REVIEW

Criteria for Intensive Care admission and monitoring after elective craniotomy

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Purpose of review
The current article revises the recent evidence on ICU admission criteria and postoperative neuromonitoring for patients undergoing elective craniotomy.

Recent findings
Only a small proportion of elective postoperative neurosurgical patients require specific medical interventions and invasive monitoring. Among these, patients undergoing elective craniotomy are frequently admitted to neuro-ICU, specialist postanaesthesia care units or intermediate-level care unit in the postoperative period.
Craniotomy patients have a high risk of neurological complications in the immediate postoperative period and might require advanced neuromonitoring, especially if sedation is continued in the ICU.
Furthermore, the concept of enhanced recovery after surgery with the goal of improving functional capacity after surgery and decreasing morbidity has expanded to encompass neurosurgery.
Postoperative clinical examination and neurological scores, bispectral index and simplified electroencephalography, and morning discharge huddles are the most used strategies in this context.

Summary
After elective craniotomy, ICU admission should be warranted to patients who show new neurological deficits, especially when these include reduced consciousness or deficits of the lower cranial nerves, or have surgical indication for delayed extubation. Currently, evidence does not allow defining standardized protocol to guide ICU admission and postoperative neuromonitoring.

Keywords
craniotomy, ICU admission, monitoring

INTRODUCTION

The rate of avoidable complications after neurosurgical procedures remains high [1]. A recent American database analysis including 38 058 neurosurgical patients reported an overall complication rate of 14.3%, with pulmonary complications occurring in 5%, cardiovascular complications in 4% and neurological complications in 3% of them [2]. Early detection and treatment of these complications often require specialist care and targeted neuromonitoring in the early postoperative phase. Among these, patients undergoing elective craniotomy are routinely admitted to the ICU, in which these treatments and monitoring can be promptly provided. Nevertheless, only a small proportion of postoperative elective craniotomy patients require medical interventions in the ICU.

Although common practice to stratify high risk patients relies on comorbidity score systems, a retrospective study, including 400 elective patients undergoing elective craniotomy identified only diabetes and older age as independent predictors for postoperative ICU admission [3].

There is large variability in the admission policy for postoperative patients in neurosurgical ICU among countries, centres and even within the same hospital, depending on local cultural tradition but predominantly on resources. In some centres, patients are admitted for a planned 24-h observation

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KEY POINTS

- Only a small proportion of elective postoperative neurosurgical patients require specific medical interventions and invasive monitoring.
- Craniotomy patients have a high risk of neurological complications in the immediate postoperative period and might require advanced neuromonitoring, especially if sedation is continued in the ICU.
- Postoperative clinical examination and neurological scores, bispectral index and simplified electroencephalography and morning discharge huddles are the most used strategies in this context.
- After elective craniotomy, ICU admission should be warranted to patients who show new neurological deficits, especially when these include reduced consciousness or deficits of the lower cranial nerves, or have surgical indication for delayed extubation. Currently, evidence does not allow defining standardized protocol to guide ICU admission and postoperative neuromonitoring.

period following all intracranial procedures [4]. In other centres, patients are only admitted to the ICU if intracranial complications (i.e. early seizures, bleeding, brain oedema) develop during or immediately after surgery [5].

Moreover, as most serious complications after elective craniotomy occur within the first hours after surgery, it is arguable whether postoperative destination of such patients should be revised to maintain optimal ICU occupancy rates [6–8] or whether ICU's stay should be limited to the immediate postsurgical phase allowing a rapid turn-over of admissions. Among the alternative postoperative destinations of patients undergoing elective craniotomy high-density care units or postanaesthesia care units (PACU) provide intermediate level of care. These solutions may represent a more cost-effective allocation of ICU resources and allow the development of enhanced recovery pathways after neurosurgery [9▪,10].

The aim of this article is to revise recent literature exploring the criteria for planned ICU admission, perioperative complications and emergency ICU admission, existing levels of care and neurological monitoring for patients undergoing elective craniotomy.

PLANNED ICU/POSTANAESTHESIA CARE UNITS ADMISSION CRITERIA

The existing large variability on postoperative admission strategies after elective craniotomy is well known at different geographical levels. A national Spanish survey aiming to describe the care pathway and postoperative treatment standards for neurosurgical interventions demonstrated that the postoperative destination of the patients is often decided by the anaesthetists (73%) with high ICU admission rates (83%) [11▪]. In many clinical contexts, this frequently happens after multidisciplinary discussion with the neurosurgical team.

The joint team decision should weigh preoperative conditions (patient comorbidities, functional level and issues related to the type and site of lesion), risk for perioperative complications and postoperative requirements (neuromonitoring, sedation, two-stage surgical intervention).

Careful consideration of the patients' comorbidities in the preoperative assessment is paramount and stratification for severity is widely used in anaesthetic practice by means of the American Society of Anaesthesiologist score (ASA) [12]. The preoperative assessment should take into account chronic and stable comorbidities as well as progressive organs and systems' impairment, intracranial disease-related conditions (such as electrolytes imbalances, seizures, vasospasm, delayed cerebral ischaemia, etc.) and pharmaco-induced alterations (steroids-induced hyperglycaemia, clotting abnormalities, arrhythmias, etc.) [12].

It is advised to plan ICU/PACU admission for patients with ASA at least three following elective craniotomy despite low level of evidence. Moreover, the presence of diabetes, advanced age (>65 years) and elective craniotomy for vascular lesions are associated with higher probability of ICU/PACU admission [3].

The type and site of intracranial lesion *per se* represent indicators of perioperative requirements and often diverse disorders (tumours, vascular, functional and congenital) have established different clinical pathways to follow. Intracranial vascular lesions are often associated with secondary intracranial disease (subarachnoid/intracerebral haemorrhage, vasospasm, cerebrospinal fluid obstruction and stroke), systemic comorbidities (hypertension, smoking history, carotid stenosis, ischaemic heart disease, previous stroke and obesity), higher risk for perioperative complications (haemorrhage, haemodynamic instability, electrolytes disturbances and seizures) [13] and finally, more likely to require tight target blood pressure (BP) control in the postoperative phase [3]. On the other hand, awake elective craniotomy for tumour resections and elective craniotomy for grid reading in epilepsy may represent 'low' risk of ICU/PACU admission and sometimes early home discharge is also considered [14].

There is no consensus on criteria for ICU admission and on the optimal timing of a postsurgical computed tomography (CT) scan in adult patients undergoing surgery for supratentorial gliomas. Of 264 patients included in a retrospective study, only 21 had planned postoperative admission to the ICU [mean length of stay (LOS) 19.7 h] based on their clinical characteristics (Karnofsky performance status <70, ASA > 2 or Charlson comorbidity index >5) and a single case of haemorrhagic complication [15▪]. A total of 24 patients had a CT scan within 24 h after the procedure (local oedema in five cases and one haematoma surgically evacuated) and two cases required unplanned ICU admission.

These data reinforce the statement that ICU admission should not be routinely planned for patients undergoing elective craniotomy for supratentorial lesions unless preassessment conditions and type of lesion will benefit the enhanced recovery after surgery to facilitate uncomplicated hospital stay and prompt discharge home.

PERIOPERATIVE COMPLICATIONS AND UNPLANNED ICU/POSTANAESTHESIA CARE UNITS ADMISSION

Complications after elective craniotomy may be neurosurgical or systemic and their anticipation is possible awareness of the surgery details and the anaesthesia technique are essential. In a prospective series of 188 patients admitted to the ICU after elective craniotomy for brain tumours resection, 89% did not require postoperative sedation. Of these patients, 30% developed at least one complication: 25% postoperative nausea and vomiting (PONV) and 16% neurological complications [16▪▪]. The latter was highly associated with intraoperative bleeding. Furthermore, of seven patients (4%) who required readmission to ICU after discharge, 43% had posterior fossa elective craniotomy.

PONV is a well recognized condition after brain surgery. Moreover, the high rate of new neurological deficit justifies the unplanned ICU admission following 'moderate to high-risk' elective craniotomy. Seemingly, intraoperative bleeding must be cautiously assessed as it might evolve into intracranial expanding haematomas. Finally, patients undergoing posterior fossa elective craniotomy may require longer ICU admissions.

Indeed, due to the high risk of damage to cranial nerves and brainstem compression, patients undergoing infratentorial craniotomy have high rates of failed extubation after surgery. In a prospective series of 2118 consecutive infratentorial elective craniotomy, 94 (4.4%) failed extubation at some point during their hospital stay [17▪]. The authors identified five independent risk factors for postoperative failed extubation: previous craniotomy, preoperative caudal cranial nerve deficit, tumour size, tumour position and maximum change in BP during the operation. On the other hand, failed extubation was associated with a higher rate of pneumonia, mortality, unfavourable Glasgow Coma Scale (GCS), longer stay in ICU and hospitalization.

Although there is missing validation yet for neurosurgery, the Surgical Apgar Score (SAS) has been used as a prediction score for postoperative complications in vascular surgery. A small recent study retrospectively explored whether the application of SAS assessed by intraoperative BP, heart rate and blood loss in 99 patients undergoing elective craniotomy for meningioma resection was an accurate predictor of major postoperative complications [18▪▪]. In the multivariate logistic regression model, SAS was an independent predicting factor of major complications following surgery for intracranial meningiomas [odds ratio (OR) 0.57, 95% confidence interval (CI) 0.38–0.87; $P = 0.009$], and a decrease of one mean SAS increased the rate of major complications by 43%. As this scoring system is relatively simple, objective and practical, they suggest that SAS be included as an indicator in the guidance for the level of care after craniotomy for meningioma resection.

LEVELS OF POSTOPERATIVE SPECIALIST CARE

The emerging development of PACU in Europe is changing the care pathways of patients undergoing elective craniotomy. Although admission to specialist neurosurgical units is associated with improved patients' outcomes after a variety of acute neurological conditions [19], the efficacy of intermediate-level of care units for some of these diseases has not been studied (except for acute stroke units) [20].

A prospective observational study recruited 200 consecutive adult patients to test the efficacy and safety of a non-ICU level of postoperative care for a selected group of patients undergoing elective craniotomy [9▪]. The proposed protocol allowed to transfer patients to the neurosurgical ward after a 4-h period of recovery in a specialist PACU following elective craniotomy for supratentorial tumours. Criteria for early transfer included haemodynamic stability and the absence of any new postoperative neurological deficit. A small proportion of patients (2.5%) required ICU transfer during the first 48 h after surgery (three for agitation, one for seizures and one for neurological deterioration). None of the patients immediately discharged to the neurosurgical ward experienced a major complication or prolonged hospital stay following this protocol implementation suggesting an intensive yet short-time in specialist postoperative units might be the best destination for a select proportion of patients undergoing elective craniotomy.

The increasing endeavours to make inpatient treatment processes more effective lead to a reduction of the LOS in hospital and to a minimization of postoperative monitoring. Therefore, a National service evaluation in Germany was used to determine potential postoperative complications for neurosurgical patients undergoing elective surgery with respect to the requirement for ICU admission [21]. A total of 499 patients were scheduled for elective craniotomy over 155 neurosurgical departments. Major complication (i.e. haemorrhage, infarct, oedema, empyema and death) occurred in 19 patients (12%), as reported in previous studies in the literature [22]. Incidence of minor complications was 38%. The results of the survey showed a broad preference for ICU monitoring of patients undergoing elective craniotomy in Germany. Authors conclude that the gold standard of postoperative monitoring of neurosurgical patients undergoing elective surgery is still the ICU as a rapid and specific intervention was required in more than 20% of patients. Although more flexible surveillance modalities are available, a cost-driven restructuring of postoperative monitoring and in particular a reduction of the stay in hospital must be subjected to detailed evaluation.

Whether the local strategy is ICU or PACU admission, level and specialist training of staff is essential in the management of the postoperative neurosurgical patient. A recent observational study aimed to evaluate the impact of a specialist in neurocritical care medicine (i.e. a physician with neurocritical care experience as well as training in neurology, anaesthesiology or general intensive care medicine) who could help for clinical management of patients with a variety of neurological and neurosurgical conditions, on safety and outcome in a neuroscience intermediate-level care unit during weekday daytime hours [23▪]. This before–after study of PACU implementation with specialist medical staff was performed over 3 years (1 year before implementation, 2 years after). Of the 2931 patients eligible, 586 were studied (postoperative surveillance for brain tumours). Following the implementation, there was a significant reduction in discharge time from PACU to the ward, as well as the reduction in the mean LOS. No significant safety concerns were identified. This study demonstrated that the optimization of a neuroscience intermediate-level care unit involving comanagement of patients by a neurocritical specialist can improve safety of patients' flow. These findings are of particular interest as pressure on economic resources use requires a careful rationalization of services.

POSTOPERATIVE MONITORING

Neurosurgical patients are at risk of neurological complications in the immediate postoperative period [24] and require specialized neurological monitoring (Table 1). A prospective observational study examined the impact of the Ramsay scale, Canadian Neurological Scale (CNS), Nursing Delirium Screening Scale (Nu-DESC) and bispectral index (BIS) in comparison with the assessment of pupils and GCS to detect early postoperative neurological complications in PACU [25▪]. Among 70 patients, 16 patients (23%) developed neurological complications. The scales-BIS were more sensitive (94 vs. 50%) and allowed a more precise estimation of neurological complications in PACU than clinical examination ($P=0.002$; OR = 7.15, 95% CI = 2.1–24.7 vs. $P=0.002$; OR = 9.5, 95% CI = 2.3–39.4).

Table 1. Postoperative monitoring after intracranial procedures

Clinical surveillance	Level of consciousness (Glasgow Coma Scale), pupillary reactivity, focal deficits, cranial nerve lesions
Systemic monitoring	ECG, HR, respiration, pulse oximetry, $EtCO_2$, BP (invasive, noninvasive), temperature
Brain-specific monitoring	ICP, CPP, TCD ultrasonography, laser Doppler flowmetry, thermal diffusion probe, transcranial cerebral oximetry, microdialysis, jugular venous oximetry, direct brain oxygen, NIRS, BIS, EEG, SSEP, BAER
Accesses	Large bore peripheral venous access is necessary; in selected cases the use of CVC might be indicated, arterial catheter, urinary catheter, gastric tube
Laboratory examinations	Blood gases, haematology, electrolytes, glucose and on indication coagulation status
Imaging examinations	Chest radiograph (ventilated patients and after lung procedures) computed tomography or MRI follow-up (as required)

BAER, brainstem auditory-evoked response; BIS, bispectral index; BP, blood pressure; CPP, cerebral perfusion pressure; CVC, central venous catheter; EEG, electroencephalography; $EtCO_2$, end-tidal CO_2 concentration; HR, heart rate; ICP, intracranial pressure; NIRS, near-infrared spectroscopy; SSEP, somatosensory-evoked potential; TCD, transcranial Doppler.

Table 2. Proposed criteria for admission to ICU after elective craniotomy

A preoperative	B intraoperative	C postoperative
ASA physical status: • >ASA 2 • >ASA 1 if any of B or C Karnofsky Index: - <70	Type of lesion: • Supratentorial: vascular tumours and malformations (AVM, aneurysms) • Infratentorial: any • Others if any of A or C Site of lesion: • Supratentorial: hypothalamic or thalamic • Infratentorial • Others if any of A or C	Major complications: • Radiological: rebleed, infarct/ischaemia, oedema, infection • Neurological: new focal deficit, deteriorating GCS, seizures, prolonged unconsciousness • Systemic: haemodynamic instability, worsening gas exchanges, electrolytes disturbances or any new or worsening organ or system dysfunction Minor complications: • All if any of A or B
Preoperative neurology: • GCS 14/15 • Fluctuating preoperative • Rapid progression of focal deficit • GCS 15 and no deficit but any of B or C	Surgery-related: • Intraoperative bleeding • Diabetes insipidus • Prolonged temporary clipping or permanent clipping of arteries • Intraoperative seizures (awake craniotomy) • Length of surgery >6 h • None but any of A or C	Monitoring: • Tight blood pressure control • Tight glucose control • Seizures chart or continuous EEG monitoring • Close neurological observations • Invasive or noninvasive ventilation and gas exchange monitoring • None but any of A or B

ASA, Anaesthesiologists score; AVM, arteriovenous malformation; GCS, Glasgow Coma Scale.

These results suggested that combined assessment of pupils, GCS, Ramsay scale, CNS, Nu-DESC and BIS improved early detection of postoperative neurological complications in PACU after elective craniotomies.

Postoperative clinical neuromonitoring varied according to the type of surgery, although strength and sensitivity were explored in between 70 and 80%. The authors' conclusion highlighted a great variability in the attitude for neurological monitoring in these patients, due to the absence of guidelines, to the different resources in terms of staff and equipment and the type of surgery [11▪].

Morning discharge huddles consist of a multidisciplinary decision from the members of the medical team and are used to improve communication and patient care and to facilitate patient flow through the hospital. A study investigated how a neurosurgeon leading interdisciplinary daily morning huddle affected various costs of patient care and patient satisfaction [26]. Huddles were conducted at 8:30 a.m. Monday through Friday, and lasted approximately 30 min; results were compared in the period before and after implementation of such strategy. There was a significant decrease in the number of ICU days, mean laboratory and pharmacy costs per patient after the huddle was implemented. This study showed that interdisciplinary huddles can result in potentially substantial reductions in costs per patient as well as improved patient satisfaction.

Moreover, clinical observation was sufficient to predict early postoperative complications. A CT scan before 24 h after surgery is not recommended in the absence of clinical worsening [15▪].

CONCLUSION

The criteria for postoperative admission to ICU, high-dependency unit or a specialized neurosurgical ward vary from institution to institution depending on local structures and characteristics of the available resources [27,28]. We propose a summary of criteria for ICU admission (Table 2). However, due to the lack of high-quality evidence on this topic [29,30], these criteria represent experts' suggestions and patient's care in this context has to be assessed on a case-to-case basis. Needless to highlight, we need better evidence to standardize the treatment and the degree of monitoring needed during the postoperative period after elective craniotomy. It is highly recommended to implement clinical vigilance in the immediate postoperative period in these patients regardless of their discharge destination (ICU, PACU or ward). A brain CT scan should be obtained rapidly in the case of neurological deterioration to exclude intracranial complications. Communication among neurosurgeons, neuroanaesthestists and neurointensivists remains a critical step to optimize perioperative management of neurosurgical patients.

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Conflicts of interest

There are no conflicts of interest.

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Papers of particular interest, published within the annual period of review, have been highlighted as:

■ of special interest

■■ of outstanding interest

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A prospective observational study tested the efficacy and safety of a non-ICU level of postoperative care for a selected group of patients undergoing elective craniotomy. It concluded that care of patients undergoing uneventful elective supratentorial craniotomy for tumour on a neurosurgical floor after 4 h of post-anaesthesia care units (PACU) monitoring appears to be a safe practice in this patient population.

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In this retrospective nonrandomized study demonstrated that that ICU should not always be used after craniotomy for supratentorial gliomas. Clinical observation was sufficient to predict early postoperative complications. A computed tomography scan before 24 h after surgery is not recommended in the absence of clinical worsening.

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