Review Article

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Recent Advances in Neuroanesthesia and Critical Care

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ABSTRACT

Neuroanesthesia has undergone substantial evolution over the past decade, paralleling advances in neurosurgical techniques, neurocritical care, and perioperative neuroscience [1-5]. Contemporary practice emphasizes individualized cerebral physiologic targets, opioid-sparing pharmacologic strategies, expanded use of total intravenous anesthesia (TIVA), and refined approaches for awake and minimally invasive neurosurgical procedures [1-6]. Multimodal neuromonitoring, intraoperative imaging, and emerging digital decision-support tools are increasingly integrated into perioperative management, while enhanced recovery pathways and evidence-mapping studies have highlighted both progress and persistent knowledge gaps. This narrative review summarizes recent advances in pharmacology, anesthetic techniques, neuromonitoring, perioperative pathways, and systems-level innovations relevant to neuroanesthesia and neurocritical care, and outlines priorities for future research [1-5].

Keywords: Neuroanesthesia; Neurocritical Care; Multimodal Neuromonitoring; Total Intravenous Anesthesia; Mechanical Thrombectomy

Introduction

Neuroanesthesia now spans intracranial and spinal neurosurgery, functional neurosurgery, neurointerventional radiology, and the continuum of neurocritical care [1-5]. Parallel advances such as mechanical thrombectomy for acute ischemic stroke, endoscopic skull base surgery, deep brain stimulation (DBS), and complex spine surgery have reshaped perioperative priorities and risk profiles. Within this context, neuroanesthesiologists focus on neuroprotective pharmacologic strategies, hemodynamic and ventilatory optimization, and structured use of neuromonitoring to improve neurologic and patient-centered outcomes [1-5]. Despite this expansion, a recent scoping review of high-level evidence in neuroanesthesia found relatively few large multicenter randomized trials addressing core management questions. Current priorities include pharmacologic advances, evolving anesthetic techniques, neuromonitoring and intraoperative technology, perioperative pathways, and systems-level innovations [1-4].

Pharmacologic Advances

Traditional concerns that ketamine uniformly increases intracranial pressure have been challenged by data showing that, under controlled ventilation with preserved cerebral perfusion pressure, ketamine can be hemodynamically advantageous in brain-injured patients. In traumatic brain injury and aneurysmal subarachnoid hemorrhage, it is increasingly used as an analgesic and sedative adjunct, with potential benefits related to N-methyl-D-aspartate receptor antagonism, anti-inflammatory actions, and mitigation of cortical spreading depolarizations, and it has a growing role in refractory and super-refractory status epilepticus. TIVA with propofol and short-acting opioids remains central for neurosurgery requiring stable cerebral physiology and compatibility with somatosensory and motor evoked potentials [1-3]. Practice is shifting toward opioid-sparing or opioid-free regimens using dexmedetomidine, ketamine, lidocaine, magnesium, and regional techniques to reduce respiratory depression, nausea, and opioid-induced hyperalgesia and to facilitate rapid extubation and early neurologic assessment [1-3,6]. Dexmedetomidine has gained prominence as a sedative-analgesic adjunct because it produces cooperative sedation with minimal respiratory depression and generally favorable intracranial dynamics, though bradycardia and hypotension remain important concerns in patients at risk for cerebral ischemia [1-3].

In complex aneurysm surgery, transient flow arrest using adenosine or rapid ventricular pacing provides short periods of profound hypotension that facilitate clip placement when temporary clipping is impractical [4-6]. Blood conservation strategies—including antifibrinolytics, point-of-care coagulation testing, and goal-directed transfusion protocols—are increasingly applied in major cranial and spine surgery, but neuro-specific randomized data to define optimal thresholds and algorithms remain limited.

Advances in Anesthetic Techniques

Awake craniotomy for tumor and epilepsy surgery near eloquent cortex has expanded, supported by improved imaging, meticulous patient selection, and structured anesthesia protocols. Asleep–awake–asleep and monitored anesthesia care techniques commonly combine propofol, remifentanil, and dexmedetomidine with scalp blocks to balance comfort and cooperation for language and motor mapping, with a strong emphasis on airway planning and preparedness to convert to general anesthesia when necessary. Concepts from awake craniotomy are being extrapolated to selected spine procedures, where "awake-light" techniques with regional anesthesia and multimodal analgesia may accelerate recovery in high-risk patients, though robust comparative trials are still needed. The rapid adoption of mechanical thrombectomy has renewed debate over anesthetic management for acute ischemic stroke. Early observational data suggested worse outcomes with general anesthesia, largely attributed to treatment delays and hypotension, whereas more recent randomized trials using protocolized hemodynamic targets demonstrate comparable or even superior outcomes with general anesthesia versus conscious sedation in selected patients. Current practice therefore favors individualized selection based on airway safety, agitation, hemodynamic stability, and local expertise, with an overarching focus on minimizing time to reperfusion and avoiding hypotension and hypocapnia. Functional neurosurgery has also evolved, with DBS now performed both as awake procedures guided by microelectrode recordings and patient feedback and as "asleep DBS" relying on intraoperative MRI or CT. Awake DBS protocols increasingly use low-dose dexmedetomidine and carefully titrated propofol and opioids to preserve neuronal firing patterns and patient cooperation, while asleep DBS prioritizes imaging quality, minimization of brain shift, and hemodynamic stability.

Neuromonitoring and Intraoperative Technology

Modern neuroanesthesia routinely incorporates somatosensory and motor evoked potentials, electroencephalography, processed EEG indices, and near-infrared spectroscopy to guide anesthetic depth, detect ischemia or mechanical injury early, and support intraoperative decision-making in spine, vascular, and tumor surgery. [1-3,6] In neurocritical care, invasive monitoring of intracranial pressure, brain tissue oxygen tension, and cerebral metabolism increasingly informs individualized cerebral perfusion pressure targets, though the impact on long-term functional outcomes remains incompletely defined. Processed EEG-guided anesthesia has shown mixed results regarding awareness and delirium reduction, and neurosurgery-specific data are still sparse. Intraoperative CT, MRI, and angiography, together with neuronavigation and robotic assistance, enhance surgical precision and permit real-time assessment of resection extent, clip position, and device placement. These technologies impose anesthetic challenges, including restricted access to the airway, prolonged and constrained positioning, and the need to balance image quality with patient safety in MRI or hybrid operating rooms.

Digital tools and artificial intelligence are emerging as adjuncts for risk prediction, hemodynamic management, and outcome prognostication in neuroanesthesia and neurocritical care. Early machine-learning models integrate hemodynamic, EEG, and neuromonitoring data to predict complications such as delayed cerebral ischemia or intracranial hypertension, but most remain in early validation and have not yet been incorporated into routine real-time decision support or closed-loop control systems.

Perioperative Pathways and Systems-Level Advances

Enhanced recovery after surgery (ERAS) principles have been adapted to cranial and spine surgery, with protocols emphasizing preoperative education, shortened fasting with carbohydrate loading, multimodal opioid-sparing analgesia, maintenance of normovolemia and normothermia, and early mobilization and catheter removal [1-3]. Observational data suggest reductions in length of stay and complications with ERAS-Neuro programs, but neurosurgery-specific randomized trials are still limited and heterogeneity in implementation remains substantial. Delirium prevention, early cognitive screening, and timely rehabilitation are increasingly recognized as essential components of postoperative care, particularly in older or frail patients.

Evidence-mapping efforts highlight key areas where high-quality data are lacking, including optimal blood pressure and carbon dioxide targets during aneurysm surgery and thrombectomy, fluid therapy and transfusion thresholds, and the role of depth-of-anesthesia guidance for neurologic outcomes. Future practice will likely emphasize personalization, integrating patient-specific risk factors, biomarker or genomic profiles, and intraoperative physiologic signatures to tailor hemodynamic, ventilatory, and pharmacologic strategies.

Expansion of ERAS-Neuro pathways, greater use of telemedicine, and development of international registries are particularly important to address evidence gaps in low- and middle-income settings, where the neurosurgical disease burden is greatest. Continued collaboration between anesthesiologists, neurosurgeons, neurointensivists, and trialists is crucial to design pragmatic multicenter studies focused on patient-centered outcomes such as functional independence, cognition, and quality of life, ensuring that technological and pharmacologic advances translate into meaningful improvements in neurologic outcomes [2,4,7-10].

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