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A Multivariable Model Predictive of Unplanned Postoperative Intubation in Infant Surgical Patients

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Abstract

BACKGROUND: Unplanned postoperative intubation is an important quality indicator, and is associated with significantly increased mortality in children. Infant patients are more likely than older pediatric patients to experience unplanned postoperative intubation, yet the literature provides few characterizations of this outcome in our youngest patients. The objective of this study was to identify risk factors for unplanned postoperative intubation and to develop a scoring system to predict this complication in infants undergoing major surgical procedures.

METHODS: In this retrospective cohort study, The National Surgical Quality Improvement Program-Pediatric database was surveyed for all infants who underwent noncardiac surgery between January 1, 2012 and December 31, 2015 (derivation cohort, n = 56,962) and between January 1 and December 31, 2016 (validation cohort, n = 20,559). Demographic and peri-operative clinical characteristics were examined in association with our primary outcome of unplanned postoperative intubation within 30 days of surgery. Risk factors were analyzed in the derivation cohort (2012–2015 data) using multivariable logistic regression with stepwise selection. Parameters from the final model were used to create a scoring system for predicting unplanned

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DISCLOSURES

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postoperative intubation. Data from the validation cohort were utilized to assess the performance of the scoring system using the area under the receiver operating characteristic curve.

RESULTS: In the derivation cohort, 2.2% of the infants experienced unplanned postoperative intubation within 30 days of surgery. Of the 14 risk factors identified in multivariable analysis, 10 (age, prematurity, American Society of Anesthesiologists physical status, inpatient status, operative time >120 minutes, cardiac disease, malignancy, hematologic disorder, oxygen supplementation, and nutritional support) were included in the final multivariable logistic regression model to create the risk score. The area under the receiver operating characteristic curve of the final model was 0.86 (95% CI, 0.85–0.87) for the derivation cohort and 0.83 (95% CI, 0.82–0.85) for the validation cohort.

CONCLUSIONS: About 1 in 50 infants undergoing major surgical procedures experiences unplanned postoperative intubation. Our scoring system based on routinely collected perioperative assessment data can predict risk in infants with good accuracy. Further investigation should assess the clinical utility of the scoring system for risk stratification and improvement in perioperative care quality and patient outcomes. (Anesth Analg XXX;XXX:00–00)

The incidence of unplanned postoperative intubation in children is estimated at 0.1%–0.34%, with a recent study utilizing the American College of Surgeons National Surgical Quality Improvement Project-Pediatric database revealing a much higher likelihood in infants and neonates.^{1–5} Though many perioperative and anesthesia-related complications are known to occur more frequently in children <1 year, the independent predictors, as well as outcomes related to unplanned postoperative intubation, have yet to be described for our youngest patients.^{2,5–7}

Unplanned postoperative intubation is an indicator of postoperative respiratory failure, and is therefore a serious, life-threatening complication. Postoperative respiratory failure is strongly correlated with 30-day all-cause mortality and long-term survival in studies of children and adults, and unplanned postoperative intubation in particular was associated with an 11-fold increased risk of mortality in children.^{1,8,9} In addition to the health implications, there are financial burdens for patients and the health system as a whole including increased length of stay, with each case totaling roughly \$50,000 in additional hospital expenses.^{10,11} As a result, postoperative respiratory failure is identified as one of the pediatric quality indicators by the Agency for Healthcare Research and Quality.¹² Pediatric quality indicators screen for problems that may be prevented by changes at the system or provider level and are intended for use in Centers for Medicare and Medicaid Services pay-for-performance programs.

Identifying those at risk of specific complications is especially challenging in pediatrics, given the differential epidemiology of child health care across various stages of development. While scoring systems have been created for the anticipation of postoperative respiratory complications in adults, they are unlikely to be useful when applied to children.^{13,14} Knowledge of the predictors of unplanned postoperative intubation may help guide surgeons, anesthesiologists, and intensivists to identify those at the greatest risk and to plan for management of these patients in the operating room, postoperative care units, and intensive care units.

To that end, this study aims to determine the incidence, timing, predictors, and associated mortality of 30-day unplanned postoperative intubation in children <1 year of age using the National Surgical Quality Improvement Program-Pediatric database, and to create a simplified scoring system to identify those at greatest risk.

METHODS

Overview

The Columbia University Institutional Review Board has deemed this study as exempt from review, with waiver of signed patient consent (Institutional Review Board: 2018 AAAE5203). Methods and reporting of the study adhered to a 22-point checklist in accordance with the Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis statement issued in 2015.¹⁵

Data Source

Data were obtained from the American College of Surgeons' National Surgical Quality Improvement Program-Pediatric, which collects multicenter clinical information on systematically sampled pediatric surgical patients from more than 100 academic and community US hospitals. The participant use file released annually to researchers since 2012 contains deidentified data on children undergoing major noncardiac surgery and includes roughly 120 strictly-coded variables such as preoperative risk factors, intraoperative events, 30-day postoperative outcomes, and in-hospital mortality in both the inpatient and outpatient settings. A participating hospital's clinical nurse reviewer captures data using medical chart abstraction, among other methods. Patients >18 years of age, trauma cases, solid organ transplantation, and cardiac surgery, as well as institutions with an interrater reliability audit disagreement rate of >5% or a 30-day follow-up rate <80% are excluded from the database. For this study, we included children in the 2012–2016 National Surgical Quality Improvement Program-Pediatric databases.¹⁶

The outcome of unplanned postoperative intubation was defined by the National Surgical Quality Improvement Program-Pediatric database variable REINTUB. This outcome was evaluated for 30 days after the surgical procedure of interest. REINTUB identifies cases of “unplanned intubation/reintubation with ventilatory support” and is assigned whenever a patient required “the placement of an endotracheal tube or other similar breathing tube (laryngeal mask, nasotracheal tube, orotracheal tube) and ventilatory support which was not intended or planned.” Detailed instructions in the American College of Surgeons National Surgical Quality Improvement Project-Pediatric Operations Manual further address several complex scenarios, so that the clinical reviewer may correctly assign the REINTUB variable.¹⁷

For instance, REINTUB can only be assigned after the patient has been extubated after their initial procedure, even if that extubation was delayed beyond the patient's departure from the operating room. Therefore, it is not meant to capture cases where a patient unexpectedly remained intubated after a procedure. In the event a patient was not intubated during surgery, any postoperative intubation would be included. If a patient was reintubated for a return to

the operating room, this would not be included, though reintubation after accidental extubation would be included.

Furthermore, patients who received ventilatory support and/or had a tracheostomy in place before a procedure could be assigned REINTUB if the clinical reviewer noted a return to unsupported breathing followed by an abrupt escalation in ventilatory support postoperatively. Preoperative mechanical ventilation is defined in the database as ventilatory support at any point during the 48 h before a procedure, including noninvasive ventilation such as continuous positive airway pressure commonly used in neonates. As such, patients with preoperative mechanical ventilation and/or tracheostomy are still at risk for developing the primary outcome and were not excluded from the analyses. See Supplemental Digital Content, Appendix, <http://links.lww.com/AA/C721>, for further clarification of these complex scenarios.¹⁷

Variables

Potential predictive variables were broadly selected on the basis of their inclusion in previously published studies of postoperative respiratory complications with attention to those relevant in infancy.^{1,3,8,9,14} The following demographic and preoperative diagnoses/characteristics were considered in relation to our outcome of interest (unplanned postoperative intubation): age at surgery (defined as <28 days, 28 days to 6 months, 6 months to 1 year), sex, race (Caucasian versus non-Caucasian/missing), operative time, American Society of Anesthesiologists (ASA) physical status classification, prematurity, urgency, transfer status, presence of sepsis or systemic inflammatory response syndrome, admission status, cardiac risk factors, nutritional support, oxygen support, mechanical ventilation, inotropic support, preoperative administration of steroids, preoperative cardiopulmonary resuscitation, chronic lung disease, structural pulmonary abnormality, congenital malformation, past or present diagnosis of malignancy, developmental delay, acquired abnormality of the central nervous system, neuromuscular disease, intraventricular hemorrhage, and a diagnosis of hematologic disorder. See Supplemental Digital Content, Appendix, <http://links.lww.com/AA/C721>, for a detailed description of variables included.

Statistical Analysis

The incidence of unplanned postoperative intubation was calculated for those <1 year of age from the combined 2012–2015 participant use files, and separately for those <1 year of age from the 2016 participant use file. For the remainder of this manuscript, we will refer to derivation (infants <1 year of age from the 2012–2015 data) and validation (infants <1 year of age from the 2016 data) cohorts.

Individual χ^2 tests were performed on patient data from the derivation cohort, examining the association between variables of interest described previously, and the outcome of unplanned postoperative intubation. Those patient characteristics and perioperative factors significantly associated with unplanned postoperative intubation in the univariable analysis were then used to fit a multivariable logistic regression model in the same cohort (2012–2015 infants) using a stepwise procedure with entry and removal significance level of $P = .1$.

Missing data were present in a small fraction of our sample for ASA physical status classification, preterm birth status, and operative time. A larger fraction of patients was missing race information (7832 cases). Given concerns about introducing bias by excluding those missing a race classification, as well as the lack of a clear mechanism (random, systematic, or patient-based) put forth by National Surgical Quality Improvement Program to aid in imputing values, we chose not to perform imputation and to designate race as either Caucasian or non-Caucasian/unknown. Otherwise, cases with missing data in the variables of interest were excluded from the model, and our analysis was performed using 55,422 complete cases (Figure 1).

The model selected from this stepwise procedure was then further simplified to a final parsimonious model including as few variables as possible while maximizing discriminative ability. The DeLong et al¹⁸ method with Bonferroni correction was performed to make pairwise comparisons of sequentially reduced models while accounting for correlations between nested data. We sequentially removed variables, beginning with the variable with the smallest regression coefficient (β), and comparing the area under the receiver operating characteristic curves of the models with and without this variable. We used a .01 level of significance (reduced to .0007 given 14 total comparisons) to determine when no further variables would be removed. Calibration of the final parsimonious model was assessed for both cohorts by comparing the predicted probability of unplanned postoperative intubation by decile with the observed frequencies.

A risk score, intended to be simpler in clinical practice, was then created using the parameters from our multivariable model. The regression coefficients were used to compare the magnitude of each risk predictor, with the smallest regression coefficient used as a reference value (1 point) for assigning points in a risk score. Each factor was then assigned points based on how many multiples of the reference value were contained within its regression coefficient and rounded to the nearest integer.¹⁹ Discrimination of our score was assessed using logistic regression of unplanned postoperative intubation as predicted by the score, once again examining the area under the receiver operating characteristic curve. Calibration was assessed for both cohorts by comparing the observed frequency of unplanned postoperative intubation at each score.

The secondary outcome of mortality was first examined using univariable logistic regression. An adjusted analysis was then performed using multivariable logistic regressions of unplanned postoperative intubation, plus the risk factors identified in our parsimonious model, on the outcome of mortality.

All analyses were performed using SAS version 9.4 (SAS, Cary, NC).

RESULTS

Descriptive Analyses

Infants in the derivation cohort experienced a rate of unplanned postoperative intubation of 2.2% (1261 of 56,962 infants total). Approximately one-third of unplanned intubations in infants occurred early in the postoperative course (within the first 3 days), and two-thirds

occurred within the first 7 days after surgery (Supplemental Digital Content, Figure 1, <http://links.lww.com/AA/C721>).

Development and Validation of the Unplanned Postoperative Intubation Risk Score

Table 1 displays the results of univariable analyses for all potential predictors of unplanned postoperative intubation comparing patients with and without unplanned postoperative intubation in the derivation cohort. All variables significantly associated with the occurrence of unplanned postoperative intubation at an α level of .05 were considered in creation of a logistic regression model of this outcome, a total of 27 predictor variables, by stepwise selection. Of these, 14 were retained in the final multivariable regression model: age, non-Caucasian/unknown race, operative time >120 minutes, ASA physical status classification, premature birth, admission status, urgency of surgery, cardiac risk factors, oxygen supplementation, mechanical ventilation, acquired central nervous system abnormality, nutritional support, history of hematologic disorder, and current or prior malignancy.

A final parsimonious model was created by the manual backward selection process described previously, with a stopping rule of $P < .0007$ (Supplemental Digital Content, Table 1, <http://links.lww.com/AA/C721>). Table 2 displays the 10 selected variables, adjusted odds ratio with 95% CIs, and P value for each predictor. The area under the curve of the 10-variable logistic regression model in the validation cohort was 0.86 (95% CI, 0.86–0.87) compared with 0.87 (95% CI, 0.86–0.87) for the 14-variable model (P value for this difference was $>.01$ after correcting for multiple comparisons). The 10 predictors included in the final model were age, operative time >120 minutes, prematurity, ASA physical status, inpatient status, cardiac risk factors, history of past or current malignancy, history of hematologic disorder, preoperative oxygen supplementation, and preoperative nutritional support.

A validation cohort, including all infants ($n = 20,559$) <1 year of age from the 2016 data, was comparable in terms of baseline characteristics (Supplemental Digital Content, Table 2, <http://links.lww.com/AA/C721>) and overall incidence of unplanned postoperative intubation (451 in total, for a rate of 2.2%). Applying the derivation model on the validation cohort using parameter estimates yielded an area under the curve of 0.83 (95% CI, 0.82–0.85). Linear relationships between the estimated predicted probabilities and actual frequency in the data were well calibrated for both the derivation and validation cohorts (Figure 2).

Subjects in both the derivation and validation cohorts were assigned a score according to the rubric in Table 3. Ranging from 0 (lowest risk) to 23 (highest risk), the unplanned postoperative intubation score showed 86% accuracy in distinguishing patients who did and did not require unplanned intubation (area under the curve 0.86 [95% CI, 0.85–0.87] in the derivation cohort and 83% accuracy (area under the curve 0.83 [95% CI, 0.82–0.85]) in the validation cohort (Supplemental Digital Content, Figure 2, <http://links.lww.com/AA/C721>). The percentage of patients with unplanned postoperative intubation in each score category between the derivation and validation cohorts are displayed in Figure 3.

Sixty-five subjects of 1261 (5.2%) experiencing unplanned postoperative intubation died within 30 days after surgery, compared to 558 of 55,701 (1.1%) patients who died without

unplanned postoperative intubation ($P < .0001$) in the derivation cohort. Unplanned postoperative intubation was associated in unadjusted analyses with increased risk of 30-day mortality with an odds ratio of 4.8 (95% CI, 3.7–6.2). However, after adjusting for the 10 variables determined to predict unplanned postoperative intubation, there was no longer a significant association between unplanned postoperative intubation and mortality, with an adjusted OR of 0.98 (95% CI, 0.7–1.3).

DISCUSSION

We observed the incidence of unplanned postoperative intubation to be 2.2% in infants, more than 10 times that reported recently in a study of children of all ages.¹ Though the literature already points to a higher incidence of perioperative respiratory complications in younger children, the extent to which infants are at greater risk of this particular adverse event has not previously been shown.^{2,5–7} This supports the need for perioperative risk assessment tools to guide patient selection and clinical care for infants undergoing surgery.

To our knowledge, this is the first study to attempt to predict the risk of unplanned postoperative intubation in infants undergoing all manner of major, noncardiac surgical procedures. A previously published report describing this outcome in children of all ages identified age <1 year as a risk factor for unplanned postoperative intubation, but did not address the differential risk profiles between infant and older pediatric surgical patients.¹ Many of the existing risk calculators used to predict respiratory complications in children have been developed for specific surgical procedure classes such as cardiac surgery, and have only moderate predictive abilities. None were developed for infants. For example, the surgical risk calculator created based on the National Surgical Quality Improvement Program-Pediatric may be used to predict postoperative complications such as unplanned postoperative intubation and mortality in children of all ages undergoing major surgical procedures.²⁰ However, the calculator was not tailored specifically to predict unplanned postoperative intubation and fared poorest in model validation for this particular outcome with a reduction in area under the curve from 0.95 to 0.65 in derivation and validation cohorts, respectively. In addition, the National Surgical Quality Improvement Program calculator was not designed for high-risk subgroups and therefore tends to under-predict risk for those most likely to experience any given complication, such as infants at risk for unplanned postoperative intubation.²⁰

Our analysis identified several novel independent risk factors for unplanned postoperative intubation: non-Caucasian or unknown race classification, prematurity, inpatient status, preoperative oxygen supplementation, nutritional support, and hematologic disease, which may form the basis for further study as well as quality improvement interventions. Our parsimonious 10-predictor multivariable model displayed excellent discriminant validity and linear calibration in predicting unplanned postoperative intubation, with no change in performance in a validation cohort. In addition, a summative score considering the 10 strongest predictors of unplanned postoperative intubation performed close to as well as the model as a whole, with a risk score >13 predictive of >5% to as much as a 16% chance of unplanned postoperative intubation.

Though many of the predictors identified in our model are nonmodifiable, a number of them lend themselves to study as potential areas for improvement in the care of this population. For instance, the postponement of surgery when possible until a child is >6 months, or until nutritional and oxygen support are weaned, could be beneficial in preventing unplanned postoperative intubation. The effect of shortening the procedure duration could be studied in association with unplanned postoperative intubation. Finally, modifications to the postoperative course including intensive care unit stays, greater vigilance for respiratory decompensation, adjustment of ventilator weaning criteria, and planned postoperative intubation could be implemented with the goal of preventing or better preparing for unplanned postoperative intubation. No such studies in infants have been performed, perhaps because risk factors have not previously been published. Finally, if not of direct benefit to patients, the utility of the score may be to allow hospitals to plan for the likely increased cost and care needs of these high-risk patients. However, at this time, we are unable to assess the utility of this risk score or to make specific recommendations for its application as further studies are needed to demonstrate whether patients at the highest risk of unplanned postoperative intubation benefit from any particular modification to their care.

This study should be interpreted with consideration of several limitations. Most importantly, National Surgical Quality Improvement Program-Pediatric does not attempt to identify the indication for unplanned intubation in children. Not all postoperative intubations are performed for primary respiratory failure (eg, cardiac arrest, airway protection in the case of a neurologic insult, sepsis). Although National Surgical Quality Improvement Program-Pediatric does provide timing information to potentially connect intubation events to other complications (respiratory or nonrespiratory), the precision is only to the postoperative day and therefore it is impossible to determine for certain whether an intubation preceded or followed another complication. The unplanned postoperative intubation risk score, therefore, is not a direct predictor of the likelihood of postoperative respiratory failure.

Second, there is a dearth of available data collected by the National Surgical Quality Improvement Program-Pediatric describing intraoperative management, of which anesthetic technique, fluid management, and any critical events may strongly impact patient outcomes.

Third, the creation of a comprehensive model predicting mortality was beyond the scope of this investigation, and therefore in the analysis of this secondary outcome, we performed adjustment only for the variables in our unplanned postoperative intubation–predictive model. This analysis could not draw from any published model for infant postoperative mortality, as one does not yet exist. Nasr et al²¹ created a model predicting mortality after surgery in children of all ages, indicating as many as 13 predictors may impact on this outcome. Although unplanned postoperative intubation did not emerge as an independent predictor of mortality in our analysis, it is nonetheless an important marker for risk of mortality and an intermediate event before mortality. Identifying patients at high risk for unplanned postoperative intubation is still of critical importance as this may allow for earlier intervention on the underlying causes.

Finally, generalizability is limited by the fact that National Surgical Quality Improvement Program-Pediatric participating hospitals are a special subset of hospitals invested in an

expensive process to maintain this database, and may not represent hospitals across the country. The procedures included in the database represent major surgery only, and therefore our model and risk score may not be applicable in minor surgical procedures.

In conclusion, unplanned postoperative intubation occurs with much greater frequency in infants compared with older children after major, noncardiac surgical procedures, and is associated with 4.8 times the unadjusted odds of 30-day mortality. Our model identified several independent risk factors for this outcome and allowed for the creation and validation of a risk score. Further investigation is needed to assess the utility of perioperative stratification according to the unplanned postoperative intubation risk score to improve management of our infant patients.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

1. Cheon EC, Palac HL, Paik KH, et al. Unplanned, postoperative intubation in pediatric surgical patients: development and validation of a multivariable prediction model. *Anesthesiology*. 2016;125:914–928. [PubMed: 27617685]
2. Hintong T, Klanarong S, Suksompong S, Chua-in W, Chatmongkolchat S, Werawatganon T. The Thai Anesthesia Incident Monitoring Study (Thai AIMS) of oxygen desaturation in the post-anesthetic care unit. *J Med Assoc Thai*. 2008;91:1531–1538. [PubMed: 18972896]
3. Ing C, Chui I, Ohkawa S, Kakavouli A, Sun L. Incidence and causes of perioperative endotracheal reintubation in children: a review of 28,208 anesthetics. *Paediatr Anaesth*. 2013;23:621–626. [PubMed: 22817271]
4. Lee PJ, MacLennan A, Naughton NN, O'Reilly M. An analysis of reintubations from a quality assurance database of 152,000 cases. *J Clin Anesth*. 2003;15:575–581. [PubMed: 14724078]
5. Murat I, Constant I, Maud'huy H. Perioperative anaesthetic morbidity in children: a database of 24,165 anaesthetics over a 30-month period. *Paediatr Anaesth*. 2004;14:158–166. [PubMed: 14962332]
6. Kawashima Y, Takahashi S, Suzuki M, et al. Anesthesia-related mortality and morbidity over a 5-year period in 2,363,038 patients in Japan. *Acta Anaesthesiol Scand*. 2003;47:809–817. [PubMed: 12859300]
7. Tay CL, Tan GM, Ng SB. Critical incidents in paediatric anaesthesia: an audit of 10 000 anaesthetics in Singapore. *Paediatr Anaesth*. 2001;11:711–718. [PubMed: 11696149]

8. Ramachandran SK, Nafiu OO, Ghaferi A, Tremper KK, Shanks A, Kheterpal S. Independent predictors and outcomes of unanticipated early postoperative tracheal intubation after non-emergent, noncardiac surgery. *Anesthesiology*. 2011;115:44–53. [PubMed: 21552116]
9. Johnson RG, Arozullah AM, Neumayer L, Henderson WG, Hosokawa P, Khuri SF. Multivariable predictors of postoperative respiratory failure after general and vascular surgery: results from the patient safety in surgery study. *J Am Coll Surg*. 2007;204:1188–1198. [PubMed: 17544077]
10. Dimick JB, Chen SL, Taheri PA, Henderson WG, Khuri SF, Campbell DA Jr. Hospital costs associated with surgical complications: a report from the private-sector National Surgical Quality Improvement Program. *J Am Coll Surg*. 2004;199:531–537. [PubMed: 15454134]
11. Khuri SF, Henderson WG, DePalma RG, Mosca C, Healey NA, Kumbhani DJ; Participants in the VA National Surgical Quality Improvement Program. Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. *Ann Surg*. 2005;242:326–341. [PubMed: 16135919]
12. Agency for Healthcare Research and Quality. Pediatric Quality Indicators Overview. 2018 Available at: qualityindicators.ahrq.gov Accessed January 1, 2018.
13. Gupta H, Gupta PK, Fang X, et al. Development and validation of a risk calculator predicting postoperative respiratory failure. *Chest*. 2011;140:1207–1215. [PubMed: 21757571]
14. Hua M, Brady JE, Li G. A scoring system to predict unplanned intubation in patients having undergone major surgical procedures. *Anesth Analg*. 2012;115:88–94. [PubMed: 22543066]
15. Collins GS, Reitsma JB, Altman DG, Moons KG. Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD): the TRIPOD statement. *Ann Intern Med*. 2015;162:55–63. [PubMed: 25560714]
16. American College of Surgeons National Surgical Quality Improvement Program (Pediatric). User Guide for the 2015 ACS NSQIP Pediatric Participant Use Data File. 2018 Available at: <https://www.facs.org/quality-programs/childrens-surgery/pediatric/program-specifics/quality-support-tools/puf> Accessed March 6, 2018
17. American College of Surgeons National Surgical Quality Improvement Program (Pediatric). Chapter 4 ACS NSQIP Pediatric Variables and Definitions American College of Surgeons National Surgical Quality Improvement Project Pediatric Operations Manual. 6 4, 2018 Chicago, IL.
18. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics*. 1988;44:837–845. [PubMed: 3203132]
19. Sullivan LM, Massaro JM, D'Agostino RB Sr. Presentation of multivariate data for clinical use: the Framingham Study risk score functions. *Stat Med*. 2004;23:1631–1660. [PubMed: 15122742]
20. Kraemer K, Cohen ME, Liu Y, et al. Development and Evaluation of the American College of Surgeons NSQIP Pediatric Surgical Risk Calculator. *J Am Coll Surg*. 2016;223:685–693. [PubMed: 27666656]
21. Nasr VG, DiNardo JA, Faraoni D. Development of a Pediatric Risk Assessment Score to predict perioperative mortality in children undergoing noncardiac surgery. *Anesth Analg*. 2017;124:1514–1519. [PubMed: 27575562]

KEY POINTS

- Question: How frequently does unplanned postoperative intubation occur in children <1 year of age, and what risk factors predict this outcome?
- Findings: This retrospective analysis of more than 50,000 infants undergoing major surgery found unplanned postoperative intubation to occur 10× more commonly in infants compared with children of all ages, and that 10 risk factors accurately predict risk of unplanned postoperative intubation.
- Meaning: Unplanned postoperative intubation after pediatric surgical procedures occurs more frequently in infants compared with older children, and a score derived from our multivariable model identifies those at greatest risk.

Figure 1. Patient inclusion and exclusion criteria for multivariable analysis. ASA indicates American Society of Anesthesiologists.

Figure 2.

Linear calibration plots for parsimonious model performance. Side-by-side comparison of linear calibration plots, with predicted probabilities from the model (by decile) plotted against observed frequencies of unplanned intubation events including 95% CI.

Figure 3. Frequency (%) of UPI by risk score. UPI indicates unplanned postoperative intubation.

Table 1.

Univariable Analysis of the Derivation Cohort (2012–2015 Data)

Risk Factor, n (%)	No Complication, n = 55,701	Unplanned Intubation, n = 1261	P Value
Age at surgery			
<28 d	10,672 (94.6)	613 (5.4)	<.0001
28 d–6 mo	23,853 (97.9)	517 (2.1)	
6 mo–1 y	21,176 (99.4)	131 (0.6)	
Female sex	18,756 (97.3)	514 (2.7)	<.0001
Non-Caucasian or unknown race	17,406 (97.1)	529 (2.9)	<.0001
Operative time (min)			
<120	41,547 (98.1)	816 (1.9)	<.0001
120–299	13,093 (97.0)	412 (3.1)	
300–359	576 (97.6)	14 (2.4)	
360	485 (96.2)	19 (3.8)	
American Society of Anesthesiologists physical status			
I–II	33,982 (99.6)	121 (0.4)	<.0001
III–V	21,564 (95.0)	1125 (5.0)	
Prematurity	12,905 (95.1)	672 (5.0)	<.0001
Urgency	14,225 (96.4)	525 (3.6)	<.0001
Transfer status			
Home	34,328 (99.1)	330 (1.0)	<.0001
Emergency room	9422 (98.7)	129 (1.4)	
Chronic care	150 (97.4)	4 (2.6)	
Other	1892 (94.4)	113 (5.6)	
Outside hospital	9909 (93.5)	685 (6.5)	
Systemic inflammatory response syndrome/sepsis/septic shock	1506 (92.9)	115 (7.1)	<.0001
Inpatient	39,352 (96.9)	1247(3.1)	<.0001
Cardiac risk factors			
None	43,508 (98.9)	479 (1.1)	<.0001
Minor	6104 (95.4)	294 (4.6)	
Major	5195 (93.0)	392 (7.0)	
Severe	894 (90.3)	96 (9.7)	

Risk Factor, n (%)	No Complication, n = 55,701	Unplanned Intubation, n = 1261	P Value
Nutritional support	10,993 (92.9)	841 (7.1)	<.0001
Oxygen support	5831 (90.8)	594 (9.2)	<.0001
Mechanical ventilation	4838 (90.5)	510 (9.5)	<.0001
Chronic lung disease	4259 (93.5)	297 (6.5)	<.0001
Structural pulmonary abnormality	5489 (94.7)	305 (5.3)	<.0001
Congenital malformation	25,646 (97.4)	681 (2.6)	<.0001
Past or present malignancy	486 (96.0)	20 (4.0)	.0085
Developmental delay	4467 (97.0)	137 (3.0)	.0003
Abnormality of the central nervous system	7285 (96.3)	279 (3.7)	<.0001
Neuromuscular disease	1657 (96.5)	60 (3.5)	<.0001
Intraventricular hemorrhage	2854 (93.6)	196 (6.4)	<.0001
Hematologic disorder	3158 (91.3)	300 (8.7)	<.0001
Inotropic support	956 (89.7)	110 (10.3)	<.0001
Cardiopulmonary resuscitation	274 (90.1)	30 (9.9)	<.0001
Steroid administration	1736 (90.9)	174 (9.1)	<.0001

Table 2.

Variables Selected for Parsimonious Multivariable Model Using 2012–2015 Data

Risk Factor	Odds Ratio (Adjusted) (95% CI)	P Value
Age		
<28 d vs 6+ mo	1.68 (1.39–2.06)	<.0001
28 d–6 mo vs 6+ mo	3.23 (2.64–3.94)	
Operative time (min)		
>120 vs <120	1.60 (1.41–1.81)	<.0001
ASA physical status		
III–V vs I–II	3.04 (2.45–3.78)	<.0001
Prematurity	1.44 (1.27–1.63)	.0001
Admission status		
Inpatient versus outpatient	6.01 (3.50–10.33)	<.0001
Cardiac risk factors		
Minor versus none	1.43 (1.22–1.68)	<.0001
Major versus none	1.59 (1.36–1.85)	
Severe versus none	2.95 (2.30–3.78)	
Oxygen support	1.82 (1.60–2.01)	<.0001
Nutritional support	2.00 (1.74–2.29)	<.0001
Hematologic disorder	1.52 (1.31–1.77)	.0015
Current or prior malignancy	2.00 (1.24–3.22)	.0044

Abbreviation: ASA, American Society of Anesthesiologists.

Table 3.

Unplanned Postoperative Intubation Scoring Rubric and Associated Risk in Both Derivation and Validation Cohorts

Risk Factor	Points
Age	
6 mo age < 1 y	0
28 d age < 6 mo	1
Age < 28 d	3
ASA physical status III–V	3
Inpatient status	5
Cardiac risk factors	
Minor	1
Major	1
Severe	3
Nutritional support	2
Current or prior malignancy	2
Oxygen support	2
Premature birth	1
Hematologic disorder	1
Operative time >120 min	1

Abbreviation: ASA, American Society of Anesthesiologists.