostasis reliability, reduce brain tissue trauma, and reduce the risk of developing or worsening neurological deficits, new technologies and modern devices utilizing ultrasound and plasma flow have been introduced into practice. Removal of meningeal tumors of the brain using modern technologies.

The following key conditions were met during surgical treatment of brain tumors: rigid fixation of the patient's head, improved visualization using an operating microscope, the use of brain retractors to reduce brain traction, the use of microsurgical instruments and a surgical disintegrator during tumor removal, and the achievement of stable and reliable hemostasis using a plasma flow. Bone perforation and craniotomy were performed using an Aesculap turbine with a mechanical (up to 25,000 rpm) or pneumatic (up to 60,000 rpm) drive.

The size of the craniotomy window depended on the location and size of the tumor, as well as the surgical approach used. The high RPM of the Aesculap Elan-Ec device allowed for this stage of the surgery to be performed virtually bloodlessly. To ensure additional hemostasis, the bone slice was treated with argon plasma coagulation in the Spray mode at 60 W.An argon flow rate of 2 l/min was used instead of wax rubbing. The dura mater of the brain was opened depending on the tumor location, ensuring a good view of the surgical field. The meningioma was removed with maximum radicality, within the limits of "physiological permissibility and anatomical accessibility." The Cusa-EXcel device was used. Using an ultrasonic cavitation disintegrator, removal of the meningeal tumor began from its outer edge toward the tumor matrix. The tumor matrix was treated last. During the tumor removal stages, permanent clips were applied to large vessels, and small vessels were coagulated using bipolar coagulation. In the presence of basal and parasagittal meningiomas, when traction of a cerebral lobe or hemisphere was necessary, the Aesculap retractor system was used, which allowed for gentle traction, creating a good view of the surgical wound. During the surgery, traction was periodically relaxed (every 15–20 min) to prevent ischemia in the traction-exposed areas of the brain.

The Simpson scale was used to formalize the degree of radicality in meningioma surgery. All patients were operated on according to the first and second types of the Simpson scale. After macroscopically complete removal of the meningioma (type 2 according to Simpson), coagulation at the site of the original tumor growth was performed using an argon plasma coagulator in the Spray mode, 60 W power, and 1–1.5 l/min argon flow rate. After removal of the meningioma, the original site of growth of which was the wall of the superior sagittal sinus, to avoid perforation of this wall, the tumor matrix was treated only in the Spray mode, 30 W power, and 0.3–0.5 l/min argon flow rate. In cases of bone damage, resection was performed with simultaneous replacement of the defect with a Konmet titanium mesh implant. During treatment of the diffusely bleeding zone of the initial meningioma growth with an argon plasma coagulator, the formation of a dense protective scab on the meningeal surface resulted in decreased intraoperative blood loss and improved hemostasis reliability. This contributed to a reduction in the volume of intraoperative blood loss, an increase in the radicality of the intervention, and a decrease in the incidence of postoperative complications. The volume of intraoperative blood loss in patients operated on for meningeal tumors of the brain using standard methods and new technologies is presented in Table 1.The tumor matrix was treated last.

During tumor removal, permanent clips were applied to large vessels, while small vessels were coagulated using bipolar coagulation. In the presence of basal and parasagittal meningiomas, when traction of a cerebral lobe or hemisphere was necessary, the Aesculap retractor system was used, allowing for gentle traction while maintaining a clear view of the surgical wound. During surgery, traction was periodically relaxed (every 15–20 minutes) to prevent ischemia in the affected cerebral areas. The D. Simpson scale was used to formalize the degree of radicality in meningioma surgery. All patients underwent surgery according to the first and second types of the D. Simpson scale. Following macroscopically complete removal of the meningioma (D. Simpson type 2), coagulation at the site of the original tumor growth was performed using an argon plasma coagulator in the Spray mode, 60 W power, and 1–1.5 L/min argon flow rate. Following removal of the meningioma, the original growth site of which was the wall of the superior sagittal sinus, to avoid perforation of this wall, the tumor matrix was treated only in the Spray mode, 30 W power, and 0.3–0.5 L/min argon flow rate. In case of bone lesion, its resection was performed with simultaneous replacement of the defect with a Konmet titanium mesh implant.

During treatment of the diffusely bleeding zone of the initial meningioma growth with an argon plasma coagulator, a decrease in intraoperative blood loss and improved hemostasis were observed due to the formation of a dense protective scab on the meningeal surface. This contributed to a reduction in intraoperative blood loss, an increase in the radicality of the intervention, and a reduction in the incidence of postoperative complications. The volume of intraoperative blood loss in patients operated on for meningeal tumors of the brain using standard methods and new technologies is presented in Table 1.The tumor matrix was treated last. During tumor removal, permanent clips were applied to large vessels, while small vessels were coagulated using bipolar coagulation. In the presence of basal and parasagittal meningiomas, when traction of a cerebral lobe or hemisphere was necessary, the Aesculap retractor system was used, allowing for gentle traction while maintaining a clear view of the surgical wound. During surgery, traction was periodically relaxed (every 15–20 minutes) to prevent ischemia in the affected cerebral areas. The D. Simpson scale was used to formalize the degree of radicality in meningioma surgery. All patients underwent surgery according to the first and second types of the D. Simpson scale.

Following macroscopically complete removal of the meningioma (D. Simpson type 2), coagulation at the site of the original tumor growth was performed using an argon plasma coagulator in the Spray mode, 60 W power, and 1–1.5 L/min argon flow rate. Following removal of the meningioma, the original growth site of which was the wall of the superior sagittal sinus, to avoid perforation of this wall, the tumor matrix was treated only in the Spray mode, 30 W power, and 0.3–0.5 L/min argon flow rate. In case of bone lesion, its resection was performed with simultaneous replacement of the defect with a Konmet titanium mesh implant. During treatment of the diffusely bleeding zone of the initial meningioma growth with an argon plasma coagulator, a decrease in intraoperative blood loss and improved hemostasis were observed due to the formation of a dense protective scab on the meningeal surface. This contributed to a reduction in intraoperative blood loss, an increase in the radicality of the intervention, and a reduction in the incidence of postoperative complications. The volume of intraoperative blood loss in patients operated on for meningeal tumors of the brain using standard methods and new technologies is presented in Table 1.5 l/min.

After removal of the meningioma, the initial growth site of which was the wall of the superior sagittal sinus, to avoid perforation of this wall, the tumor matrix was treated only in the "Sprai" mode, a power of 30 W, and an argon flow rate of 0.3-0.5 l/min. In case of bone damage, its resection was performed with a single-stage defect replacement with a "Konmet" titanium mesh implant. During treatment of the diffusely bleeding zone of the initial growth of the meningioma with an argon plasma coagulator, due to the formation of a dense protective scab on the surface of the shell, a decrease in intraoperative blood loss and an increase in the reliability of hemostasis were noted, which contributed to a decrease in the volume of intraoperative blood loss, an increase in the radicality of the intervention, and a decrease in the incidence of postoperative complications. The volume of intraoperative blood loss in patients operated on for meningeal tumors of the brain, using the standard method and new technologies, is presented in Table 1.5 l/min. After removal of the meningioma, the initial growth site of which was the wall of the superior sagittal sinus, to avoid perforation of this wall, the tumor matrix was treated only in the "Sprai" mode, a power of 30 W, and an argon flow rate of 0.3-0.5 l/min. In case of bone damage, its resection was performed with a single-stage defect replacement with a "Konmet" titanium mesh implant.

During treatment of the diffusely bleeding zone of the initial growth of the meningioma with an argon plasma coagulator, due to the formation of a dense protective scab on the surface of the shell, a decrease in intraoperative blood loss and an increase in the reliability of hemostasis were noted, which contributed to a decrease in the volume of intraoperative blood loss, an increase in the radicality of the intervention, and a decrease in the incidence of postoperative complications. The volume of intraoperative blood loss in patients operated on for meningeal tumors of the brain, using the standard method and new technologies, is presented in Table 1.

Table 1. Volume of intraoperative blood loss during removal of meningeal tumors of the brain

Volume of blood loss, ml	Main group (n = 21)		Comparison group (n = 15)	
	Abs.	% (M ± m)	Abs.	% (M ± m)
50–100	1	4.8 ± 4.6	-	-
110–200	9	42.8 ± 10.8	1	6.7 ± 6.4
210–300	4	19.0 ± 8.6	1	6.7 ± 6.4
310–400	2	9.5 ± 6.4	2	13.3 ± 8.8
410–500	1	4.8 ± 4.6	4	26.7 ± 11.4
510–600	1	4.8 ± 4.6	2	13.3 ± 8.8
610–800	1	4.8 ± 4.6	3	20.0 ± 10.3
810–1000	1	4.8 ± 4.6	1	6.7 ± 6.4
More than 1000	1	4.8 ± 4.6	1	6.7 ± 6.4
Total	**21**	**100**	**15**	**100**

Note:the differences between the main group and the comparison group are statistically significant ($p < 0.05$).

In the main group, the largest number of patients (42.8%) experienced intraoperative blood loss ranging from 110 to 200 ml, while in the comparison group, the largest number of patients (26.7%) experienced blood loss of 410–500 ml. Blood loss of up to 100 ml was observed in 4.8% of patients in the main group, while in the comparison group, all patients experienced blood loss exceeding 100 ml. The use of new technologies during the removal of meningeal tumors of the brain contributed to a significant reduction in the duration of the surgical intervention. The duration of surgical intervention for the removal of meningeal tumors of the brain is presented in Table 2.

Table 2. Duration of surgical intervention for removal of meningeal tumors of the brain

Extent of surgical intervention	Main group (n = 21)			Comparison group (n = 15)		
	Abs.	% (M ± m)	Duration of operation, min	Abs.	% (M ± m)	Duration of operation, min
Type 1	9	42.8 ± 10.8	110	5	33.3 ± 12.2	180
Type 2	10	47.6 ± 10.9	90	6	40.0 ± 12.6	160
Type 3	2	9.5 ± 6.4	70	3	20.0 ± 10.3	110
Type 4	-	-	-	1	6.7 ± 6.4	80
Type 5	-	-	-	-	-	-
Total	**21**	**100**	-	**15**	**100**	-

The existing differences in the main and comparison groups are statistically significant ($p<0.05$).

Significant advantages of new technologies in reducing the duration of surgery for meningeal tumors were noted compared to that in the comparison group. When removing neuroepithelial tumors using modern technologies, we applied two methods of anesthesia. In 20 patients (58.8%) with neuroepithelial formations of the brain of various localizations, total intravenous anesthesia with tracheal intubation and respiratory support using the Drager Primus apparatus was used; 14 patients (41.2%) underwent surgery under local infiltration anesthesia (in full consciousness). For anesthesia, 0.5% novocaine solution or 0.5% marcaine solution was used. In both groups, MRI and ultrasound intraoperative marking were performed using the B-K Medical-2102 Hawk apparatus. Thus, the minimum distance from the cerebral cortex to the neoplasm was determined. Depending on the lesion's relationship to functionally significant areas of the brain, the safest access trajectory was selected. This trajectory did not always coincide with the minimum distance from the cortex to the lesion, as determined by CT and MRI data. Table 3 presents data on the length of the surgical access trajectory for the removal of neuroepithelial tumors of the brain.

Table 3. Access trajectories from the surface of the cerebral cortex to the neoplasm

Access path length, mm	Number of observations (abs.)	%
No more than 20	3	15.8
21–60	12	63.1
More than 60	4	21.0
Total	**19**	**100**

In the greatest number of patients (63.1%), surgical intervention was performed with an access trajectory length from 21 to 60 mm. Additionally, to select the access trajectory, cerebral cortex mapping was performed in patients operated on under local infiltration anesthesia, and neurological status was monitored intraoperatively. After opening the dura mater of the brain and determining the tumor topography using ultrasound scanning, cerebral cortex areas were stimulated and the neurological status was monitored to find the safest site for encephalotomy. Given the individual variability of cortical topography and the localization of functional zones, intraoperative mapping of cerebral cortex excitation was performed using the OCS-1 (Ojemann Cortical Stimulator) device to find a favorable zone for corticotomy. Craniotomy was performed under local anesthesia with the patient conscious, and the cerebral cortex was stimulated in the projection of the tumor. The cortex stimulation range was from 2 to 7 mA. After mapping the surgical field, corticotomy and tumor removal were performed. The patient's neurological status was monitored throughout the surgery. This method helps prevent the onset or worsening of neurological deficit. After minimal traction of the brain, a small tumor fragment was exposed with a flexible brain retractor.

The tumor tissue was penetrated through this fragment, and its central portion was removed with an ultrasonic disintegrator. Microdissection of large tumor vessels allowed for their clipping and rapid fragmentation of the tumor node. Subsequently, sequential coagulation of small and medium-sized feeding vessels was performed. Gradual reduction in tumor volume allowed for atraumatically separating the remaining fragments from the adjacent brain tissue. In 50% of cases of macroscopically complete removal of the glial tumor, hemostasis was achieved using an APC-300 argon plasma coagulator (ERBE) in the "Sprai" mode, 60 W power, and 0.8–1.6 l/min argon flow rate. In 50% of cases, a SOERING-CPC 3000 cold plasma coagulation device (with a power variation from 10 to 25 W) at power level 3 or 4 was used to achieve hemostasis. Preference was given to the argon plasma coagulation device, since it produces a more reliable coagulation clot, which remains intact upon contact with instruments.

Additionally, fragmented TachoComb plates were applied to the tumor bed walls to ensure hemostasis. The operation was completed by tightly suturing the dura mater of the brain. A mandatory stage of the operation was the installation of a Shpigelberg subdural intracranial pressure sensor with its continuous monitoring for 1-2 days and correction if necessary. Patients operated on under respiratory support were transferred to spontaneous breathing in the first hours after surgery.This indicated the absence of significant cerebral edema (confirmed by intracranial pressure measurements) directly related to surgical trauma. Table 4 presents comparative data on the magnitude of intraoperative blood loss during removal of glial brain tumors in patients in both groups.

Table 4. Volume of intraoperative blood loss in patients with neuroepithelial tumors of the brain

Volume of blood loss, ml	Main group (n = 19)		Comparison group (n = 15)	
	Abs.	% (M ± m)	Abs.	% (M ± m)
50–100	4	21.0 ± 9.3	-	-
110–200	6	31.6 ± 10.7	1	6.7 ± 6.4

210–300	4	21.0 ± 9.3	1	6.7 ± 6.4
310–400	2	10.5 ± 7.0	4	26.7 ± 11.4
410–500	1	5.3 ± 5.1	6	40.0 ± 12.6
510–600	1	5.3 ± 5.1	2	13.3 ± 8.8
More than 600	1	5.3 ± 5.1	1	6.7 ± 6.4
Total	**19**	**100**	**15**	**100**

Note:the differences between the main group and the comparison group are statistically significant ($p < 0.05$).

In the main group, the largest number of patients (31.6%) experienced intraoperative blood loss ranging from 110 to 200 ml, while in the comparison group, the largest number of patients (40%) experienced 410–500 ml. Blood loss of up to 100 ml was observed in 21% of patients in the main group, while in the comparison group, all patients experienced blood loss exceeding 100 ml. The duration of surgical intervention for removal of neuroepithelial tumors of the brain in the groups is presented in Table 5. According to the indicators presented in the table, the main and comparison groups are homogeneous ($P> 0.05$). The average duration of intervention for total glioma resection in the main group is 2 times shorter, and for subtotal resection, 3 times shorter than in the comparison group.

CONCLUSION

The comparative analysis demonstrates that incorporation of modern intraoperative technologies in surgery for meningeal and neuroepithelial brain tumors is associated with clinically meaningful advantages over standard techniques. The technology-assisted strategy (microsurgical visualization, optimized craniotomy instruments, controlled brain retraction, ultrasonic aspiration, intraoperative ultrasound/navigation support, and plasma-based hemostasis) contributes to a significant reduction of intraoperative blood loss, shorter operative time, and improved hemostatic reliability. For neuroepithelial tumors, the use of intraoperative mapping (particularly during awake procedures when indicated) and real-time imaging facilitates safer trajectory selection and minimizes traction-related cortical injury, thereby reducing the risk of new or worsened neurological deficit. Overall, the presented approach supports the concept that outcome optimization in neuro-oncologic surgery requires a structured multimodal intraoperative platform aimed at maximal safe resection with minimized surgical morbidity and improved postoperative quality of life.

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