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Role of modified enhanced recovery after surgery (mERAS) in awake craniotomy performed under monitored anesthesia care (MAC); a single center retrospective study

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Abstract

Background This study aims to explore the safety and efficacy of awake craniotomy procedures under monitored anesthesia care (MAC), focusing on the impact of modified Enhanced Recovery after Surgery (ERAS) protocols on patient outcomes.

Methods Patients undergoing elective awake craniotomy between 2017 and 2022 were divided into two groups: those receiving the ERAS protocol after 2020 and a control group of pre-2020 patients. Factors examined included demographics, intraoperative awakening time, procedure durations, pain management, hospital stay length, complications, discharge disposition, and follow-up symptoms.

Results From 2017 to 2022, 61 patients underwent awake craniotomy using MAC anesthesia at University Hospitals Cleveland Medical Center, with 23 receiving the ERAS protocol after 2020. Demographics were comparable between the control and ERAS groups. Total awake time, time to wake up, and total procedure time showed no significant differences ($P > 0.05$). Awake craniotomy was discontinued in 8 cases due to anxiety and pain (mERAS = 1, Control = 7). The mERAS group experienced fewer cases of awake failure, nausea/vomiting, and postoperative cognitive and speech deficits, though these differences were not statistically significant. No significant differences were found in postoperative pain medication consumption, complications, or length of hospital stay ($P > 0.05$).

Conclusions Awake craniotomy under MAC with a modified ERAS protocol is feasible but did not show statistically significant improvements in patient outcomes. Further research with larger sample sizes and multi-center collaboration is necessary to draw more definitive conclusions.

Keywords Awake craniotomy, Enhanced recovery after surgery, Monitored Anesthesia Care, Brain, Failure

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Background

Supra-marginal resection of gliomas has repeatedly shown to be associated with improved overall survival [1, 2]. For lesions that are located in vital areas of the brain such as speech and motor cortices, awake craniotomy has been used to increase the safety margins and effectiveness of tumor resection [3–6]. Furthermore, awake craniotomy reduces hospitalization duration, lowers complication rates, results in fewer neurological deficits, and decreases surgical duration in comparison to procedures conducted under general anesthesia [7].

Enhanced Recovery After Surgery (ERAS) protocols have received significant attention due to their potential to improve patient outcomes, reduce hospital length of stay, decrease complications, and expedite recovery after major surgeries [8]. This has led to a paradigm shift in medicine over the last few years. ERAS begins in the preoperative clinic and is employed at every stage of the preoperative, intraoperative, postoperative and rehabilitation periods. It is a multi-disciplinary and multimodal endeavor that requires planning and active physician and patient participation. ERAS research in lumbar spine fusion surgeries led to creation of 28 recommendations for perioperative care with a comprehensive consensus review presented by the ERAS® Society in 2021 [9]. ERAS has been associated with reduced length of hospital stay, readmission rate, and improved functional recovery in many specialties such as cardiac surgery [10], vascular surgery [11], orthopedic surgery [12], and neurosurgery [13–18]. However, the role of ERAS in awake craniotomy procedures performed under MAC anesthesia has yet to be fully elucidated.

This manuscript aims to present findings on the safety and effectiveness of awake craniotomy conducted under MAC anesthesia. We are showcasing the clinical outcomes of this anesthetic approach within our institution, focusing on parameters such as intraoperative awakening time, mapping duration, hospital length of stay, and short/long-term patient outcomes. Additionally, we conducted an internal analysis, comparing patients who underwent awake craniotomy with a modified ERAS protocol (mERAS) to those without ERAS protocol, serving as the control group. This study serves as a preliminary investigation for our future objective of establishing ERAS guidelines for perioperative management in elective awake craniotomy procedures performed under MAC anesthesia.

Methods

Patient selection and demographics

Patients were identified from a database of those who underwent awake craniotomy for brain mapping of the eloquent brain areas at University Hospitals Cleveland Medical Center in Cleveland, Ohio. All patients were treated between January 2017 and May 2022 and received monitored anesthesia care. The Institutional Review Board (IRB) of University Hospitals approved this retrospective analysis on 07/19/2022(STUDY20220624).

Inclusion criteria were as follows: (1) Planned surgical intervention of awake craniotomy for brain mapping; (2) Patients receiving MAC anesthesia; (3) Patients older than 18 years of age; (4) Radiographically identified intracranial pathology. A total of 72 patients met our inclusion criteria and were eligible for inclusion in this study. However, 11 patients were excluded due to missing documentation, resulting in a final count of 61 cases.

The patients were internally categorized into two groups: those who were administered the ERAS protocol after 2020 and the control group comprising patients who underwent awake craniotomy before that time. Various preoperative, intraoperative, and postoperative variables were examined, encompassing demographics (age, sex), clinical parameters (ASA scores, diagnosis, tumor grade based on pathology if applicable), intraoperative awakening time, total mapping and procedure durations, postoperative pain management regimen, length of hospital stay, associated complications, discharge disposition, and symptoms observed during follow-up visits.

Modified ERAS protocol

Prior to 2020, our institution lacked an organized, written ERAS protocol for patients undergoing awake craniotomy procedures, resulting in inconsistent perioperative care. For example, some patients received only local infiltration at the pinning site, while others underwent a full scalp block. Preoperative preparation also varied—some patients attended a preadmission anesthesia clinic, while others did not. Additionally, fluid management, pain control strategies, and postoperative care were inconsistent and depended on the preferences of individual anesthesiologists and the neurosurgery service.

In January 2020, we formed a modified Neurosurgical ERAS Working Group comprising professionals from neurosurgery, anesthesiology, inpatient and operative nursing, and physiotherapy services. We refer to it as modified ERAS because the preoperative carbs intake was not incorporated into the protocol during that period. Drawing upon insights from established protocols for craniotomy surgery, the protocol was specifically tailored for patients undergoing awake craniotomy. Its development involved a comprehensive review of current evidence-based perioperative care interventions documented in the literature. The key difference now is that we have standardized preoperative, intraoperative, and postoperative management as part of the ERAS protocol. Additionally, we have a dedicated team—comprising an anesthesiologist and a neurosurgeon—responsible for overseeing the intraoperative protocol to ensure

consistency and compliance. They continuously evaluate the process and make necessary adjustments, enhancing the overall quality and effectiveness of patient care. The OR staff were trained to communicate effectively and support patients, helping to ease their anxiety and improve their overall experience. The key management changes introduced with the implementation of the ERAS protocol are highlighted in Table 1. Our ERAS protocol is divided into three primary phases (Table 1):

1. Preop: All patients underwent a preadmission anesthesia clinic visit to discuss the procedure. During this visit, anesthesia providers thoroughly explained the anesthesia plan, helping patients understand what to expect and reducing anxiety related to uncertainty. On the day of surgery, the neurosurgery team conducted preoperative functional, cognitive, and language assessments. Additionally, all operating room (OR) staff introduced themselves to the patient, fostering a collaborative environment that promotes trust and reassurance. Oral acetaminophen was administered preoperatively unless contraindicated due to allergy or a history of liver dysfunction.
2. Intraop: We refined our anesthetic techniques to improve patient comfort and outcomes. This included ensuring optimal patient positioning, performing full scalp blocks for better pain control, and administering continuous low-dose dexmedetomidine infusions during the awake portions of the surgery to reduce anxiety and enhance patient cooperation. These measures significantly improve patient comfort during awakening and brain mapping. Additionally, a dedicated neuromonitoring technician assesses baseline tasks such as counting, reciting the alphabet, identifying objects, and responding to orientation questions. These tasks are reassessed intraoperatively by same staff to monitor the patient's neurological status. Furthermore, we implemented measures to achieve normothermia using various warming devices, employed goal-directed fluid therapy to prevent hyper- or hypovolemia, and applied non-opioid analgesic therapy.
3. Postop: multimodal pain regimen, anti-emetic administration, delirium precautions, nutritional assessment and consult to insure adequate caloric intake, blood glucose management, early mobilization, and early multidisciplinary meeting for expedited safe discharge planning. As part of the multimodal regimen, acetaminophen 650 mg was administered every six hours, cyclobenzaprine was prescribed 5 mg three times per day for muscle pain, and gabapentin was either initiated at 300 mg dose or continued at a higher dosage of up to 800 mg three times a day for patients already on this medication. Additionally, a lidocaine patch was applied, oral oxycodone was prescribed for mild to moderate pain (4–6), and intravenous hydromorphone or morphine was used for breakthrough severe pain (7–10).

Anesthesia and surgical technique

Informed consent was obtained, and patients are familiarized with all members of the team in preop. The sedation-awake-sedation technique was employed using a combination of intravenous dexmedetomidine, remifentanil, and propofol for sedation. Prophylactic antibiotics, steroids, mannitol, and anti-epileptic medications were administered to optimize patient safety. The patient's head was secured in a three-point fixation after a full scalp block and registered to the neuronavigation system. For the scalp block, pinning site, and wound infiltration, we used a local anesthetic mixture consisting of 10 mL of 1% lidocaine with 1:100,000 epinephrine, 10 mL of 0.5% bupivacaine, and 2 mL of sodium bicarbonate.

At this juncture, patients were roused by discontinuation of the propofol and remifentanil infusion. A low dosage (0.2–0.4 mcg/kg/h) of dexmedetomidine drip was maintained unless patients failed to awaken within 10 min following cessation of the propofol and remifentanil drip. Upon awakening, patients were instructed to engage in tasks such as counting numbers, reciting the alphabet, identifying objects, responding to orientation questions (e.g., day of the week, month of the year), and moving their extremities upon demand while specific areas around the lesion were stimulated. Areas of speech arrest and movement impairment were determined, marked, and avoided. Areas without functional impairment were determined as safe for resection or grid placement (for epileptic lesions). Planned surgical intervention continued with the patient remaining awake to monitor for functional impairment. After maximal resection, sedation was achieved via propofol and remifentanyl drip. Closure was performed in standard fashion. Further local anesthetics were injected in the temporalis area. Head was removed from pins. Subsequently, the patient was awakened and transported to the recovery room.

Post-operative management included monitoring patient vitals and hemodynamic intervention if required. Pain scores were also assessed with opioids analgesics given for pain management. Patients were also monitored for postoperative seizures. After patients were determined stable by the staff and anesthesiology attending, they were transported out of the recovery unit to ICU or step-down unit for continued inpatient monitoring. The extent of resections was evaluated using post-operative MRI performed on postoperative day one or two. Patients were mobilized with physical and occupational therapists

Table 1 Modified ERAS (mERAS) protocol for patients undergoing elective awake craniotomy using MAC. Modified ERAS protocol created at university hospitals Cleveland medical center for awake craniotomy procedures

Phase of care	Item(s)	mERAS protocol
Preoperative	Patient and family counseling and education	• Routine consultation for awake craniotomy in surgeon's office, preoperative anesthesia clinic and preoperative unit • Patients were explained the risk and benefit of the awake craniotomy. The full procedure and recovery process were described to the patient and family • The operative staff including surgical staff, anesthesia team, nursing and neurology/neuro monitoring team introduce themselves to the patient to establish connection and trust
	Preoperative evaluation	• Patient's functional capacity, mental status and language capability were assessed prior to the surgery
	Preemptive analgesia	• Acetaminophen 975 mg p.o. administered at preoperative care unit except for those with allergy or liver dysfunction
	Infection prevention and control	• Pre-operative MRSA screening • Surgical prophylactic antibiotic administration within 1 h prior to skin incision (weight based cefazolin IV if MRSA negative and vancomycin IV if MRSA positive, alternative for those with allergies)
Intraoperative	Local anesthetic	• Scalp block before pinning and subcutaneous local mixture of lidocaine/ bupivacaine/ sodium bicarbonate administered at the incision
	Normothermia	• Forced air warmer, fluid warmer and circuit warmer
	Fluid management	• Goal-directed fluid therapy
	Non-opioid analgesia	• Intraoperative scalp block and local incision anesthesia, dexmedetomidine drip intraoperatively
Postoperative	Postoperative analgesia	• Multimodal analgesic regimen: acetaminophen, cyclobenzaprine, gabapentin, lidocaine patch, oxycodone, breakthrough hydromorphone, etc.
	Postoperative nausea and vomiting (PONV)	• PONV prophylaxis and treatment with dexamethasone, ondansetron, promethazine, metoclopramide, etc.
	Delirium precautions	• Address sensory impairments, encourage mobility, regulate sleep-wake cycle with optimizing room environment, avoid noise and light at nights, etc. • Avoiding anticholinergics, antipsychotics, and benzodiazepines
	Early mobilization and ambulation	• Regular assessment and nursing care, physical and occupational therapy postop day zero
	Glycemic control	• Insulin sliding scales • Proton pump inhibitors
Discharge	Mobility	• Independent mobility or mobility with minimal assistance
	Destination	• Arrange Safe discharge home or to rehabilitation center
Follow-up	Home & clinic follow-up	• Timely follow-up with outpatient clinic visit • Two weeks and three month follow up in surgeon's clinic

Table 2 Patient demographics

	Level	Overall *n* = 61	mERAS *n* = 23	Control *n* = 38	*p*-value
Age	Mean ± SD	53.21 ± 14.93	52.83 ± 16.82	53.45 ± 13.89	0.527
	Median (25th, 75th)	56 (46, 62)	58 (36, 65.5)	54.5 (47, 60)	
Gender, n (%)	Female	18 (29.51%)	7 (30.43%)	11 (28.95%)	0.902
	Male	43 (70.49%)	16 (69.57%)	27 (71.05%)	
ASA	Mean ± SD	2.53 ± 0.50	2.43 ± 0.51	2.59 ± 0.50	0.235
	Median (25th, 75th)	3 (2, 4)	2 (2, 3)	3 (2, 3)	0.236
History of seizure		14 (22.95%)	9 (39.13%)	5 (13.16%)	0.019
Tumor Grade, n (%)	1	1 (1.92%)	1 (6.25%)	0	0.609
	2	21 (40.38%)	6 (37.5%)	15 (41.76%)	
	3	3 (5.77%)	1 (6.25%)	2 (5.56%)	
	4	27 (51.92%)	8 (50%)	19 (52.78%)	

Table 3 Intraoperative data

	Level	Overall *n* = 61	mERAS *n* = 23	Control *n* = 38	*p*-value
Desaturation, n (%)		5 (8.20%)	3 (13.04%)	2 (5.26%)	0.356
Total awake time (min)	Mean ± SD	105.57 ± 38.24	100.65 ± 36.44	108.55 ± 39.47	0.434
	Median (25th, 75th)	100 (85, 125)	100 (92.5, 115)	102.5 (85, 135)	
Time to wake up (min)	Mean ± SD	16.95 ± 13.69	18.87 ± 18.56	15.79 ± 9.76	0.843
	Median (25th, 75th)	15 (10, 20)	10 (10, 20)	15 (10, 20)	
Total procedure time (min)	Mean ± SD	392.54 ± 67.99	387.17 ± 66.65%	395.79 ± 69.46	0.503
	Median (25th, 75th)	385 (350, 420)	375 (350, 427.5)	395 (353.75, 408.75)	
Seizure, n (%)		4 (6.56%)	2 (8.70%)	2 (5.26%)	0.628
Awake failure, n (%)		8 (13.11%)	1 (4.35%)	7 (18.42%)	0.239

as well as nursing staff as early as postoperative day zero and discharged as deemed appropriate by house staff. Each patient was reevaluated at 2 weeks post-op visit for wound check, functional status, presence or absence of preoperative symptoms, new symptoms, language, and cognitive functions as well as 3 months post-operation for further symptomatic monitoring, complications, and deficits.

Statistical analysis

We used R version 3.4.2 for the data analysis. For the continuous variables, the assumptions of normal distribution and homogeneity of variance were examined through the Shapiro-Wilk's test and the Levene'stest, respectively. When these assumptions were evidently violated, we used the Wilcoxon test, otherwise, the student t-test for the analysis of the continuous variables. For the analysis of the categorical variables, we used the Fisher's exact test when the assumption of large sample approximation was violated, otherwise, the Peason's chi-square test was employed. $P < 0.05$ is considered statistically different.

Results

Patient demographics (Table 2)

Total of 61 patients have been identified that underwent awake craniotomy using MAC anesthesia at University Hospitals Cleveland Medical Center between January 2017 to May 2022. Twenty-three of these patients underwent awake craniotomy after 2020 for which they received mERAS protocol. There is no difference between control and ERAS group in term of demographics ($P > 0.05$). 52 of the patients had primary glioma of various grades of which grade 4 was the most common. The remaining 9 had other pathologies such as metastatic disease, inflammatory processes, and seizure foci. 14 patients had either presented with seizure episodes due to their intracranial pathology or had a history of seizure (mERAS = 9, Control = 5, $P < 0.05$).

Intraoperative findings (Table 3)

Total awake time (mapping and resection) was on average over 105 min. Time to wake up was roughly 16 min and the total procedure time was around 6.5 h. These

Table 4 Post anesthesia care unit

	Level	Overall *n* = 61	mERAS *n* = 23	Control *n* = 38	*p*-value
Opiate consumption*	Mean ± SD	5.16 ± 6.59	6.13 ± 7.01	4.58 ± 6.34	0.469
	Median (25th, 75th)	1.6 (0, 8.80)	4 (0, 11.2)	1.60 (0, 7.8)	
N/V, n (%)		9 (16.36%)	3 (16.67%)	6 (16.22%)	1.000

*measured in morphine milligram equivalent; N/V: nausea/vomiting

Table 5 Postoperative data

	Level	Overall *n* = 61	mERAS *n* = 23	Control *n* = 38	*p*-value
Pain medication consumption*					
Day 1	Mean ± SD	11.18 ± 15.98	8.62 ± 14.87	12.73 ± 16.62	0.112
	Median (25th, 75th percentile)	7.5 (0, 15)	0 (0, 15)	7.75 (0, 15)	
Day 2	Mean ± SD	12.93 ± 18.89	14.63 ± 22.89	11.90 ± 16,026	0.783
	Median (25th, 75th percentile)	0 (0, 22.5)	0 (0, 26.25)	0.8 (0, 21.63)	
Day 3	Mean ± SD	5.13 ± 12.21	6.59 ± 15.54	4.25 ± 9.79	1.000
	Median (25th, 75th percentile)	0 (0, 0)	0 (0, 0)	0 (0, 0)	
N/V n (%)	Yes	13 (22.81%)	4 (20%)	9 (24.32%)	1.000
Length of stay, days	Mean ± SD	6.53 ± 4.92	7.04 ± 5.58	6.13 ± 4.48	0.827
	Median (25th, 75th percentile)	5.5 (3, 8)	6 (3, 8.5)	5 (3, 8)	
Disposition, n (%)	Home	42 (73.68%)	15 (75%)	27 (72.97%)	0.868
	Rehab	15 (26.32%)	2 (25%)	10 (27.03%)	
POCD After 2 weeks, n (%)		7 (13.21%)	2 (10.53%)	5 (14.71%)	1.000
POCD After 3 months, n (%)		3 (10%)	1 (10%)	2 (10%)	1.000

*measured in morphine milligram equivalent; N/V: Nausea/Vomiting; POCD: postoperative cognitive dysfunction

variables were comparable between the ERAS and control groups.

Five patients experienced transient desaturation that required intervention—three in the mERAS group and two in the control group. In all cases, desaturation was successfully managed by pausing sedation and performing a jaw thrust, with or without the use of a nasal trumpet. None of the patients required a supraglottic airway or intubation, and all remained included in the study. Four patients experienced intraop seizures (mERAS = 2 and control = 2, $P > 0.05$) and Awake craniotomy was discontinued in 8 cases because the patients were unable to complete the task due to anxiety and pain (mERAS = 1 and Control = 7, $P > 0.05$).

PACU findings (Table 4)

Average opiate consumption in PACU was 5.16 morphine equivalent. 9 patients experienced nausea/vomiting (mERAS = 3 (16.67%), Control = 6 (16.22%), $P > 0.05$). None of the patients had immediate postop seizure in the PACU.

Postoperative finding (Table 5)

No significant differences were observed between the control and mERAS groups regarding postoperative pain consumption, complications, length of hospital stay, and postoperative cognitive and speech deficits ($P > 0.05$). At the two-week and three-month follow-up visits, most patients demonstrated preserved or improved speech. Additionally, there were no discernible differences in cognitive dysfunction between the ERAS and control groups ($P > 0.05$).

Discussion

Our study findings indicate that awake craniotomy conducted under monitored anesthesia care (MAC) is a safe and efficient approach for achieving maximal supramarginal resection of malignant brain tumors or other pathologies situated in eloquent brain regions. Clinically, the mERAS group experienced fewer cases of awake failure, nausea/vomiting, and postoperative cognitive and speech deficits compared to the control group. However, these differences were not statistically significant.

Awake craniotomy stands out as one of the safest methods for achieving maximal resection of malignant

brain tumors, offering a distinctive experience for both patients and surgical teams. However, this procedure can entail significant stress for all involved parties. Thus, a structured, step-by-step protocol overseen by a multidisciplinary working group is essential to alleviate anxiety, ensure a successful experience, and optimize outcomes. Research indicates that the implementation of the ERAS protocol can lead to improved surgical outcomes and a better quality of life for patients undergoing craniotomy for brain tumors [18]. Notably, most of previous studies often did not encompass awake craniotomy. To our knowledge, this study represents the first assessment of the impact of ERAS on the outcomes of awake craniotomy.

The feasibility of awake craniotomy has been documented with a reported failure rate of 6.4% in leading neurosurgical centers with seasoned surgeons [19]. Aabedi et al. [20] quantified the degree of wakefulness based on 5 brief measures as the proxy for a patient's intro-operative language task performance in the setting of anesthetics, which can result in transient language and cognitive deficit. They found that decline in rapid counting and vigilance correlated with the language task performance in the operative setting [21]. In our study, it was found that anxiety and pain were the main factors contributing to awake failures. Furthermore, the ERAS group displayed a reduced rate of awake failure compared to the control group, potentially due to factors such as preoperative education, a standardized pain management protocol, and effective teamwork.

The anesthetic management of patients undergoing awake craniotomy has been extensively reviewed over the past decade, with various approaches proposed. These approaches primarily differ in the choice of drugs and their delivery methods, as well as in airway management strategies. Both propofol alone [22, 23] or in combination with opioids [24], and dexmedetomidine alone [25] have been successfully utilized in awake craniotomy procedures. Regarding airway management, techniques such as Asleep-Awake-Asleep with a laryngeal mask airway (LMA), and sedation-awake-sedation without an airway device, have been described. However, there is currently no consensus favoring one medication or airway management approach over another. Harvey-Jumper et al. [26] outlined the evolution in awake craniotomy methodology over the last thirty years, suggesting its safe execution with a minimal complication profile regardless of factors such as the patient's American Society of Anesthesiology (ASA) class, body type, smoking habits, psychiatric or seizure history, tumor characteristics, location, and pathology. Studies indicate that appropriate anesthesia techniques and comprehensive perioperative patient consultation contribute to a seamless intraoperative experience and ensure successful postoperative recovery. In our institution, the preference has been for sedation-awake-sedation techniques for awake craniotomy procedures. Initially, a combination of propofol and remifentanil was employed to closely monitor and control the patient's level of analgesia and sedation at the start of the procedure. However, it was observed that many patients experienced anxiety upon awakening. To address this issue, dexmedetomidine was added to the propofol and remifentanil regimen. A low dose of dexmedetomidine drip, without an initial bolus, was administered to mitigate the risk of oversedation, hypotension, and bradycardia. This combined regimen led to minimal respiratory depression during sedation, with patients exhibiting increased calmness upon awakening.

We showed a high success rate in achieving timely intra-operative awake time, mapping, and resection via MAC anesthesia achieved via dexmedetomidine, propofol and remifentanil. Almost 87% of the patients successfully emerged from anesthesia within an average time of 17 min. This was even more robust in the mERAS group (over 95%). Four patients had intraoperative seizure which was aborted using ice cold saline and intravenous anti-epileptic medications. Overall, all patients who woke up from anesthesia had successful surgical resection without any other major complications.

Length of hospital stay for our patients was around 6.5 days, which is similar to the national average of 3 to 8 days [27]. 13% of the patients demonstrated some levels of cognitive decline at 2-week visit and 10% at the 3-month mark. This is similar to the post-operative cognitive decline reported by Kapoor et al. of 26% during the first week and 10% at 3-month post-surgery [28]. We demonstrated that awake craniotomy can be performed with high success rate and low complication profile using MAC as anesthesia and following a modified ERAS protocol.

The limited impact of the mERAS protocol on awake craniotomy outcomes can largely be attributed to the small size of our study. Our power analysis indicated that we need at least 678 patients to achieve statistically significant results. However, awake craniotomies are infrequent due to their complexities and the specialized skills required to perform them. For instance, in Japan, a significant portion of institutions (66%) perform fewer than 10 awake craniotomies annually, highlighting the rarity of these procedures [29]. This scarcity is mirrored in Europe, where centers report varying frequencies, with a median of 15 patients operated on per year. These numbers illustrate the challenges in accumulating a large enough sample size for statistically significant studies. Our institution has conducted 72 awake craniotomies over a span of four years and five months, placing us in the medium range for such procedures. While this level of activity is relatively robust compared to some other centers, it still presents a

significant barrier to reaching the necessary sample size. At our current rate, it would take approximately 42 years to accumulate the 678 patients required for a statistically significant analysis. This extended timeline underscores the difficulty of conducting large-scale studies in this specialized field and highlights the need for multi-center collaborations to advance research and improve outcomes in awake craniotomy procedures. Additionally, barriers to implementing ERAS practices could have influenced our results. The adoption of ERAS protocols poses challenges for healthcare systems, especially for major surgeries [30]. Studies highlight obstacles such as staffing shortages, funding limitations, coordination issues, and a lack of awareness about ERAS benefits. In our hospital, staffing challenges particularly nurse shortages during the pandemic likely hindered the full implementation of the mERAS protocol, especially in postoperative care. These barriers emphasize the need for systemic support and resources to effectively implement and benefit from ERAS protocols in complex surgical procedures.

This study provides valuable insights for the integration of new ERAS protocols. Future protocols should focus on creating and assessing strategies such as education, training for new nurses, fostering collaboration, providing institutional support to alleviate staff shortages, and introducing an ERAS coordinator. These methods aim to overcome barriers to ERAS adoption, facilitating its widespread implementation and enhancing patient outcomes.

The study is subject to several limitations. Firstly, the study has a small sample size and is conducted at a single center, limiting its generalizability. Secondly, as a retrospective study, inherent biases may be present compared to randomized controlled trials. Larger, multicenter randomized controlled trials are warranted to assess the efficacy of ERAS in neurosurgical patients undergoing awake craniotomy. Nevertheless, this study may serve as a pilot investigation for future randomized controlled trials.

Conclusion

In conclusion, the mERAS group exhibited lower rates of awake failure, postoperative pain, and nausea/vomiting compared to the control group. However, the mERAS protocol did not show a statistically significant difference in the overall outcomes of awake craniotomy procedures. Larger-scale studies with increased sample sizes and multi-center collaboration are needed to draw more definitive conclusions.

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Author contributions
XD: Conceived and designed the study, contributed to data analysis, and revised the manuscript. AA: Collected data and drafted the manuscript. MS, KM, MA, KS: Collected data. MAM: Conducted data analysis. VS: Draft the manuscript. TH: Designed the study.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This retrospective chart review analysis was approved by The Institutional Review Board (IRB) of University Hospitals Cleveland Medical Center on 07/19/2022 (STUDY20220624). No experiments on humans were conducted, and no human tissue samples were used. The entire chart review process was conducted in accordance with the guidelines and regulations of the University Hospitals Cleveland Medical Center IRB (STUDY20220624).

Consent for publication
Not applicable.

Competing interests
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Consent for participate
As this study is a retrospective chart review, the requirement for consent to participate was waived by the University Hospitals Cleveland Medical Center Institutional Review Board (IRB) (STUDY20220624).

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