Review Article

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Anaesthetic Management of Cerebellopontine Angle Tumours: A Narrative Review of Neuroanatomy, Perioperative Strategies and Contemporary Advances

Anaesthesia Section

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ABSTRACT

Cerebellopontine Angle (CPA) tumours represent complicated lesions in the posterior fossa, which have significant anaesthetic complications as they are closely adjacent to cranial nerves, brainstem nuclei, and Cerebrospinal Fluid (CSF) pathways. Vestibular schwannomas are the most common, followed by meningiomas and epidermoid cysts. Progressive tumour growth usually leads to cranial nerve dysfunction, compression of the brainstem, and hydrocephalus; thus, careful perioperative planning is crucial for achieving the best results. This narrative review is a comprehensive assessment of CPA neuroanatomy that is relevant to anaesthesia and its implications for perioperative management. It outlines preoperative neurological and airway assessment, including a focus on lower cranial nerve involvement and risk of aspiration. Intraoperative strategies are critically discussed, with Total Intravenous Anaesthesia (TIVA) being the method of choice to maintain the integrity of intraoperative neuromonitoring such as Brainstem Auditory Evoked Potentials (BAEP) and cranial nerve Electromyography (EMG). Other factors such as patient positioning, haemodynamic stability, brain relaxation techniques and the prevention of neuromuscular blockage are additional considerations to facilitate reliable monitoring conditions. The approaches to postoperative care emphasise airway protection, delayed extubation, neurological monitoring, and the prevention of complications such as aspiration, cranial nerve deficits, and increased intracranial pressure. The novelty of this review lies in its integrated anaesthesia-centric synthesis of CPA tumour management, combining detailed neuroanatomical correlations with contemporary perioperative strategies. It also highlights the potential of emergent innovations like multimodal neuromonitoring, Enhanced Recovery After Surgery (ERAS) protocol and evolving potential of Artificial Intelligence (AI) in intraoperative decision support and postoperative critical care. In conclusion, a structured, anatomy-guided, patient-specific anaesthetic approach incorporating advanced monitoring and emerging technologies is essential to improve safety and neurological outcomes in CPA tumour surgery.

Keywords: Anaesthesia, Brain stem, Cranial nerves, Intraoperative monitoring, Postoperative complications

INTRODUCTION

The CPA tumours represent a distinct group of extra-axial neoplasms that arise in an anatomically complex region which is bordered by the cerebellum, pons, as well as the petrous temporal bone, where multiple cranial nerves and critical vascular structures co-exist [1]. These tumours account for a significant subset of posterior fossa lesions, along with vestibular schwannomas (which were formerly known as acoustic neuromas), comprising approximately 70-80% of cases, which is followed by meningiomas, epidermoid cysts, as well as other less commonly known pathologies [1,2]. Vestibular schwannomas originate from Schwann cells of the vestibular division of the eighth cranial nerve. These are slow-growing, benign neoplasms which usually extend from the internal auditory canal into the CPA cistern thereby resulting in unilateral sensorineural hearing loss, tinnitus, balance disturbance, facial numbness or other cranial nerve dysfunction as they enlarge as well as compress adjacent structures [2,3].

The historical evolution of understanding as well as management of CPA tumours is intertwined with the development of neurosurgery [4]. Early anatomical descriptions regarding nerve sheath tumours date back to the 18th century, which laid the groundwork for later clinical recognition, but it was not until the late 19th -early 20th centuries that surgeons began performing surgical treatment [4]. Early surgical milestones include the first attempted resection of a vestibular schwannoma by von Bergmann in 1890, followed by the first successful excision of a CPA tumour via posterior fossa craniectomy by Sir Charles Ballance in 1894 [4,5]. Subsequent contributions by Sir Victor Horsley and Fraenkel in the early 20th century further refined suboccipital approaches, laying the foundation for modern skull base surgery [4,5]. Advances in microsurgical techniques and intraoperative neuromonitoring in the latter half of the 20th century improved surgical safety as well as functional outcomes, while developments in neuroimaging, mainly in Magnetic Resonance Imaging (MRI) helped to enhance early detection and preoperative characterisation of CPA lesions [1,5]. The present narrative review aims to comprehensively evaluate anaesthesia-relevant neuroanatomy, preoperative risk assessment, intraoperative anaesthetic strategies including neuromonitoring, and postoperative critical care considerations in cerebellopontine angle tumour surgery while highlighting emerging innovations influencing future neuroanaesthetic practice.

Anaesthesia-Relevant Surgical Anatomy of the Cerebellopontine Angle (CPA)

The CPA represents an important subarachnoid space which is located in the posterior cranial fossa bounded by the cerebellum, pons, and petrous temporal bone, which contains an intricate array of neurovascular structures critical for anaesthesia considerations [6]. In this region, cranial nerves VII (facial) and VIII (vestibulocochlear) traverse acousticofacial bundle in upper CPA that lies between pontomedullary sulcus as well as the internal auditory meatus [7]. High-resolution MRI, particularly T2-weighted and constructive interference in steady state (CISS/FIESTA) sequences, enables precise delineation of these cranial

nerve complexes, facilitating preoperative mapping and risk stratification for nerve preservation [7,8].

Inferiorly-medially, glossopharyngeal (IX), vagus (X), and accessory (XI) nerves course near vertebral as well as posteroinferior cerebellar arteries, reflecting their posterior fossa trajectories just lateral to the medulla, also close to vital autonomic nuclei [7]. Although CN XII (hypoglossal) exits via the hypoglossal canal more caudally, its nucleus-fibres lie adjacent to the ventrolateral medulla, which are vulnerable to mass effect from large CPA lesions [7]. Advanced imaging techniques such as Diffusion Tensor Imaging (DTI) with fibre tractography further enhance visualisation of cranial nerve displacement and brainstem tract involvement, allowing better anticipation of intraoperative neural risk and aiding anaesthetic planning for neuromonitoring [9]. Familiarity with all these nerve positions is very essential for anticipating, monitoring deficits such as facial palsy, swallowing or airway compromise, as well as changes in gag or cough reflexes during surgery [6,7].

Anaesthesia-relevant CPA anatomy is also inclusive of brainstem respiratory-cardiovascular centers, which is embedded within the pons and medulla that underlie the CPA [10]. The medullary reticular formation, adjacent autonomic control areas, regulates breathing, heart rate and vascular tone [10]. Surgical retraction and manipulation in the CPA region can further provoke profound haemodynamic as well as respiratory perturbations requiring vigilant anaesthetic titration and prompt intervention [10]. Preoperative MRI plays a crucial role in identifying brainstem compression, oedema, or distortion of these autonomic centers, which may correlate with perioperative autonomic instability and guide intraoperative haemodynamic management strategies [11,12].

Venous drainage in the CPA is dominated by the petrosal venous complex, usually the superior petrosal veins and sinus, which collect blood from the cerebellar surface and brainstem before draining into the transverse sinus [13]. These veins are consistently used as anatomical landmarks during retrosigmoid and petrosal approaches, but they are also at high risk during dissection, as their injury may precipitate venous infarction, haemorrhage, or increased intracranial pressure [13,14]. Magnetic Resonance Venography (MRV) provides valuable preoperative delineation of the petrosal venous system, helping to identify dominant venous channels and reduce the risk of intraoperative venous injury [12,15].

Lastly, CPA cistern forms a part of the broader CSF pathways in the posterior fossa, continuous with the prepontine cistern as well as the fourth ventricle outlets [16]. Obstruction of CSF flow from expansion of CPA lesions and surgical oedema can rapidly result in obstructive hydrocephalus, which requires close anaesthetic monitoring of intracranial pressure and cerebral perfusion throughout the perioperative period [16]. MRI, particularly phase-contrast CSF flow studies, is instrumental in assessing CSF dynamics and identifying early hydrocephalus, thereby guiding preoperative interventions such as CSF diversion and optimising perioperative neuroanaesthetic management [15,17]. Anaesthesia-relevant surgical anatomy of the CPA is mentioned in [Table/Fig-1] [6,7,10,13,14,16].

Anatomical structure	Location in CPA	Anaesthetic relevance / implications	Key references
Cranial nerve VII (Facial)	Upper CPA; acousticofacial bundle between pontomedullary sulcus and internal auditory meatus	Facial nerve palsy risk; need for facial nerve EMG monitoring; avoidance of long-acting neuromuscular blockers	[6,7]
Cranial nerve VIII (Vestibulocochlear)	Upper CPA; accompanies CN VII	Hearing preservation; BAEP monitoring; sensitivity to anaesthetic agents and hypotension	[6,7]
Cranial nerves IX-XI (Glossopharyngeal, Vagus, Accessory)	Inferomedial CPA near medulla; close to vertebral artery and PICA	Dysphagia, impaired gag/ cough reflex, aspiration risk; postoperative ventilatory and airway concerns	[7,10]
Cranial nerve XII (Hypoglossal-nucleus/fibres)	Ventrolateral medulla; affected by mass effect from large CPA lesions	Tongue weakness, airway obstruction, swallowing difficulty; influences extubation strategy	[7,10]
Brainstem respiratory centers	Pons and medulla underlying CPA	Surgical manipulation may cause apnoea or respiratory irregularities; requires vigilant ventilatory control	[10]
Brainstem cardiovascular centers	Medullary reticular formation and autonomic nuclei	Risk of bradycardia, hypotension, hypertension, arrhythmias during brainstem manipulation	[10]
Petrosal venous complex (superior petrosal vein/sinus)	Drains cerebellum and brainstem into transverse sinus	Injury may cause venous infarction, haemorrhage, raised ICP; affects brain relaxation and haemodynamics	[13,14]
CPA cistern and CSF pathways	Continuous with prepontine cistern and fourth ventricular outlets	Obstruction → obstructive hydrocephalus; necessitates ICP monitoring and CPP optimisation	[16]

[Table/Fig-1]: Anaesthesia-relevant surgical anatomy of the Cerebellopontine Angle (CPA) [6,7,10,13,14,16]
CPA: Cerebellopontine Angle; CN: Cranial Nerve; EMG: Electromyography; BAEP: Brainstem Auditory Evoked Potentials; PICA: Posterior Inferior Cerebellar Artery; CSF: Cerebrospinal Fluid; ICP: Intracranial Pressure; CPP: Cerebral Perfusion Pressure

Spectrum of Cerebellopontine Angle (CPA) Tumours

The CPA harbours a diverse spectrum of lesions, the majority of which are benign, slow-growing and extra-axial in origin [1]. Vestibular schwannomas constitute the predominant pathology, which accounts for approximately 70-80% of all CPA tumours arising from Schwann cells of the vestibular portion of the eighth cranial nerve [1,18]. These are further followed by meningiomas (10-15%), which originate from arachnoid cap cells along the petrous ridge or tentorium, epidermoid cysts (5-7%), congenital lesions which are characterised by insinuating growth along cisternal spaces rather than mass effect alone [19,20]. Less frequently encountered CPA lesions are inclusive of arachnoid cysts, facial nerve schwannomas, lipomas, metastatic tumours [1,21].

Beyond common benign entities, a smaller but also clinically significant CPA tumours comprises malignant or aggressive lesions, which are inclusive of metastatic deposits, primary cerebellar or brainstem tumours with CPA extension, lymphoma, and rare sarcomas [22]. Metastases usually originate from the lung, breast, melanoma, gastrointestinal primaries, as well as often present along with rapid symptom progression and radiological features distinct from benign CPA tumours [23]. Additionally, Neurofibromatosis type 2 (NF2) represents a very unique pathological spectrum that is characterised by bilateral vestibular schwannomas, associated meningiomas or ependymomas, posing distinct diagnostic as well as perioperative challenges [20,24]. The biology of the tumour, growth

pattern, and relationship to adjacent neurovascular structures are more critical determinants related to clinical impact than size alone [20,24]. In a case reported by Fitryono EP et al., a 49-year-old female with prior nasopharyngeal carcinoma presented with a CPA tumour causing brainstem compression and hydrocephalus, and was successfully managed with prolonged craniotomy under general anaesthesia, with histopathology confirming metastatic squamous cell carcinoma [25]. A retrospective series of 14 CPA tumour patients by Ahmed BSF et al., reported vestibular schwannoma as the predominant pathology, with most cases presenting as large or giant tumours and significant preoperative hearing loss [26]. Facial nerve preservation was achieved in most patients, but complications such as CSF leak, meningitis and lower cranial nerve paresis were noted thus reflecting the balance between maximal resection and functional preservation [26].

From a surgical-anaesthetic perspective, the spectrum of CPA tumours is usually appreciated by their pattern of growth, involvement of cranial nerve also effect on CSF pathways [27]. Epidermoid tumours tend to encase cranial nerves and vessels, increasing the risk of intraoperative neural injury, whereas meningiomas are usually hypervascular as well as associated with significant dural attachment [20,28]. Large vestibular schwannomas and malignant CPA lesions can further compress the brainstem or obstruct fourth ventricular outflow, thereby predisposing patients to raised intracranial pressure along with hydrocephalus [2,18].

Preoperative Neurological and Anaesthetic Risk Assessment in CPA Tumours

A detailed preoperative neurological assessment is said to be essential in patients having CPA tumours due to the high prevalence of cranial nerve involvement as well as the risk of brainstem compression [12]. CPA lesions usually present with deficits of cranial nerves V through X, leading to symptoms like facial numbness, hearing loss, lower cranial nerve dysfunction, dysphagia, along with impaired gag reflex, which directly further influence anaesthetic planning, and risk startification [12]. Dysphagia and risk of aspiration must be evaluated adequately as compromised lower cranial nerve function (especially IX and X) further predisposes patients to silent aspiration, which also complicates airway protection both during induction and emergence from anaesthesia [12]. Moreover, large tumours or those having brainstem involvement can produce signs of raised intracranial pressure such as headache, vomiting, and papilloedema, thereby necessitating careful assessment of intracranial dynamics to guide induction technique, ventilation strategy, along with avoidance of secondary insults [17]. Hydrocephalus is known as a common sequela of CPA mass effect on fourth ventricular outflow, and patients can require External Ventricular Drain (EVD) planning or CSF diversion before definitive surgery for optimisation of perioperative cerebral physiology [11].

Airway evaluation in CPA tumour patients must extend beyond routine assessments for specifically identifying the impact of lower cranial nerve palsies [11]. Vocal cord paralysis because of involvement of the vagal nerve or impaired laryngeal sensation from glossopharyngeal dysfunction increases the risk of ineffective airway protection, difficult intubation, as well as perioperative aspiration [11]. Poor gag reflex, pharyngeal muscle weakness mandate a cautious approach for manipulation of the airway, usually requiring awake intubation techniques, fibreoptic guidance for minimisation of aspiration risk while also maintaining airway reflexes and spontaneous ventilation when indicated [9]. These neurological findings gleaned during preoperative examination correlate with advanced imaging, which further delineates tumour relationships to surrounding neural structures, thus reinforcing their anaesthetic relevance [9].

In addition to neurologic-airway concerns, cardiovascular and respiratory assessments are very critical because CPA tumours with brainstem compression can disrupt autonomic centres, resulting in haemodynamic lability, arrhythmias, and respiratory irregularities [29]. Preoperative evaluation must include screening for sleep-disordered breathing, usually in patients having large tumours and involvement of the brainstem, as obstructive or central sleep apnoea can further cause exacerbation of perioperative respiratory compromise [30]. Cardiorespiratory optimisation, which is inclusive of baseline pulmonary function as well as cardiovascular status, allows anaesthesiologists to anticipate potential autonomic instability and tailor anaesthetic depth, ventilation strategies, and haemodynamic support accordingly [29,30]. Preoperative neurological and anaesthetic risk assessment in CPA tumours is depicted in [Table/Fig-2] [9,11,12,17,19,29,30].

Assessment domain	Key findings in CPA tumours	Anaesthetic implications	Key references
Cranial nerve involvement (V–X)	Facial numbness, hearing loss, facial weakness, dysphagia, impaired gag reflex	Influences anaesthetic risk stratification; dictates need for neuromonitoring, airway protection strategies	[12]
Lower cranial nerve dysfunction (IX–X)	Dysphagia, hoarseness, impaired cough, silent aspiration	High aspiration risk; affects induction and extubation planning; may necessitate delayed extubation	[12]
Brainstem compression	Long-tract signs, altered consciousness, autonomic instability	Risk of haemodynamic and respiratory instability during anaesthesia; mandates careful titration and monitoring	[12,29]
Raised intracranial pressure	Headache, vomiting, papilloedema	Requires ICP-friendly induction, controlled ventilation, avoidance of hypoxia/hypercapnia	[17]
Hydrocephalus	Obstructive hydrocephalus due to fourth ventricular outlet compression	May require preoperative CSF diversion (EVD/VP shunt); affects positioning and intraoperative ICP management	[11]
Airway assessment	Vocal cord paralysis, poor gag reflex, pharyngeal weakness	Difficult airway, aspiration risk; favours awake or fibreoptic intubation techniques	[9,11]
Respiratory function	Central or obstructive sleep apnoea in large CPA tumours	Increased risk of perioperative respiratory compromise; impacts opioid dosing and extubation timing	[29]
Cardiovascular autonomic function	Arrhythmias, blood pressure variability	Anticipation of autonomic instability; requires invasive monitoring and tailored anaesthetic depth	[29,30]
Imaging correlation	Tumour size, extension, brainstem relationship	Guides anaesthetic planning, neuromonitoring needs, airway and positioning strategy	[9]

[Table/Fig-2]: Preoperative neurological and anaesthetic risk assessment in Cerebellopontine Angle (CPA) tumours [9,11,12,17,19,29,30].
CPA: Cerebellopontine Angle; V–X: Cranial Nerves V–X (Trigeminal to Vagus nerves); IX–X: Cranial Nerves IX–X (Glossopharyngeal and Vagus nerves); ICP: Intracranial Pressure; CSF: Cerebrospinal Fluid; EVD: External Ventricular Drain; VP shunt: Ventriculoperitoneal Shunt

Choice of Anaesthetic Technique and Intraoperative Neuromonitoring

The choice of anaesthetic technique in surgery of CPA tumour is usually dictated by the need for facilitating reliable Intraoperative

Neurophysiological Monitoring (IONM) while maintaining optimal brain relaxation and haemodynamic stability [31]. TIVA using a propofol-remifentanil combination is mostly preferred as it helps to provide stable anaesthetic depth with minimal interference with evoked potentials and cranial nerve EMG [32]. Recent evidence further suggests that remimazolam-based anaesthesia can serve as an emerging alternative to propofol-based TIVA thereby offering haemodynamic stability along with minimal suppression of IONM signals [33]. Propofol preserves Somatosensory Evoked Potentials (SSEPs), Motor Evoked Potentials (MEPs) as well as BAEPs more consistently than inhalational agents, while also remifentanil allows precise titration of analgesia without prolonged postoperative respiratory depression [31,33]. This technique is usually advantageous in CPA tumours where continuous monitoring of cranial nerves VII and VIII is important for facial nerve preservation and auditory function [33]. Comparatively, remimazolam has shown preservation of somatosensory MEPs with stable electrophysiological signals, thus making it a promising alternative in neurosurgical procedures requiring IONM [33]. In a case reported by Wankhede P et al., CPA vestibular schwannoma surgery in the sitting position was successfully managed using a propofol-based anaesthetic technique without neuromuscular blockade to facilitate facial nerve electromyographic monitoring, with stable haemodynamics and no postoperative facial nerve deficit [34].

In contrast, volatile anaesthetic agents are known to dose-dependently suppress cortical as well as brainstem evoked potentials mainly by reducing synaptic transmission and neuronal excitability within the central nervous system [31,33]. Even low concentrations of inhalational agents can further significantly attenuate BAEP amplitudes as well as prolong latencies, thereby compromising the sensitivity of neuromonitoring during CPA tumour dissection [33]. When balanced anaesthesia is employed, volatile agents are therefore restricted to ≤0.5 Minimum Alveolar Concentration (MAC) which are often supplemented using intravenous opioids to mitigate their depressant effects on neurophysiological signals [35]. Nitrous oxide is generally avoided as it further degrades evoked potential quality also it can increase intracranial pressure [33,35].

From an anaesthetic management perspective, maintaining a stable, motionless surgical field, optimal Cerebral Perfusion Pressure (CPP) along with the predictable neuromonitoring conditions is paramount [36]. TIVA allows rapid adjustments in anaesthetic depth during periods of brainstem manipulation thereby minimising autonomic instability while also preserving integrity of evoked potential [37]. In a case reported by Arshad NM et al., a CPA tumour in a primigravida was successfully managed using TIVA with propofol-dexmedetomidine and intraoperative neuromonitoring, with avoidance of neuromuscular blockade after intubation, resulting in favourable maternal and fetal outcomes [38]. Additionally, avoidance of long-acting neuromuscular blocking agents after intubation is essential for permitting continuous cranial nerve electromyographic monitoring [36,37]. Thus, propofol-based TIVA remains the current standard, although emerging agents such as remimazolam are gaining interest as potential alternatives of choice for CPA tumour surgery, along with balanced anaesthesia reserved for selected cases where neuromonitoring requirements permit limited volatile use [37]. However, emerging anaesthetic agents such as remimazolam can provide comparable neuromonitoring conditions with improved haemodynamic stability, thereby warranting further investigation in CPA tumour surgeries [33].

Intraoperative Neuromonitoring, Airway, and Haemodynamic Considerations

Intraoperative neuromonitoring is a main aspect of CPA tumour surgery, given the close relationship of these lesions to the facial nerve, cochlear nerve, lower cranial nerves, and brainstem [39]. Facial nerve EMG is routinely used to detect mechanical or thermal irritation during tumour dissection. At the same time, BAEPs provide continuous assessment of the cochlear nerve as well as brainstem auditory pathway integrity [39]. In selected cases, lower cranial nerve monitoring (IX-XII) is used for the reduction of the risk of postoperative dysphagia and vocal cord dysfunction [40,41]. In a study by Jahangiri F et al., intraoperative monitoring of lower cranial nerves (IX-XII) during posterior fossa tumour surgery enabled preservation of neural function and influenced surgical decision-making to avoid postoperative deficits [42]. Similarly, Topsakal C et al., reported that intraoperative monitoring of lower cranial nerves in skull base tumours significantly reduced nerve injury and facilitated safer tumour resection in high-risk cases [43]. From an anaesthetic standpoint, reliable monitoring requires avoidance of neuromuscular blocking agents after tracheal intubation, maintenance of a stable Mean Arterial Pressure (MAP) for preservation of neural perfusion as well as strict normothermia, as hypothermia-hypotension are known to degrade evoked potential amplitudes while it also prolongs latencies thereby reducing monitoring sensitivity [44].

Airway management in patients having CPA tumour requires individualised planning, which is usually based upon preoperative neurological deficits and aspiration risk [45]. Patients with lower cranial nerve palsy and impaired gag reflex can further benefit from rapid sequence induction for reduction of risk of aspiration [45]. Given the frequent usage of lateral, park-bench positioning, a reinforced (armoured) endotracheal tube is usually preferred for prevention of kinking-obstruction during prolonged surgery and head rotation [46]. Emergence as well as extubation pose unique challenges; delayed extubation is common, usually in cases having brainstem manipulation, prolonged operative duration, and pre-existing bulbar dysfunction [47]. The risk of vocal cord paresis and airway obstruction mandates careful assessment of airway reflexes along with respiratory adequacy before extubation with a low threshold for postoperative ventilatory support [47].

Patient positioning and haemodynamic management are equally important for further ensuring brain protection and surgical access [45]. The lateral or park-bench position is advantageous for exposure of CPA, but it also carries risks, including venous air embolism, pressure-related nerve injuries, and endotracheal tube displacement because of excessive neck flexion-rotation [46]. Haemodynamic goals must focus on maintaining adequate CPP with an emphasis on avoiding hypotension during the process of brainstem manipulation, which can further result in ischaemia or autonomic instability [47]. Brain relaxation strategies usually include judicious usage of mannitol, hypertonic saline combined with controlled ventilation for maintaining normocapnia-mild hypocapnia, thereby it helps optimisation of surgical conditions while minimising secondary brain injury [47,48].

Postoperative Airway, Neurological, and Intensive Care Management

Postoperative airway, ventilatory management represent an important component of care following CPA tumour surgery owing to high incidence of lower cranial nerve dysfunction as well as brainstem manipulation [49]. Delayed extubation is encountered usually in patients having preoperative bulbar symptoms, prolonged operative duration, significant intraoperative brainstem handling [49]. In a case reported by Handoko A et al., a patient developed postoperative neurological deficits and airway complications requiring tracheostomy following CPA tumour excision, highlighting the importance of vigilant postoperative airway and neurological monitoring [50]. Impairment of cranial nerves IX and X predisposes to ineffective protection of the airway, silent aspiration, as well as postoperative respiratory insufficiency [49]. In such cases,

planned postoperative mechanical ventilation along with staged neurological assessment is often safer than early extubation [49]. Standardised extubation readiness assessment using objective parameters such as the Rapid Shallow Breathing Index (RSBI), cuff leak test, and neurological evaluation scores including the Glasgow Coma Scale (GCS) has been advocated to guide safe extubation in neurosurgical patients, particularly following posterior fossa surgery [17,51]. Tracheostomy can be required in patients having severe-persistent lower cranial nerve palsy, recurrent aspiration, prolonged ventilatory dependence to facilitate airway protection along with pulmonary hygiene in the Intensive Care Unit (ICU) [49,52]. Additionally, swallowing assessment protocols and Fibreoptic Endoscopic Evaluation of Swallowing (FEES) have been recommended in patients with suspected lower cranial nerve dysfunction to reduce aspiration risk and guide airway management decisions [53].

Close neurological monitoring in the postoperative period is very essential for early detection of complications related to cranial nerve injury and brainstem oedema [54]. Facial nerve palsy remains one of the most common postoperative neurological deficits, as it can range from transient weakness to permanent paralysis depending on tumour size, pathology, and extent of surgical dissection [49,54]. Dysphagia, hoarseness, and impaired cough reflex reflect involvement of the lower cranial nerve, and it also requires early speech and swallowing evaluation to prevent aspiration pneumonia [55]. Altered level of consciousness in the immediate postoperative period can indicate raised intracranial pressure, hydrocephalus, brainstem ischemia, metabolic disturbances and warrants adequate neuroimaging and correction of secondary insults [55]. In a case reported by Bharti N et al., a parturient with CPA meningioma and hydrocephalus was managed with ventriculoperitoneal shunting followed by caesarean section under general anaesthesia, with careful ICP control resulting in favourable maternal and fetal outcomes [56].

Effective postoperative pain, Postoperative Nausea and Vomiting (PONV) control are said to be very essential for prevention of sympathetic surges, coughing, straining which can adversely affect intracranial dynamics [57]. Pain following posterior fossa and CPA surgery has distinct characteristics due to suboccipital muscle dissection, dural traction and involvement of upper cervical nerves (C2-C3), usually resulting in significant occipital and nuchal pain [58]. Posterior fossa craniotomies are associated with more intense and prolonged postoperative pain compared to supratentorial procedures due to extensive suboccipital muscle dissection, sustained head fixation, and positioning-related muscular strain [58,59]. Additionally, excessive analgesia-particularly opioids-must be judiciously titrated as these patients are at increased risk of respiratory depression due to brainstem proximity and lower cranial nerve dysfunction [59]. Furthermore, proximity to brainstem respiratory centers increases vulnerability to opioid-induced ventilatory impairment, which can delay extubation and complicate postoperative airway management [59]. Regional analgesic techniques such as scalp block or greater occipital nerve block have demonstrated efficacy in reducing opioid consumption and improving early postoperative recovery in posterior fossa craniotomies [58,60].

A multimodal analgesic approach with the usage of paracetamol, nonsteroidal anti-inflammatory drugs (where appropriate), along with low-dose opioids is preferred for providing adequate analgesia while also minimising respiratory depression and sedation [61]. Excessive administration of opioids must be avoided, particularly in patients with compromised brainstem function or sleep-disordered breathing. Prophylactic antiemetic therapy is strongly recommended as PONV can increase discomfort in patients, delay neurological assessment and exacerbate intracranial pressure fluctuations [57]. Meticulous management in ICU, which integrates airway vigilance, neurological surveillance, and judicious analgesia, is important in the optimisation of outcomes following CPA tumour surgery [61]. Postoperative airway, neurological, and intensive care management in Cerebellopontine Angle (CPA) tumour surgery is described in [Table/Fig-3] [49,52,54,55,57,61].

Management domain	Common postoperative issues	Anaesthetic / ICU implications	Key references
Airway and ventilation	Lower cranial nerve (IX–X) dysfunction, impaired airway reflexes	High aspiration risk; favors planned postoperative ventilation and delayed extubation	[49]
Extubation strategy	Preoperative bulbar symptoms, prolonged surgery, brainstem manipulation	Staged neurological assessment before extubation; low threshold for delayed extubation	[49]
Tracheostomy consideration	Persistent lower cranial nerve palsy, recurrent aspiration, prolonged ventilation	Facilitates airway protection and pulmonary hygiene in ICU	[49,52]
Neurological monitoring	Brainstem oedema, cranial nerve injury	Frequent neurological examination; early imaging if deterioration occurs	[54]
Facial nerve dysfunction	Transient or permanent facial palsy	Impacts postoperative rehabilitation and quality of life; requires early documentation	[49,54]
Swallowing dysfunction	Dysphagia, hoarseness, impaired cough reflex	Early speech and swallowing assessment; aspiration prevention strategies	[55]
Altered consciousness	Raised ICP, hydrocephalus, ischemia, metabolic derangements	Requires urgent neuroimaging and correction of secondary brain insults	[55]
Pain management	Post-craniotomy pain	Multimodal analgesia preferred; avoid excessive opioids	[57,61]
PONV prevention	High incidence after posterior fossa surgery	Prophylactic antiemetics to reduce ICP fluctuations and discomfort	[57]
ICU care integration	Airway, neurological, and analgesic challenges	Coordinated ICU management optimises outcomes after CPA tumour surgery	[61]

[Table/Fig-3]: Postoperative airway, neurological, and intensive care management in Cerebellopontine Angle (CPA) tumour surgery [49,52,54,55,57,61].

Innovations in Neuromonitoring and Perioperative Care for CPA Tumours

Recent advancements into surgery of CPA tumour have focused on enhancement of intraoperative neuromonitoring, surgical precision for better preservation of neurological function while also maximising tumour resection [39]. Multimodal monitoring approaches which take into consideration facial nerve EMG, BAEPs, as well as direct cranial nerve mapping continue to evolve, providing more reliable real-time feedback on neural integrity [10,39]. Refinements in the interpretation of BAEP, such as analysis of specific wave latencies for anticipating auditory pathway compromise during tumour manipulation, which

has contributed to improved functional preservation [62]. Advanced monitoring techniques are being increasingly used along with neuronavigation, tailored surgical strategies for minimisation of trauma to critical neurovascular structures, while it also reducing postoperative deficits [62,63].

Few emerging concepts, such as awake neurosurgical procedures, though said to be rare for posterior fossa lesions like CPA tumours, are being explored for maximisation of functional preservation in select patients [64]. While most awake craniotomy research has focused on supratentorial lesions, evolving evidence from monitored anaesthesia care protocols shows feasibility as well as safety using modified enhanced recovery pathways suggesting that adaptations for CPA approaches might be possible with further study [64]. Similarly, broader adoption of ERAS protocols in neuro-oncologic procedures has shown improved perioperative outcomes, reduced complications, along with shorter hospital stays in patients having cranial tumours, thereby underscoring the potential for standardised perioperative pathways which are tailored to complex skull-base surgeries [65].

AI as well as machine learning are increasingly poised to transform neuroanaesthesia, intraoperative decision support [66]. Early evidence suggests that AI algorithms can further help to enhance predictive analytics, optimise anaesthesia depth while also potentially assist in real-time neuromonitoring interpretation thereby improving precision and safety during neurosurgical procedures [66]. The integration of AI-assisted monitoring, data interpretation tools can further support more nuanced intraoperative adjustments while also facilitating improved functional outcomes in surgery of CPA tumour thereby representing a scope for research, clinical innovation in neuroanaesthesia-neurosurgery [66].

From an anaesthetic perspective, AI-assisted systems can further help into real-time titration of anaesthetic depth, prediction of haemodynamic instability as well as optimisation of cerebral perfusion during brainstem manipulation which are very important considerations in CPA tumour surgery [66]. These emerging applications are further supported by clinical evidence in perioperative and neurocritical care settings [66]. Yilmaz R et al., reported the use of computer vision-based AI for continuous intraoperative monitoring of surgical performance, highlighting its potential to enhance precision, safety, and real-time intraoperative feedback in neurosurgical procedures [67]. Khan MM et al., reported that AI-integrated wearable monitoring systems can help to detect early physiological deterioration in postoperative patients thereby allowing timely intervention and reducing complications in surgical and neurosurgical settings [68]. Feng R et al., demonstrated that AI-based video analysis can continuously monitor neurological status in neuro-ICU patients, enabling early detection of clinical deterioration and improving real-time decision-making in neurosurgical care [69]. However, direct case-based evidence of AI-guided anaesthetic management in CPA tumour surgery is currently limited.

CONCLUSION(S)

The CPA tumours usually pose significant anaesthetic challenges because of their intimate relationship with critical cranial nerves, brainstem centers as well as CSF pathways. Comprehensive preoperative evaluation, meticulous intraoperative anaesthetic management along with reliable neuromonitoring as well as vigilant postoperative critical care are very essential for optimising neurological-functional outcomes. Advancements in microsurgical techniques, neuroanaesthesia, enhance recovery protocols also emerging technologies like AI continue refinement of perioperative care. A multidisciplinary, anatomy-driven, patient-specific anaesthetic approach is said to be fundamental for improving safety as well as outcomes in CPA tumour surgery.

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