

Predictors and Clinical Outcomes Associated with Delayed Extubation after Elective Intracranial Surgery: Systematic Review and Meta-Analysis

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DOI: <https://doi.org/10.36347/sasjm.2026.v12i10.010>

| Received: 12.08.2026 | Accepted: 04.10.2026 | Published: 10.10.2026

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Abstract

Original Research Article

Background: After elective intracranial surgery, immediate extubation enables early neurological assessment, but it is not always safe. Planned postoperative ventilation may be justified when neurological status, airway protection, gas exchange, or operative conditions are unfavorable. This review evaluates the incidence of delayed extubation, its predictors, and its associations with major postoperative outcomes. **Methods:** PubMed/MEDLINE and Europe PMC were searched from inception to 21 September 2026. Adult cohorts comparing extubation in the operating room or post-anesthesia care unit with later extubation after transfer to intensive care were eligible. Random-effects models produced pooled proportions and odds ratios. Risk of bias was assessed using an adapted Newcastle-Ottawa Scale, and certainty was judged according to GRADE principles. **Results:** Four cohorts including 1,345 patients were included, of whom 632 underwent delayed extubation. The pooled incidence was 42.3% (95% CI 27.7–58.4; $I^2 = 96.0\%$). In two infratentorial cohorts, preoperative hydrocephalus (OR 3.01; 95% CI 1.25–7.21), lower cranial nerve dysfunction (OR 3.97; 2.15–7.34), and blood loss $\geq 1,000$ mL (OR 5.88; 1.74–19.92) were associated with delayed extubation. Delayed extubation was also associated with unfavorable neurological outcome (OR 3.74; 1.30–10.80) and intensive care stay >24 hours (OR 7.62; 4.75–12.23), without a statistically demonstrated difference in reintubation (OR 1.52; 0.49–4.77). **Conclusion:** Delayed extubation is common and mainly reflects neurological and operative complexity. The observed associations do not prove that delayed extubation is itself harmful because all data are observational and highly susceptible to confounding by indication. A protocolized, individualized, and repeatedly reassessed decision appears preferable to a uniform strategy.

Keywords: craniotomy; neuroanesthesia; delayed extubation; postoperative ventilation; infratentorial surgery; intensive care; meta-analysis.

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1 INTRODUCTION

Emergence after intracranial surgery involves two potentially competing objectives. On the one hand, rapid discontinuation of anesthetic agents and early extubation enable immediate neurological assessment, facilitate detection of hematoma, ischemia, focal deficit, or intracranial hypertension, and limit exposure to sedation and mechanical ventilation. On the other hand, premature extubation may expose the patient to airway obstruction, aspiration, hypoventilation, hypercapnia, and difficult reintubation in a setting where any hypoxemia or hypertensive surge may worsen brain injury [1,16,17].

The decision therefore cannot rely on respiratory criteria alone. It should integrate

consciousness, the ability to follow simple commands, cough effectiveness, swallowing, and protective reflexes, as well as lesion location, brainstem manipulation, hydrocephalus, edema, operative duration, bleeding, and transfusion [2,3,5,10–12]. Infratentorial procedures are particularly sensitive because the nuclei and pathways of the lower cranial nerves directly contribute to laryngeal protection and ventilatory control.

Practice varies widely among teams. An international survey of infratentorial craniotomy documented heterogeneous thresholds for early extubation [4]. Available cohorts report delayed-extubation rates ranging from approximately 17% to 66% [2,3,5,6]. This dispersion reflects case mix,

Citation: Moutaoukil, M., Enaimi, M., Errachki, M., Najout, H., El Wali, A., & Bensghir, M. (2026). Predictors and Clinical Outcomes Associated with Delayed Extubation after Elective Intracranial Surgery: Systematic Review and Meta-Analysis. *SAS J Med*, 12(10), 1070-1077. <https://doi.org/10.36347/sasjm.2026.v12i10.010>

definitions, monitoring resources, local practices, and the time at which surgery ends. An isolated rate should therefore not be interpreted as a direct quality indicator.

The primary objective of this systematic review was to estimate the incidence of delayed extubation after elective intracranial surgery in adults. Secondary objectives were to identify associated perioperative factors and evaluate relationships with reintubation, pulmonary complications, neurological outcome, and intensive care resource use.

Evidence from neurocritical care usefully complements the postoperative literature. A recent meta-analysis confirmed the roles of age, duration of ventilation, cough, and swallowing in extubation failure after acute brain injury [21]. The European consensus on ventilation in brain-injured patients recommends joint assessment of respiratory, neurological, and airway functions [22]. Practice surveys nevertheless show substantial variability in weaning [23]. Several cohorts have associated delay, failure, or reintubation with neurological status, cough, secretions, and airway patency [24–29].

Other recent studies have examined determinants of emergence after neurosurgery, conditions for uneventful delayed extubation, and outcomes associated with the timing of extubation after postoperative intensive care admission [13–15]. They broaden the clinical context without providing sufficiently homogeneous data for inclusion in the principal meta-analyses.

2 METHODS

2.1 Design and reporting framework

The review was conducted according to PRISMA 2020 and the MOOSE recommendations applicable to meta-analyses of observational studies [7,8]. The protocol was defined before quantitative extraction but was not prospectively registered. Because the data were aggregate and already published, institutional ethics approval was not required.

2.2 Eligibility criteria

Comparative cohort studies of adults aged 18 years or older undergoing elective intracranial surgery under general anesthesia were included. Early extubation was defined as extubation in the operating room or during the immediate postoperative period in the post-anesthesia care unit. Delayed extubation was defined as postoperative transfer with an endotracheal tube followed by later extubation in intensive care or another postoperative care unit.

Exclusion criteria were exclusively pediatric or emergency series, patients intubated before surgery, spinal surgery, endovascular procedures, awake craniotomy, case reports, surveys without patient-level outcomes, and studies focused solely on extubation

failure after a weaning trial. Mixed populations were eligible only when the elective intracranial subgroup could be extracted.

2.3 Sources, search, and study selection

PubMed/MEDLINE and Europe PMC were searched from inception to 21 September 2026 without language restrictions. The strategy combined concepts for craniotomy or intracranial surgery, extubation or postoperative ventilation, and early, delayed, or prolonged timing. Reference lists of included articles and relevant reviews were searched manually. One reviewer performed selection and extraction, followed by a second verification of all included studies and full-text exclusions.

2.4 Data, outcomes, and analysis

Extracted data included country, study design, surgical population, definition of the extubation strategy, sample size, events, adjusted estimates, and postoperative outcomes. Primary outcomes were the incidence of delayed extubation and its predictors. Secondary outcomes included reintubation, pulmonary complications, unfavorable Glasgow Outcome Scale score (GOS 1–3), intensive care stay longer than 24 hours, hospital length of stay, reoperation, and mortality.

Odds ratios were reconstructed from compatible contingency tables. Random-effects models used the DerSimonian-Laird estimator [9]. Heterogeneity was described using I^2 and τ^2 ; I^2 should be interpreted as an indicator of between-study variability rather than a validity test [18]. Publication-bias testing was not performed because fewer than ten studies contributed to each synthesis. Risk of bias was examined by domains informed by Newcastle-Ottawa and ROBINS-I [19]. Overall certainty was judged according to GRADE principles [20].

3 RESULTS

3.1 Study selection

The search identified 250 records. After removal of 73 duplicates, 177 titles and abstracts were screened. Thirteen full-text reports were assessed and four cohorts met the inclusion criteria [2,3,5,6]. Exclusions were mainly due to the absence of an eligible comparator, non-separable non-elective populations, pediatric age, or a non-comparative design.

Selection process. The search identified 250 records: 170 in PubMed/MEDLINE and 80 in Europe PMC. After removal of 73 duplicates, 177 unique records were screened by title and abstract; 164 were excluded at this stage. Thirteen articles were then assessed in full text, nine of which were excluded with justification. Finally, four cohort studies totaling 1,345 patients were retained for quantitative synthesis.

3.2 Study characteristics

The four studies, published between 2011 and 2025, included 1,345 adults. Three cohorts mainly or exclusively involved infratentorial procedures [2,3,5],

and one involved resection of supratentorial or infratentorial brain metastases [6]. No randomized study compared a planned early-extubation policy with a delayed-extubation policy.

Table 1: Main characteristics of the included cohorts. EMG: electromyography; PACU: post-anesthesia care unit.

Study	Design and population	Early / delayed	Definition and main findings
Cata <i>et al.</i> , 2011 [2]	United States, retrospective; 145 prone infratentorial procedures	120 / 25	Operating-room versus later extubation. Delayed group: higher ASA status, longer surgery, greater blood loss, and longer hospital stay.
Cai <i>et al.</i> , 2013 [3]	China, prospective; 800 infratentorial tumor resections	402 / 398	Operating room versus neuro-ICU. Hydrocephalus, lower cranial nerve dysfunction, brainstem involvement, duration ≥ 6 h, and blood loss $\geq 1,000$ mL were predictive.
Wanawananont <i>et al.</i> , 2025 [5]	Thailand, retrospective; 210 infratentorial tumor resections	126 / 84	Operating room versus postoperative unit. Associations with hydrocephalus, opioids, EMG monitoring, after-hours completion, fluids >3 L, and transfusion.
Khalafov <i>et al.</i> , 2025 [6]	Germany, retrospective; 190 brain-metastasis resections	65 / 125	PACU versus intensive care extubation. Transfusion was more frequent in the delayed group; adjusted complications were comparable.

3.3 Risk of bias

In every study, clinicians determined the extubation strategy. Patients who remained intubated were therefore, by design, those perceived as more severely ill or complex. This confounding by indication

is the main threat to causal interpretation. The prospective cohort by Cai *et al.*, provided the most detailed multivariable model, whereas retrospective series remained susceptible to missing data, temporal changes in practice, and residual confounding.

Table 2: Summary of risk of bias by major domain.

Study	Selection	Comparability	Outcome assessment	Overall judgment
Cata 2011 [2]	Moderate risk	Important confounding	Moderate risk	Moderate to high
Cai 2013 [3]	Low to moderate	Detailed adjusted model	Low to moderate	Moderate
Wanawananont 2025 [5]	Moderate	Adjusted model; post hoc cutoffs	Moderate	Moderate
Khalafov 2025 [6]	Moderate	Limited outcome adjustment	Moderate	Moderate to high

3.4 Incidence and predictors

Overall, 632 of 1,345 patients underwent delayed extubation. The pooled incidence was 42.3% (95% CI 27.7–58.4%), with very high heterogeneity ($I^2 = 96.0\%$). Individual incidences ranged from 17.2% in the Cleveland cohort to 65.8% in the brain-metastasis cohort. This estimate therefore summarizes heterogeneous institutional practices and should not be considered a universal target.

Two infratentorial cohorts provided compatible data for several factors [3,5]. Preoperative hydrocephalus approximately tripled the odds of delayed extubation. Lower cranial nerve dysfunction was associated with a pooled OR of 3.97, and blood loss $\geq 1,000$ mL with an OR of 5.88. ASA III–IV status did not reach statistical significance.

Adjusted analyses confirmed the association with hydrocephalus in both cohorts: adjusted OR 1.69 (95% CI 1.17–2.45) in Cai *et al.*, and 6.12 (2.60–14.41) in Wanawananont *et al.*, [3,5]. Other independent signals included brainstem involvement, surgery lasting at least six hours, late opioid administration, electromyographic

monitoring, completion outside regular working hours, crystalloid volume $>3,000$ mL, and transfusion.

3.5 Postoperative outcomes

Delayed extubation was associated with unfavorable GOS in two infratentorial cohorts (OR 3.74; 95% CI 1.30–10.80; $I^2 = 55.3\%$) and with intensive care stay >24 hours (OR 7.62; 4.75–12.23; $I^2 = 0\%$). Median lengths of stay were consistently longer in delayed groups. In Wanawananont *et al.*, median intensive care stay was 40 versus 20 hours and hospital stay was 201.5 versus 144 hours [5]. In Cai *et al.*, postoperative hospital stay was 12 versus 9 days [3].

Reintubation, analyzed in two 2025 cohorts, did not differ significantly (OR 1.52; 95% CI 0.49–4.77; $I^2 = 0\%$). Cai *et al.*, reported pneumonia in 12.3% of delayed patients versus 2.0% after early extubation [3], but the absence of comparable definitions in other studies precluded reliable pooling. Khalafov *et al.*, found no significant adjusted difference in overall adverse events [6].

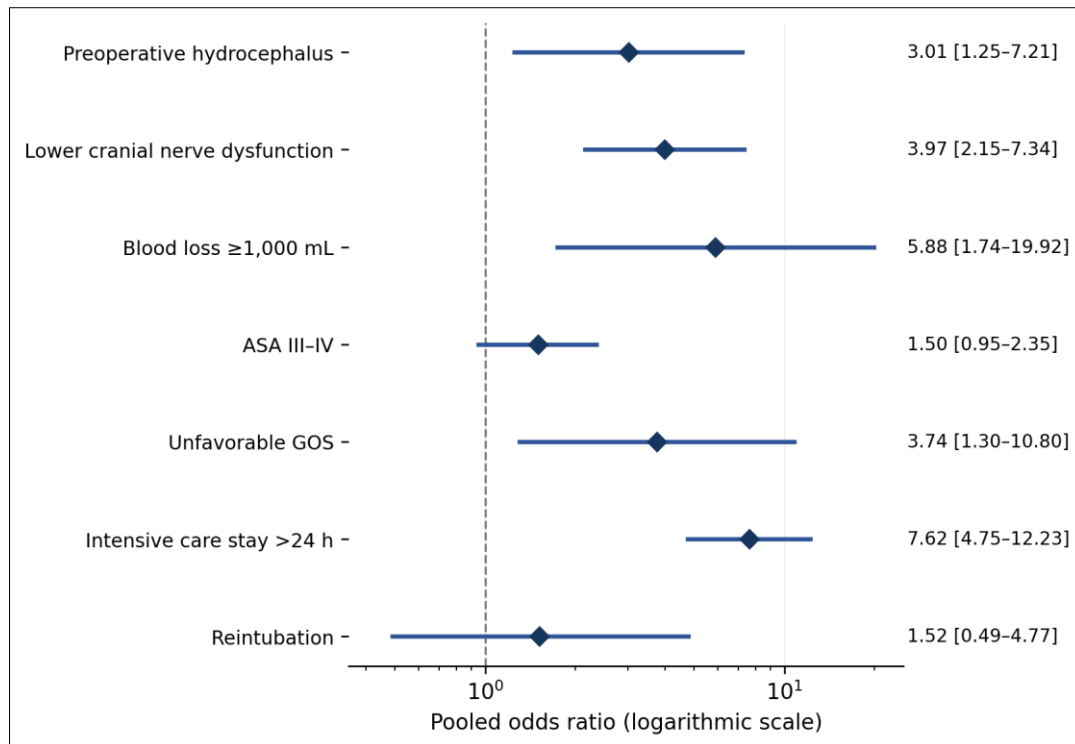


Figure 1: Summary of associations with delayed extubation and postoperative outcomes. An OR greater than 1 indicates a more frequent association in the delayed-extubation group.

Sources: [3,5,6]

Table 3: Main quantitative findings. GOS: Glasgow Outcome Scale; OR: odds ratio.

Outcome	Studies	Pooled effect 95% CI	I ²
Incidence of delayed extubation [2,3,5,6]	4	42.3% [27.7–58.4]	96.0%
Hydrocephalus [3,5]	2	OR 3.01 [1.25–7.21]	84.4%
Lower cranial nerve dysfunction [3,5]	2	OR 3.97 [2.15–7.34]	41.8%
Blood loss $\geq 1,000$ mL [3,5]	2	OR 5.88 [1.74–19.92]	72.1%
ASA III–IV [3,5]	2	OR 1.50 [0.95–2.35]	38.0%
Unfavorable GOS [3,5]	2	OR 3.74 [1.30–10.80]	55.3%
Intensive care >24 h [3,5]	2	OR 7.62 [4.75–12.23]	0%
Reintubation [3,5]	2	OR 1.52 [0.49–4.77]	0%

4 DISCUSSION

4.1 Principal findings

This synthesis shows that delayed extubation affects approximately two in five patients after elective intracranial surgery, but this average conceals major variation between centers. The most reproducible signals are hydrocephalus, lower cranial nerve dysfunction, major bleeding, transfusion, and operative duration or complexity. These correspond to plausible mechanisms: impaired emergence, fragile protective reflexes, brainstem edema, hemodynamic and metabolic consequences of hemorrhage, fluid overload, and drug accumulation.

The most robust resource-use finding is the association with an intensive care stay longer than 24 hours. However, this relationship is partly tautological: transferring an intubated patient requires intensive care monitoring and mechanically prolongs the time before discharge. Likewise, the association with unfavorable GOS may reflect initial neurological severity or intraoperative events that prompted continued

ventilation rather than an independent effect of ventilation itself.

4.2 Clinical interpretation

The extubation decision should be structured around four domains: neurological status, airway protection, respiratory function, and systemic condition. Neurological assessment should consider expected wakefulness, comprehension of simple commands, absence of acute focal worsening, and the risk of edema or hematoma. Airway protection depends on cough, secretion management, pharyngolaryngeal motor function, and lower cranial nerve integrity. Respiratory assessment verifies spontaneous ventilation, gas exchange, and neuromuscular recovery. Hemodynamic stability, temperature, acid-base balance, hemostasis, and the extent of fluid administration should also be integrated [1,16,17].

Weaning recommendations emphasize daily assessment, a spontaneous breathing trial, and an extubation decision that is distinct from the ability to

breathe without assistance alone [30,31]. Even after a successful trial, age, weak cough, secretion burden, and comorbidities increase the risk of failure [32]. Unplanned reintubation is associated with increased morbidity, supporting an explicit monitoring and rescue plan [33].

A low Glasgow Coma Scale score should not be considered in isolation. In neurocritical populations, the ability to protect the airway and manage secretions may be more informative than the GCS value alone [16]. Conversely, an apparently awake patient with bulbar dysfunction after posterior fossa surgery remains at high risk of aspiration and failure. Extubation is therefore a multidimensional judgment rather than the simple validation of a respiratory trial.

After extubation, noninvasive support should not be applied indiscriminately. NIV used as rescue therapy for established respiratory failure may delay reintubation [34], whereas prophylactic use in selected high-risk patients may reduce failure [35]. Trials of high-flow nasal oxygen and NIV show that the patient's risk level should guide post-extubation support [36–39]. Continuing enteral nutrition until extubation did not

increase failure in a cluster-randomized trial, but this finding does not remove the need to assess swallowing and aspiration risk [40].

Completion outside regular working hours and late opioid administration are potentially modifiable factors, but their causality remains uncertain. The former may reflect surgical duration and complexity or reduced team availability. The latter may be a marker of a long or painful procedure. These associations should prompt audits of organization and analgesic protocols without turning an observational signal into a rigid prohibition.

Safe extubation also requires an anticipated reintubation strategy, particularly when airway access may be difficult [41]. The cuff-leak test may be useful when laryngeal edema is suspected, but its performance does not replace clinical assessment [42,43]. Finally, objectively confirmed neuromuscular recovery is essential: residual neuromuscular blockade increases postoperative respiratory events, and contemporary guidelines favor quantitative monitoring and appropriate reversal [44,45].

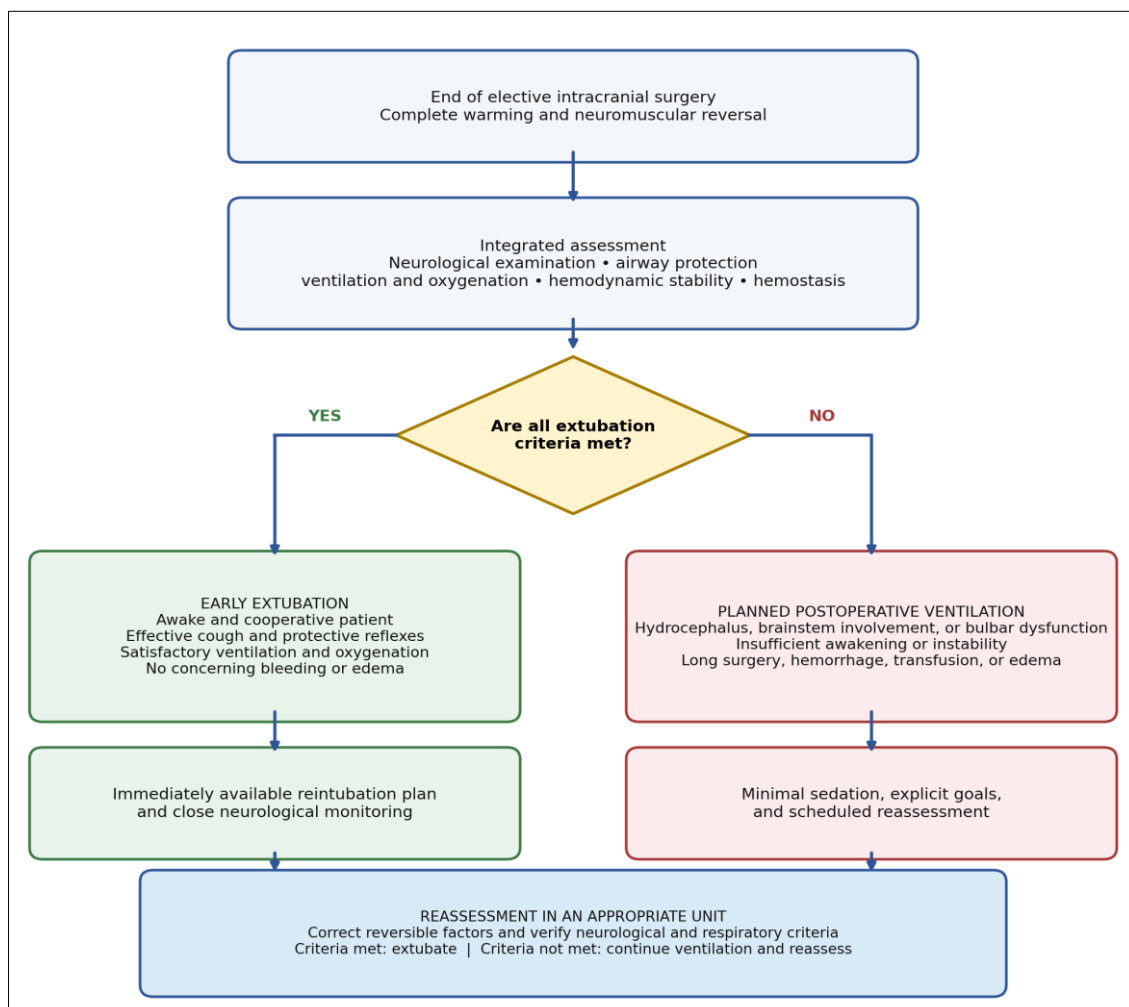


Figure 2: Proposed clinical reasoning for the extubation decision. This algorithm summarizes the identified factors and is not a validated rule. Sources: [1,2,3,5,6,16,17,21,22,27–31,41–45]

4.3 Practical proposal

Table 4: Summary framework for an individualized decision

Domain	Features favoring early extubation	Features prompting delay and reassessment
Neurological [1,3,5,16,17,21,22]	Coherent awakening, interpretable examination, no acute worsening	Insufficient or unexpected awakening, uncontrolled hydrocephalus, suspected edema or hematoma, brainstem involvement
Airway protection [1,3,5,16,17,27–33,41–45]	Effective cough, controlled secretions, satisfactory swallowing and pharyngolaryngeal function	Lower cranial nerve dysfunction, weak cough, secretion burden, aspiration risk
Respiratory [1,16,17,27–33]	Stable spontaneous ventilation, satisfactory oxygenation, complete neuromuscular recovery	Hypoventilation, hypoxemia, hypercapnia, potential obstruction, residual neuromuscular blockade
Surgical and systemic [2,3,5,6,16,17,21,22,41–45]	Hemostasis achieved, normothermia, hemodynamic stability, limited blood loss	Blood loss $\geq 1,000$ mL, transfusion, major fluid loading, prolonged surgery, instability
Organization [1,5,21,22,41–45]	Appropriate monitoring and an immediately available reintubation plan	After-hours completion, insufficient resources, difficult transfer or airway access

4.4 Strengths and limitations

This review explicitly distinguishes planned delayed extubation from failure of an extubation already performed, includes recent cohorts, and combines several clinically relevant factors. Separate presentation of crude estimates and adjusted results also limits the risk of overinterpretation.

Important limitations remain. Only four single-center studies were eligible, and several meta-analyses contained only two cohorts. Definitions, surgical populations, and thresholds varied. Heterogeneity of incidence was extreme. Several pooled effects relied on unadjusted aggregate data, while clinicians specifically selected the most severely ill patients for prolonged ventilation. The search did not include Embase or Scopus, initial selection was not performed independently in duplicate, and the protocol was not registered. Certainty is therefore low or very low for all outcomes.

4.5 Research implications

Future studies should adopt a consensus definition: early extubation in the operating room or PACU, delayed extubation after transfer with an endotracheal tube, and failure defined as reintubation within 48 hours. A minimum variable set should include preoperative neurological status, bulbar function, hydrocephalus, lesion location and volume, surgical duration, blood loss, transfusion, fluid balance, hypnotic and opioid exposure, neuromuscular monitoring, and completion time. Multicenter cohorts using propensity-score adjustment or target-trial emulation would be more realistic than systematic randomization.

5 CONCLUSION

After elective intracranial surgery, delayed extubation is common but highly dependent on the institutional context. Hydrocephalus, lower cranial nerve

dysfunction, and major blood loss are the most reproducible predictors. Patients who remain ventilated stay longer in intensive care and more often have unfavorable neurological outcomes, without a statistically demonstrated increase in reintubation. These associations primarily describe a more severely ill population and do not demonstrate that delayed extubation is causally harmful. The best strategy is an individualized, explicit, and repeatedly reassessed decision based on neurological examination, airway protection, respiratory function, and surgical constraints.

DECLARATIONS

Ethics approval: not applicable; the study used exclusively published aggregate data.

Consent for publication: not applicable.

Funding: no external funding was received.

Conflicts of interest: the authors declare no conflicts of interest.

Data availability: all quantitative data were obtained from the cited publications.

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