

Predictors of Extubation Failure in Critically Ill Children: A Systematic Review

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How to citation this article: Dr. Priyanka Bhateja, Dr. Suman Gupta, Dr. Shifali Gupta, “Predictors of Extubation Failure in Critically Ill Children: A Systematic Review”, IJMACR– September – 2026, Volume – 9, Issue – 5, P. No. 892 – 905.

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Type of Publication: Review Article

Conflicts of Interest: Nil

Abstract

Extubation failure remains an important complication in critically ill children receiving invasive mechanical ventilation because it exposes patients to urgent reintubation, recurrent airway instrumentation, longer ventilator exposure, and increased intensive care resource use. This systematic review evaluated demographic, clinical, airway, disease-specific, ventilatory, and physiologic predictors of extubation failure among children undergoing planned extubation in pediatric intensive care settings. A structured search of PubMed/MEDLINE, PubMed Central, open publisher databases, Google Scholar-style open web sources, and reference lists was performed from database inception to 14 September 2026. Studies were eligible when they included children beyond the neonatal period through

adolescence, reported planned extubation after invasive mechanical ventilation, and provided extractable information on extubation failure or candidate predictors. Neonatal-only studies, adult-only studies, unplanned extubations, conference abstracts without sufficient data, and reviews without primary data were excluded. Twenty-four pediatric studies were included in qualitative synthesis. Owing to heterogeneity in extubation-failure definitions, case mix, predictor thresholds, and effect measures, formal pooled meta-analysis was not performed. The most consistently supported predictors were younger age, prolonged invasive ventilation, chronic respiratory or neurologic disease, syndromic or complex comorbidity, airway abnormality or upper-airway obstruction, and reduced respiratory muscle strength. In cardiac intensive care cohorts, additional predictors

included preoperative ventilation, longer postoperative ventilation, palliative or complex surgery, genetic abnormalities, pleural effusion, diaphragm paralysis, inhaled nitric oxide at extubation, and abnormal physiologic risk analytics. Single conventional indices, including respiratory rate and rapid shallow breathing index, showed inconsistent predictive performance. Pediatric extubation readiness should therefore be assessed as a multidomain decision integrating spontaneous breathing performance, airway risk, respiratory-muscle reserve, neurologic status, secretion burden, hemodynamic stability, disease context, and post-extubation support planning.

Keywords: Extubation Failure, Pediatric Intensive Care, Mechanical Ventilation, Airway Extubation, Ventilator Liberation, Risk Factors, Reintubation, Extubation Readiness

Introduction

Invasive mechanical ventilation is a lifesaving intervention for children with acute respiratory failure, shock, neurologic impairment, postoperative instability, and complex cardiorespiratory disease. However, continued endotracheal intubation carries risks, including airway injury, ventilator-associated infection, sedation-related morbidity, diaphragmatic dysfunction, impaired communication, and longer pediatric intensive care unit (PICU) stay. Pediatric ventilator liberation therefore requires clinicians to balance the harm of unnecessary ventilation against the danger of premature extubation^{3,4}. Extubation failure is generally defined as the need for reintubation after planned removal of the endotracheal tube, most often within 24-72 hours. The 48-hour window is frequently used in pediatric and adult critical-care literature, but important variation exists. Some studies count only reintubation, whereas others include rescue

noninvasive ventilation, high-flow nasal cannula escalation, or death within a specified period. This heterogeneity is clinically important because broader definitions yield higher failure rates and may identify different mechanisms of failure^{5,20,28,29}.

The incidence of extubation failure varies across pediatric populations. Multicenter PICU data have reported failure rates around 5-6%, while single-center general PICU studies have reported higher rates, and pediatric cardiac cohorts often show distinct rates depending on operative complexity, age, and physiologic substrate^{5,6,20-22}. These differences reflect variation in age distribution, comorbidity, ventilation duration, airway risk, extubation criteria, post-extubation respiratory support, and definitions of failure.

Predicting extubation outcome in children is more difficult than in adults because developmental physiology, airway caliber, respiratory reserve, neurologic maturity, and disease phenotype change substantially across infancy, childhood, and adolescence. Extubation failure may result from upper-airway obstruction, unresolved parenchymal lung disease, excessive respiratory load, respiratory-muscle weakness, cardiovascular intolerance, secretion burden, altered mental status, or inadequate airway protection. No single test captures all these mechanisms⁷⁻¹⁷.

Previous pediatric synthesis has focused mainly on pre-extubation tests and indices, concluding that many individual assessments have limited or inconsistent diagnostic value²³. Contemporary studies have added airway-versus-non-airway phenotyping, large pediatric cardiac datasets, physiologic risk analytics, and multicenter trends in post-extubation support¹⁹⁻²⁸. A systematic review of the broader predictor landscape is therefore clinically useful.

The objective of this systematic review was to identify and synthesize predictors of extubation failure in critically ill children undergoing planned extubation after invasive mechanical ventilation, with attention to general PICU cohorts, pediatric cardiac intensive care cohorts, pre-extubation predictors, early post-extubation warning signs, and methodological limitations of the available evidence.

Review

Materials and Methods

Reporting standard and protocol

This review was prepared according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement¹. A formal protocol was not prospectively registered. Because this was a review of previously published studies, ethics approval and informed consent were not required.

Eligibility criteria

Table 1: PECO framework and eligibility criteria

PECO item	Operational definition
Population	Children older than the neonatal period through adolescence, admitted to a PICU, pediatric cardiac ICU, or mixed pediatric critical-care setting and receiving invasive mechanical ventilation.
Exposure/predictor	Any demographic, clinical, disease-related, airway, ventilatory, laboratory, physiologic, respiratory-muscle, or extubation-readiness factor evaluated in relation to extubation outcome.
Comparator	Children without the predictor, with lower levels of the predictor, or with successful extubation, depending on study design.
Outcome	Extubation failure, preferentially reintubation within 48 hours after planned extubation; studies using 24-hour, 72-hour, seven-day, or broader respiratory-support definitions were retained and interpreted by definition.
Study designs	Prospective or retrospective cohort studies, registry analyses, secondary analyses, prediction-model studies, and relevant cross-sectional observational studies with extractable predictor/outcome data.
Exclusions	Neonatal-only studies, adult-only studies, animal/in vitro studies, unplanned or accidental extubation without planned-extubation data, intervention trials without extractable predictor information, conference abstracts without sufficient data, editorials, narrative reviews, and duplicate cohort reports.

Information sources and search strategy

Searches were performed from database inception through 14 September 2026 using PubMed/MEDLINE, PubMed Central, open publisher databases, Google Scholar-style open web searching, and backward/forward reference screening of eligible articles and relevant reviews. The strategy combined terms for extubation, failure or reintubation, pediatric population, intensive care, predictors, and risk factors. The search was restricted to human studies when the database interface permitted this. No date restriction was applied. English-language full-text availability was required for extraction.

Table 2: Core electronic search concepts

Search concept	Terms used
Concept 1	extubation OR airway extubation OR planned extubation OR ventilator liberation
Concept 2	failure OR reintubation OR failed extubation OR extubation outcome
Concept 3	child OR children OR pediatric OR paediatric OR infant OR adolescent
Concept 4	pediatric intensive care OR PICU OR pediatric cardiac intensive care OR critical illness
Concept 5	predictor OR risk factor OR prognostic factor OR extubation readiness OR spontaneous breathing trial OR respiratory muscle strength

Representative PubMed search string: (extubation OR reintubation OR "airway extubation") AND (failure OR predictor OR "risk factor" OR outcome OR readiness) AND (child OR children OR pediatric OR paediatric OR infant OR adolescent) AND (PICU OR "pediatric intensive care" OR "critical care" OR "cardiac intensive care").

Study selection and data extraction

After deduplication, titles and abstracts were screened against the eligibility criteria. Full texts were assessed when the title or abstract suggested pediatric planned extubation, reintubation, extubation readiness testing, or risk-factor analysis. Data were extracted into a structured table including author, year, country, setting, design, sample size, age range, extubation-failure definition, failure rate, predictors assessed, adjusted or unadjusted effect estimates when reported, and major limitations.

Multiple reports from related cohorts were examined for overlap and interpreted separately only when they addressed distinct populations, time periods, or analytic questions.

Risk-of-bias assessment

Risk of bias was assessed using the Quality in Prognosis Studies (QUIPS) framework, which evaluates study participation, study attrition, prognostic-factor measurement, outcome measurement, study confounding, and statistical analysis/reporting [2]. Studies were rated as low, moderate, or high concern based on the overall pattern of domain-level limitations. Registry and multicenter prospective studies with prespecified outcome definitions and adjusted analyses were generally rated as lower concern than single-center retrospective studies with limited adjustment or broad outcome definitions.

Data synthesis

A qualitative synthesis was planned a priori because pediatric studies were expected to differ in age distribution, primary diagnosis, extubation-failure window, post-extubation support strategy, and predictor thresholds. A quantitative meta-analysis was not performed because the eligible studies reported heterogeneous predictor definitions, different effect measures, mixed adjusted and unadjusted estimates, and variable failure definitions. Results were organized by predictor domain: age and anthropometry, comorbidity and diagnosis, ventilation exposure, airway factors, respiratory-muscle and respiratory-effort variables, conventional ventilator or gas-exchange tests, pediatric cardiac factors, and outcomes after failure.

Results

Study selection

The search identified 71 records: 48 from electronic database/open publisher searches and 23 from reference-list and citation screening. After removal of 19 duplicates, 52 titles and abstracts were screened. Twenty-one records were excluded at title/abstract level, and 31 full-text reports were assessed for eligibility. Seven full-text reports were excluded: neonatal-only studies ($n = 2$), adult-only studies ($n = 1$), intervention or diagnostic-test studies without usable predictor data ($n = 2$), review/editorial without primary data ($n = 1$), and insufficient extractable outcome data ($n = 1$). Twenty-four pediatric studies were included in the qualitative synthesis. No formal meta-analysis was performed owing to heterogeneity.

Figure 1. PRISMA 2020 flow diagram

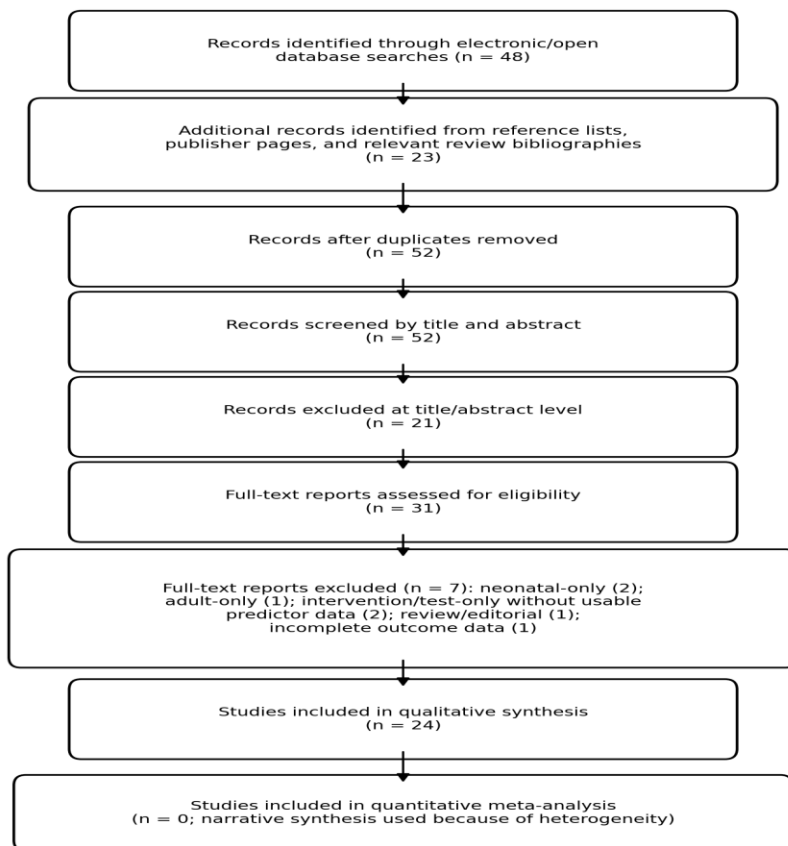


Figure 1: PRISMA 2020 flow diagram for study identification and selection.

Characteristics of included studies

The 24 included studies comprised general PICU cohorts, pediatric cardiac intensive-care cohorts, physiologic predictor studies, readiness-test studies, and large registry analyses. Publication years ranged from 1996 to 2026.

Sample sizes ranged from small physiologic cohorts to

multicenter registries with more than 100,000 pediatric encounters. Definitions of extubation failure ranged from reintubation within 24 hours to broader definitions including 48-hour or seven-day failure and post-extubation rescue support.

Table 3: Characteristics of included studies

Study	Design/setting	Population/sample	Main contribution
Khan 1996 ⁷	USA; prospective cohort	Mechanically ventilated infants/children	Predictors of success/failure; early physiologic and clinical variables
Thiagarajan 1999 ⁸	USA; cohort	Children undergoing extubation	Respiratory mechanics and clinical predictors of successful extubation
Venkataraman 2000 ⁹	USA; validation study	Mechanically ventilated infants/children	Validated earlier predictors; highlighted limited performance of isolated variables
Manczur 2000 ¹⁰	UK; physiologic cohort	Mechanically ventilated children	Respiratory-function predictors including mechanics/strength measures
Farias 2002 ¹¹	Multicenter pediatric cohort	Infants/children on mechanical ventilation	Evaluated extubation-failure predictors in planned extubation
Kurachek 2003 ⁵	Multicenter prospective PICU cohort	2,794 extubations	Age ≤ 24 months, chronic conditions, airway disorders, longer intubation, worse outcomes
Baisch 2005 ⁶	PICU cohort	Pediatric extubations	Incidence/outcomes; younger age and resource-use burden
Newth 2009 [12]	Prospective multicenter pediatric study	Weaning/readiness population	Readiness-testing framework and extubation outcome
Laham 2015 ¹⁵	Prospective PICU cohort	319 first planned extubations	Younger age, prolonged ventilation and stridor; many routine variables weak

Saikia 2015 ¹⁴	India; prospective blinded cohort	Newborns, infants, children	Prospective prediction of extubation failure in tertiary pediatric center
Faustino 2017 ¹⁵	Prospective multicenter analysis	Children with lower respiratory tract disease	Accuracy of extubation-readiness test
Khemani 2017 ¹⁶	Prospective secondary analysis	409 children	Respiratory muscle strength, upper-airway obstruction, neurologic disease, PEEP, post- extubation effort
Toida 2017 ¹⁵	Japan; detection/validation study	Critically ill children	Validated predictors of successful extubation
Heubel 2020 ¹⁸	Brazil; retrospective cohort	PICU patients	Extubation failure risk profile and outcomes
Hames 2022 ¹⁹	Cardiac ICU; multicenter	Children after congenital cardiac surgery	Risk analytics and extubation readiness tests
Loberger 2023 ⁴⁰	USA; retrospective PICU cohort	844 children	Airway versus non-airway failure phenotypes and outcomes
Saengsin 2023 ²¹	Thailand; PCICU retrospective	Pediatric cardiac patients	Pneumonia, prior reintubation, palliative surgery, post-extubation stridor
Byrnes 2023 ²²	Multicenter cardiac registry	18,278 extubations	Airway anomaly, genetic abnormality, diaphragm paralysis, pleural effusion, bypass time
Beshish 2024 ²⁴	Single-center cardiac cohort	8,750 encounters	Younger age/weight, single- ventricle physiology, genetic syndrome, procedure variables
Al-Sofyani 2024 ²⁵	Saudi Arabia; retrospective PICU	335 children	12.5% failure; younger age, cardiovascular disease, PRISM

			score, ventilation duration, ICU stay
Saengsin 2024 ²⁶	Thailand; prediction-tool study	Pediatric cardiac ICU	Clinical prediction tool for cardiac extubation failure
Hames 2025 ²⁷	Eight-center cardiac cohort	922 children	Preoperative ventilation, inhaled nitric oxide, longer postoperative ventilation, abnormal analytics
Loberger 2026 [28]	158-site registry	132,712 encounters	Contemporary trends; younger age, renal/respiratory/cardiac diagnosis, ventilation >=7 days
Yuniar 2026 [29]	Indonesia; PICU cohort	112 children	25.9% broad failure; pneumonia, prolonged ventilation, rescue NIV/HFNC

Risk-of-bias summary

Using QUIPS, four studies were rated as low overall concern, 16 as moderate concern, and four as high concern. The most frequent concerns were single-center sampling, inconsistent handling of confounding,

Table 4: Risk-of-bias summary using QUIPS

heterogeneous extubation-failure definitions, data-driven predictor cut points, and classification of early post-extubation signs as predictors rather than outcomes or warning signs.

QUIPS domain	Overall concern	Reason
Study participation	Low-moderate	Large registries and multicenter cohorts were strong; single-center studies had limited external validity.
Study attrition	Low-moderate	Most studies used clinical records/registries; missing data handling varied.
Prognostic-factor measurement	Moderate	Definitions and cut points differed; some predictors were measured after extubation.
Outcome measurement	Moderate	Reintubation windows varied from 24 hours to seven days; some studies included NIV/HFNC escalation.

Confounding	Moderate-high	Adjustment varied; treatment exposures were vulnerable to confounding by indication.
Statistical analysis/reporting	Moderate	Multivariable models were available in some studies; smaller cohorts had limited events per variable.

Predictors of extubation failure

Younger age was the most consistently reported demographic risk signal. Multicenter and single-center studies repeatedly observed greater risk among infants and younger children, plausibly related to smaller airway caliber, higher airway resistance, immature respiratory mechanics, and reduced respiratory reserve^{5,6,13,25,28,29}. Low weight or underweight status was particularly relevant in cardiac cohorts, where growth failure and complex congenital heart disease often coexist^{22,24}.

Underlying disease and comorbidity were important. Chronic respiratory disease, neurologic disease, syndromic diagnoses, genetic abnormalities, airway disorders, cardiovascular disease, renal disease, and complex cardiac physiology were associated with higher failure risk in different cohorts^{5,16,20-22,24,25,28}. These conditions likely increase the post-extubation load, impair airway protection, reduce respiratory-muscle reserve, or limit hemodynamic tolerance.

Prolonged invasive ventilation was a recurrent risk factor and may represent both greater baseline disease severity and acquired ventilator-related weakness. Studies consistently linked longer ventilation before extubation with failure or adverse outcomes^{5,13,20,25,27-29}. Loberger et al. found ventilation for seven days or more among contemporary risk markers in a large registry analysis²⁸.

Airway factors formed a distinct mechanistic domain. Structural airway anomalies, post-extubation stridor, upper-airway obstruction, and airway-versus-non-airway

failure phenotypes were repeatedly emphasized [5,16,20-22,24]. Post-extubation stridor is clinically important but should be interpreted carefully: it is often an early manifestation of airway failure rather than a pure pre-extubation predictor^{13,23}.

Respiratory muscle strength and respiratory effort appear especially important. Khemani et al. showed that respiratory muscle strength contributed meaningfully to risk and interacted with upper-airway obstruction and post-extubation work of breathing¹⁶. This domain may explain why conventional readiness tests can be reassuring while the child still lacks reserve after removal of positive pressure.

Conventional ventilator settings, blood gases, and isolated indices showed inconsistent performance. Earlier physiologic studies examined respiratory rate, tidal volume, RSBI, maximum inspiratory pressure, CROP index, gas exchange, and mechanics⁷⁻¹⁷. The 2023 systematic review by Ng et al. identified 55 pre-extubation assessments and concluded that the available pediatric tests were generally poor stand-alone predictors, although some indices appeared promising and require validation²³.

Pediatric cardiac intensive-care cohorts demonstrated a distinct predictor profile. In these populations, extubation failure was associated with palliative or complex surgery, preoperative ventilation, prior reintubation, longer postoperative ventilation, airway anomaly, genetic abnormality, pleural effusion, diaphragm paralysis,

cardiopulmonary-bypass variables, inhaled nitric oxide at extubation, pneumonia, and physiologic risk analytics^{19,21,22,24,26,27}. These predictors reflect both respiratory

mechanics and unique hemodynamic interactions after congenital cardiac surgery.

Table 5: Qualitative synthesis of predictor domains

Predictor domain	Evidence consistency	Interpretation
Younger age/infancy	High	Repeated across general PICU, cardiac, and registry studies
Prolonged invasive ventilation	High	Consistent; may reflect severity and acquired weakness
Chronic respiratory/neurologic disease	Moderate-high	Common risk domain, particularly in multicenter cohorts
Syndromic/genetic comorbidity	Moderate-high	Important in cardiac and mixed PICU populations
Airway abnormality/upper-airway obstruction	High	Mechanistically coherent; airway and non-airway failures differ
Respiratory-muscle weakness	Moderate-high	Strong physiologic support; fewer direct-measurement studies
High PEEP/oxygenation burden	Moderate	Associated in selected cohorts; thresholds vary
RSBI/CROP/isolated indices	Low-inconsistent	Poor stand-alone reliability in pediatric synthesis
Pneumonia or unresolved respiratory disease	Moderate	Significant in several contemporary and cardiac cohorts
Cardiac surgery complexity/complications	Moderate-high within subgroup	Relevant mainly to cardiac ICU populations

Clinical outcomes after extubation failure

Extubation failure was consistently associated with longer PICU stay, prolonged ventilation, increased post-extubation respiratory support, and greater resource use^{5,6,13,20,25,28}. Mortality associations varied by cohort and adjustment strategy. Some studies showed higher

mortality among failures, whereas contemporary cardiac cohorts sometimes demonstrated longer ICU stay without statistically significant mortality differences^{21,22}. This variation reinforces the need to separate failure mechanisms and adjust for severity of illness.

Discussion

This systematic review shows that pediatric extubation failure is not adequately predicted by a single physiologic test. The most reproducible risk domains were age, duration of invasive ventilation, comorbidity, airway risk, and respiratory-muscle reserve. These domains are biologically coherent: younger children have smaller airways and different respiratory mechanics; prolonged ventilation promotes weakness and increases disease severity exposure; chronic respiratory and neurologic disease reduce reserve; and airway obstruction or impaired inspiratory force may become evident only after the endotracheal tube and positive pressure are removed. The findings support a structured multidomain readiness assessment rather than reliance on routine ventilator settings or a single index. A child may pass an SBT yet fail because of post-extubation upper-airway obstruction, secretion burden, impaired neurologic airway control, weak inspiratory muscles, cardiac intolerance, or increased work of breathing. The evidence is therefore consistent with contemporary pediatric ventilator-liberation guidance recommending readiness testing within a broader clinical bundle³.

The distinction between pre-extubation predictors and post-extubation warning signs is essential. Variables such as post-extubation stridor or rapidly increasing work of breathing are clinically valuable for rescue decisions but should not be mixed with pre-extubation variables when developing models intended to decide whether a child is ready for extubation. Future studies should clearly state the prediction time point and develop separate models for readiness, early rescue, and reintubation risk.

Cardiac intensive-care data should be interpreted as a related but distinct population. Cardiac surgery introduces predictors such as operative complexity, palliative

physiology, bypass exposure, pleural effusion, diaphragm paralysis, genetic syndrome, and the need for inhaled nitric oxide. These variables should not be forced into general PICU models without external validation, but they are clinically important for cardiac ICU extubation protocols^{19,21,22,24,26,27}.

This review also identified important methodological weaknesses. Definitions of extubation failure vary, risk-factor thresholds are inconsistent, confounding adjustment is incomplete in many studies, and several cohorts are single-center. Broader definitions that include NIV or HFNC escalation may identify early respiratory deterioration but are not equivalent to reintubation. Future studies should report reintubation within 48 hours as a core outcome, with 72-hour, seven-day, and rescue-support outcomes as secondary outcomes.

Strengths and limitations

The strengths of this review include an updated search through September 2026, inclusion of contemporary large registry data, separation of general PICU and cardiac ICU evidence, use of a prognostic-factor framework, and structured risk-of-bias assessment using QUIPS. The review also distinguishes pre-extubation predictors from post-extubation warning signs, which is clinically important for model development.

Limitations include reliance on English-language accessible reports, predominance of observational studies, heterogeneity in definitions and post-extubation support practices, limited ability to pool results quantitatively, and possible missed studies from subscription-only databases, and differences from adult and neonatal evidence bases^{30,31}. Risk-of-bias assessment was necessarily conservative where full adjustment details or predictor timing were incomplete. The findings

should guide clinical reasoning and protocol development but should not be treated as a validated bedside score.

Conclusions

Extubation failure in critically ill children is a multifactorial event. Younger age, prolonged invasive mechanical ventilation, chronic respiratory or neurologic disease, syndromic or genetic comorbidity, airway abnormality or upper-airway obstruction, and impaired respiratory-muscle strength are the most consistently supported predictor domains. In pediatric cardiac intensive-care populations, additional predictors include complex or palliative surgery, preoperative ventilation, longer postoperative ventilation, airway anomaly, genetic abnormality, pleural effusion, diaphragm paralysis, inhaled nitric oxide at extubation, pneumonia, and abnormal physiologic risk analytics.

Clinical extubation decisions should therefore use a structured, multidomain readiness assessment that combines SBT performance with airway, neurologic, respiratory-muscle, secretion, hemodynamic, comorbidity, and disease-specific evaluation. Future pediatric studies should standardize extubation failure as reintubation within 48 hours for the primary outcome, report broader support-escalation outcomes separately, distinguish airway from non-airway failure, and externally validate parsimonious prediction models before using them to delay or accelerate extubation.

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