Unplanned Extubations Requiring Reintubation in Pediatric Critical Care: An Epidemiological Study

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OBJECTIVES: Unplanned extubations are an infrequent but life-threatening adverse event in pediatric critical care. Due to the rarity of these events, previous studies have been small, limiting the generalizability of findings and the ability to detect associations. Our objectives were to describe unplanned extubations and explore predictors of unplanned extubation requiring reintubation in PICUs.

DESIGN: Retrospective observational study and multilevel regression model.

SETTING: PICUs participating in Virtual Pediatric Systems (LLC).

PATIENTS: Patients (≤ 18 yr) who had an unplanned extubation in PICU (2012–2020).

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: We developed and trained a multilevel least absolute shrinkage and selection operator (LASSO) logistic regression model in the 2012–2016 sample that accounted for between-PICU variations as a random effect to predict reintubation after unplanned extubation. The remaining sample (2017–2020) was used to externally validate the model. Predictors included age, weight, sex, primary diagnosis, admission type, and readmission status. Model calibration and discriminatory performance were evaluated using Hosmer-Lemeshow goodness-of-fit (HL-GOF) and area under the receiver operating characteristic curve (AUROC), respectively. Of the 5,703 patients included, 1,661 (29.1%) required reintubation. Variables associated with increased risk of reintubation were age (< 2 yr; odds ratio [OR], 1.5; 95% CI, 1.1–1.9) and diagnosis (respiratory; OR, 1.3; 95% CI, 1.1–1.6). Scheduled admission was associated with decreased risk of reintubation (OR, 0.7; 95% CI, 0.6–0.9). With LASSO (lambda = 0.011), remaining variables were age, weight, diagnosis, and scheduled admission. The predictors resulted in AUROC of 0.59 (95% CI, 0.57–0.61); HL-GOF showed the model was well calibrated ($p = 0.88$). The model performed similarly in external validation (AUROC, 0.58; 95% CI, 0.56–0.61).

CONCLUSIONS: Predictors associated with increased risk of reintubation included age and respiratory primary diagnosis. Including clinical factors (e.g., oxygen and ventilatory requirements at the time of unplanned extubation) in the model may increase predictive ability.

KEY WORDS: critical care; intubation; patient safety; pediatric intensive care units

Krista Wollny, RN, PhD[1–4]
Deborah McNeil, RN, PhD[1–3,5]
Stephana J. Moss, PhD[1,6]
Tolulope Sajobi, PhD[1]
Simon J. Parsons, MBBS[4]
Karen Benzies, RN, PhD[1–3,7]
Amy Metcalfe, PhD[1,3,8,9]

Unplanned extubations in pediatric critical care require emergent, critical attention from clinicians to assess and support the patient's respiration and ventilation. Reintubations after an unplanned extubation are associated with a higher risk of complications and a lower probability of success, when compared with a planned intubation in a controlled environment (1). Inserting the breathing tube multiple times increases the risk of airway injury, causing

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RESEARCH IN CONTEXT

- Requiring reintubation after unplanned extubation increases the risk of morbidity and mortality in pediatric critical care.
- Previous research in this area has been conducted using small sample sizes and single-center designs, limiting the generalizability of findings and the ability to detect associations.
- This study uses a large North American pediatric critical care database to explore the epidemiology of unplanned extubations and predictors of reintubations after unplanned extubations.

inflammation to the oropharynx or nasopharynx, larynx and trachea (2). Previous studies have explored risks for requiring reintubation after unplanned extubation in PICUs and have found that associated variables include: full ventilatory support (3, 4), sedation (3, 5), copious secretions (3, 5–8), and patient procedures (3, 5, 6). Most of these studies have used single-center designs (3–6, 8, 9), with one multicenter study taking place across 11 PICUs (7). Unplanned extubations are a fairly infrequent but life-threatening event in pediatric critical care, with recent studies reporting rates between 0.74 and 1.5 events per 100 intubation days (5, 7, 9–12). Due to the rarity of these events, the sample sizes of unplanned extubations in previous studies are small, ranging from 36 to 458 unplanned extubations total. Small sample sizes and single-center studies limit the generalizability of findings and the ability to detect associations (13, 14). The overarching aim of our study was to provide an epidemiological overview of unplanned extubations in patients admitted to PICUs in North America. Specifically, our objectives were to: describe patients who experienced an unplanned extubation requiring reintubation and explore predictors of unplanned extubation requiring reintubation.

METHODS

Study Design

This study was conducted and reported according to the Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis guidelines (15). Ethics approval was received from the Conjoint Research Ethics Board at the University of Calgary (Ethics identification: REB20-0363). The data management plan can be found in **Supplementary File 1** (http://links.lww.com/PCC/C291).

Data Source and Sample

The Virtual Pediatric Systems (VPS, LLC) database was used to obtain routinely collected, observational data on all patients (≤ 18 yr old) discharged from PICUs who experienced an unplanned extubation from January 1, 2012, to December 31, 2020 (16). Patients who experienced multiple unplanned extubations were treated as independent events. The VPS database is the largest pediatric critical care research database, prospectively collecting data from all patients admitted to 149 PICUs in North America (16). PICUs voluntarily participate in VPS and range in size from less than 100 to greater than 4,200 patient discharges per year, with the majority of the units being in the United States and Canada. The sample did not include patients admitted to neonatal or adult ICUs. No identifying data on patients or PICU units were available to the study team.

Variables

The primary outcome variable was reintubation within 24 hours after unplanned extubation, which was determined by evaluating all procedures that occurred within 24 hours of the unplanned extubation. The 24-hour time period was chosen to capture the respiratory support required immediately after the unplanned extubation and for consistency with literature on the topic (3–5). VPS defined unplanned extubation as "any displacement/removal of an endotracheal tube from the trachea when it was not deliberately removed by a provider. This includes unplanned extubation occurring within minutes of a planned extubation" (16). The patient-level variables that were obtained included age, weight, sex, race, primary diagnosis, admission type, readmission to PICU, PICU length of stay, hospital length of stay, and PICU outcome. Age of the patient at admission was categorized by VPS (0 to < 29 d, 29 d to < 2 yr, 2 to < 6 yr, 6 to < 12 yr, 12 to < 18 yr). The weight of the patient at admission was continuous (kg) and dichotomized (< 10 and ≥ 10 kg) to facilitate interpretation. Sex was dichotomized (female, male), and

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race was categorized (White, Black, Hispanic, Asian/Indian/Pacific Islander, other). The primary diagnosis was identified as the principal reason for the patient's admission to the PICU and was categorized (respiratory, cardiovascular, neurologic, oncologic, other). Admission type identified whether the PICU received notification of the patient's admission greater than or equal to 12 hours in advance (dichotomized: scheduled, unscheduled). Readmission status identified if the patient had been admitted to the PICU previously (dichotomized: yes, no). Previous admission to PICU could be at any point in the patient's life. The PICU and hospital length of stay were both continuous variables, expressed as days, and PICU outcome provided information about the patient's end-outcome in PICU (dichotomized: survived, died).

The PICU unit-level variables included unit size, standardized mortality ratios, average ventilator days, and unplanned extubation rates. The unit size provided the number of discharges in years 2019 and 2020, per PICU unit, presented as continuous numbers. The Pediatric Index of Mortality 3 (PIM-3) (17) was used to calculate the risk of mortality compared with the observed mortality for each unit, providing a standardized mortality ratio. The standardized mortality ratio is a measure that compared each unit to a reference group of similar patient populations (in terms of size and mix of patients). The values for the standardized mortality ratio were continuous; a number less than 1.0 indicated that observed mortality was lower than expected mortality, whereas a number greater than 1.0 indicated that observed mortality was higher than expected mortality. The average ventilator days provided the average number of days that intubated and ventilated patients remained on a ventilator provided for 2019–2020. The unplanned extubation rates were the average rate of unplanned extubations for each unit for years 2019–2020, calculated as the number of unplanned extubations per 100 ventilator days. See **Supplementary Tables 2** and **3** (http://links.lww.com/PCC/C291) for variable definitions.

Statistical Analyses

Sample demographics were summarized and presented as frequencies and proportions for categorical data, and means with 95% CIs for normally distributed continuous variables, or medians and interquartile ranges (IQRs) for non-normally distributed continuous variables. Multivariable logistic regression models were used to explore the association between variables known at the time of admission (age, weight, sex, primary diagnosis, admission type, and readmission status) and the outcome: unplanned extubations requiring reintubation. We chose to exclude race from the models because we did not have other social variables to adequately assess the association from an antiracist approach, as suggested by Zurca et al (18). The associations were presented as odds ratios (ORs) with 95% CI. An alpha of 0.05 was used to establish statistical significance. Statistical analyses were conducted using Stata 17 software (19).

Model Development and Validation

We explored the predictive performance of the regression model using methods described by Steyerberg (20) to assess variables predictive of unplanned extubations requiring reintubation. The model was developed in the sample of patients who were admitted from January 1, 2012, to December 31, 2016. Multilevel modeling was used to account for PICU-level clustering; PICU sites were considered random factors, and patient-level variables were the fixed characteristics within each PICU (20). To avoid overfitting, we used least absolute shrinkage and selection operator (LASSO) logistic regression. LASSO is a penalized regression approach and variable selection technique that introduces a penalty parameter (lambda [λ]), determined using cross-validation (20, 21). Coefficients are reduced as lambda increases, which decreases the variance in the model; if coefficients shrink to zero, they are eliminated from the model (20, 21).

The initial model included the variables: age (dichotomized: < 2 or ≥ 2 yr); weight (dichotomized < 10 or ≥ 10 kg); sex (dichotomized: female or male); the primary diagnosis (categorical: respiratory, cardiovascular, neurologic, oncologic, or other); if the admission known for greater than 12 hours (dichotomized: scheduled or unscheduled); and if the patient was readmitted to PICU (dichotomized: readmission or not), clustered by PICU unit. To test the model's performance through internal validation, each regression model was fit in a bootstrapped sample with an equal number of participants as the original sample. The bootstrapped sample was drawn with replacement and was replicated 500 times to generate precise CIs (20). Calibration, the

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agreement between the predicted and the observed outcomes, was assessed using the Hosmer-Lemeshow goodness-of-fit test (22). The area under the receiver operating characteristic curve (AUROC) was used to quantify the discriminative ability of each model, providing information on how well the model can predict reintubation after an unplanned extubation (22). The sensitivity, specificity, positive predicted values, and negative predicted values associated with this AUROC were derived using the optimal threshold estimated via Youden Index (23).

The remaining sample (patients admitted from January 1, 2017, to December 31, 2020) was used to test temporal external validation of the models. Calibration was assessed using the Hosmer-Lemeshow goodness-of-fit test and visually using calibration slopes (22). The AUROC was used to quantify the discriminative ability of each model (22).

RESULTS

A total of 5,703 patients who experienced an unplanned extubation in any of the 149 PICUs were included in the sample. Of these, 1,661 (29.1%) required reintubation within the first 24 hours after unplanned extubation (**Table 1**). Of the 4,042 patients who did not require reintubation, 663 (16.4%) required noninvasive ventilation within the first 24 hours, and 3,379 (83.6%) did not require any positive-pressure ventilatory support during the same period.

Patients were clustered into 149 PICU units. Of these, we were able to obtain information on 116 PICU units (**Table 2**). The mean unit size was 1,889 discharges per year in 2019 (95% CI, 1,036–1,343), ranging from 62 to 4,206 discharges per year. The standardized mortality ratio calculated from PIM-3 (17) ranged from 0 to 4.3, with an IQR of 0.8–1.2. The median number of ventilator days was 5.8 (IQR, 4.5–7.4), ranging from 1.9 to 14.3 days. The mean unplanned extubation rate for these units was 0.5 (95% CI, 0.4–0.6) events per 100 ventilation days, ranging from 0 to 3.6 events per 100 ventilation days.

As described in Table 1, approximately half of the sample (n = 2,830; 49.6%) were between the ages of 29 days to 2 years. We did not find a statistically significant difference in the odds of reintubation between the patients 0 to less than 29 days and the patients 29 days to less than 2 years; therefore, these were merged, dichotomizing age into less than 2 years and greater than or equal to 2 years. In the univariate analysis, patients who were less than 2 years old had 1.6 (95% CI, 1.4–1.8; p < 0.001) times increased odds of requiring reintubation within the first 24 hours after an unplanned extubation, compared with patients greater than or equal to 2 years old. The median weight of the sample was 9 kg (IQR, 4.3–17.2 kg); patients who were less than 10 kg had 1.5 (95% CI, 1.4–1.7; p < 0.001) times increased odds of requiring reintubation, compared with patients greater than or equal to 10 kg. Patients who were admitted with a primary diagnosis categorized as respiratory had 1.5 (95% CI, 1.3–1.7; p < 0.001) times increased odds of requiring reintubation. Patients whose admission to the PICU was scheduled had decreased odds (OR, 0.8; 95% CI, 0.6–0.9; p < 0.001) of requiring reintubation. Patients who required reintubation after unplanned extubation had a significantly longer length of stay in PICU (22.8 d [IQR, 12.1–46.5 d] vs 15.3 d [IQR: 5.9–37.9 d]; p < 0.001) and had increased odds of mortality during the current PICU admission (OR, 1.4; 95% CI, 1.1–1.8; p = 0.003).

When adjusted for confounders in the multivariable analysis (**Table 3**), the variables that remained statistically significant were age, respiratory primary diagnoses and scheduled admission to PICU. Younger patients (< 2 yr) had 1.5 (95% CI, 1.1–2.0; p = 0.006) times the adjusted OR (aOR) of requiring reintubation within the first 24 hours after an unplanned extubation. Patients who were admitted with a primary diagnosis categorized as respiratory had 1.3 (95% CI, 1.1–1.6; p = 0.003) times increased odds of requiring reintubation after adjusting for confounders. Patients whose admission to the PICU was scheduled had decreased odds (aOR, 0.7; 95% CI, 0.6–0.9; p = 0.003) of requiring reintubation. In the multivariable model, lower weight (< 10 kg) was no longer statistically significantly associated (p = 0.384).

The initial model developed in the 2012–2016 sample (n = 3,435) included the variables age, weight, sex, the primary diagnosis, whether the admission was scheduled, and whether the patient had previously been admitted to PICU, clustered by unit (**Supplementary Table 4**, http://links.lww.com/PCC/C291). With LASSO, a lambda of 0.011 was added to the model; the variables that remained in the model following LASSO logistic regression were age, weight, the primary diagnosis, and scheduled admission. The

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TABLE 1.
Descriptive Characteristics of Study Cohort

Variable	All Patients Who Had a UE (n = 5,703)	Intubated After UE (n = 1,661)	Not Intubated After UE (n = 4,042)
Age			
0 to < 29 d	656 (11.5)	203 (12.2)	453 (11.2)
29 d to < 2 yr	2,830 (49.6)	941 (56.7)	1,889 (46.7)
2 to < 6 yr	1,038 (18.2)	235 (14.2)	803 (19.9)
6 to < 12 yr	554 (9.7)	146 (8.8)	408 (10.1)
12 to < 18 yr	625 (11.0)	136 (8.2)	489 (12.1)
Weight, kg	16.4 (± 20.4)	14.0 (± 18.4)	17.3 (± 21.1)
	9 (4.3–17.2)	7.3 (4–14.2)	9.8 (4.5–18.9)
Sex			
Female	2,265 (39.7)	684 (41.2)	1,581 (39.1)
Male	3,438 (60.3)	977 (58.8)	2,461 (60.9)
Race			
White	2,056 (36.1)	585 (35.2)	1,471 (36.4)
Black	1,350 (23.7)	422 (25.4)	928 (23.0)
Hispanic	780 (13.7)	208 (12.5)	572 (14.2)
Asian/Indian/Pacific Islander	158 (2.8)	52 (3.1)	106 (2.6)
Other/unknown	1,359 (23.8)	394 (23.7)	965 (23.9)
Primary diagnosis			
Respiratory	2,252 (39.5)	769 (46.3)	1,483 (36.7)
Cardiovascular	811 (14.2)	232 (14.0)	579 (14.3)
Neurologic	696 (12.2)	166 (10.0)	530 (13.1)
Oncologic	189 (3.3)	46 (2.8)	143 (3.5)
Other	1,755 (30.8)	448 (27.0)	1,307 (32.3)
Scheduled admission			
Yes	1,050 (18.4)	256 (15.4)	794 (19.6)
Readmission to PICU			
Yes	1,435 (25.2)	419 (25.2)	1,016 (25.1)
PICU LOS, d	9.6 (3.6–20.5)	12.8 (7.3–23.9)	7.7 (2.7–18.8)
Hospital LOS, d	17.8 (7.4–40.1)	22.8 (12.1–46.5)	15.3 (5.9–37.9)
PICU outcome			
Died	329 (5.8)	120 (7.2)	209 (5.2)

LOS = length of stay, UE = unplanned extubation.
Values presented as n (%); mean (± SD) or median (interquartile range).

calibration and discrimination of the updated model produced a Hosmer-Lemeshow goodness-of-fit p value of 0.88 and an AUROC of 0.59 (95% CI, 0.57–0.61). The sensitivity and specificity of the model were 54.3% and 58.7%, respectively, with a classification cutoff of 0.30. The positive predictive value was 35.2%, and the negative predictive value was 75.7%.

The model performed comparably in external validation using the 2017–2020 sample (n = 2,268). The calibration slope for the model was 1.0, suggesting excellent calibration (**Fig. 1**). The AUROC was 0.58 (95% CI, 0.56–0.61). The sensitivity and specificity of the model were 51.3% and 61.5%, respectively, with a classification cutoff of 0.30. The positive predictive

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TABLE 2.
Descriptive Characteristics of the PICUs

Variable	Unit of Measurement	Units (*n*)	Mean (95% CI)	Median (IQR)	Range
Unit size 2019	Number of patients discharged in 2019	114	1,889.4 (1,036.2–1,342.7)	1,018 (552–1,656)	62–4,206
Unit size 2020	Number of patients discharged in 2020	108	968.1 (841.8–1,094.4)	865 (423–1,400)	43–3,524
SMR from Pediatric Index of Mortality-3	SMR	116	1.0 (0.9–1.1)	0.9 (0.8–1.2)	0–4.3
SMR from Pediatric Risk of Mortality	SMR	115	1.0 (0.9–1.1)	1.0 (0.7–1.2)	0–3.0
Average ventilator days	Average number of ventilator days	116	6.1 (5.7–6.5)	5.8 (4.5–7.4)	1.9–14.3
UE rates 2019–2020	Number of UE per 100 ventilator days 2019–2020	116	0.5 (0.4–0.6)	0.4 (0.2–0.6)	0–3.6
Duration of ventilation 2019–2020	Number of ventilation days 2019–2020	116	2,085.6 (1,720.8–2,450.4)	1,625.4 (516.7–2,879.4)	2.0–12,127.6

IQR = interquartile range, SMR = standardized mortality ratio, UE = unplanned extubation.

TABLE 3.
Multivariable Regression Analysis Results

Variable	Adjusted Odds of Reintubation After Unplanned Extubation OR (95% CI)	*p*	β Coefficient
Age			
Under 2 yr	1.48 (1.12–1.96)	**0.006**	0.39
Weight			
Under 10 kg	1.11 (0.87–1.46)	0.384	0.12
Sex			
Female	1.13 (0.97–1.31)	0.113	0.12
Primary reason for admission			
Respiratory	1.31 (1.10–1.57)	**0.003**	0.27
Cardiovascular	1.13 (0.85–1.50)	0.398	0.12
Neurologic	0.90 (0.69–1.18)	0.460	−0.10
Oncologic	0.95 (0.59–1.52)	0.818	−0.05
Other	Reference	Not applicable	Not applicable
Scheduled admission to PICU			
Yes	0.70 (0.56–0.88)	**0.003**	−0.36
Readmission to PICU			
Yes	1.07 (0.89–1.28)	0.472	0.07
Constant (Y intercept)			−1.33

OR = odds ratio.
Boldface values indicate statistical significance ($p < 0.05$).

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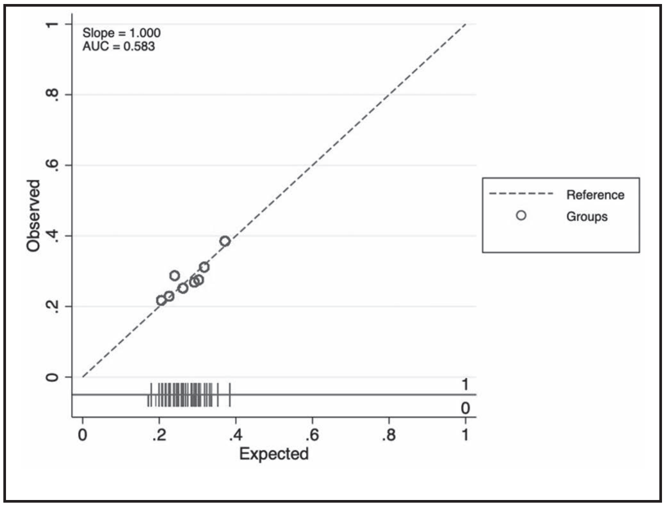

Figure 1. Calibration slope for regression model (external validation). AUC = area under the curve.

value was 35.4%, and the negative predictive value was 75.4%.

AT THE BEDSIDE

- Under one-third of patients in this sample required reintubation after unplanned extubation. Patients who required reintubation had longer length of stay and increased odds of mortality during the PICU admission.
- Patients who were younger, admitted for a respiratory diagnosis, and unscheduled admissions had the highest risk of requiring reintubation.
- These findings should motivate clinicians to increase vigilance when caring for intubated patients that fall into the higher-risk categories (younger age, respiratory diagnosis, unscheduled admission).

DISCUSSION

In this retrospective observational study, we explored factors associated with increased odds of requiring reintubation after unplanned extubation in a sample of over 5,700 patients admitted across 149 PICUs. To our knowledge, this is the largest study exploring unplanned extubations requiring reintubation in pediatric critical care. We found that just under one-third of the patients required reintubation after unplanned extubation, which is lower than what has been previously reported in the literature (4, 6, 7, 11). As noted in the methods, VPS includes unplanned extubations that occur "within minutes of a planned extubation if "not deliberately removed by a provider" (16). This may have influenced the lower rate of patients requiring reintubation. There have been some studies that report rates of unplanned extubations ranging from 30% to 40%, which is not far off from our sample's rates (10, 24–27). Further research exploring factors influencing the rate of reintubation after unplanned extubation in pediatric critical would benefit from considering a combination of patient-level factors (age, acuity, ventilator settings, timing of unplanned extubation, sedation), staff-level factors (staff comfort with assessment and reintubation, staff available), and unit-level factors (unit culture, policies) (5, 7).

We found that variables associated with the increased odds of requiring reintubation were age (< 2 yr), weight (< 10 kg) and a respiratory primary diagnosis. An admission identified as scheduled (known within 12 hr) was associated with a decreased odds of reintubation after unplanned extubation. We did not find an association between a patient's sex or readmission status and the odds for reintubation after unplanned extubation. We explored the performance of the regression model to predict the risk of unplanned extubation requiring reintubation, which, to our knowledge, is the first of its kind. With the data we had available, we were unable to construct a model with good predictive ability, evidenced by the AUROC of 0.59 and 0.58 in internal and external validation, respectively. However, these findings add to the existing literature by suggesting that age, weight, primary diagnosis, and admission type together may be predictors of reintubation after unplanned extubation. There are likely missing variables that could, when integrated into the model, lead to better predictive abilities. Without these missing variables, our mathematical models can not fully predict or explain unplanned extubations requiring reintubation and should therefore not be considered predictive for clinical use.

An unplanned extubation is almost always an emergency; even if clinicians anticipate that the patient will do well without the endotracheal tube, there is always the possibility that the patient will experience hypoxia due to inadequate oxygenation or ventilation. For this reason, extubations should always occur when there is

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adequate staff and equipment nearby, ready to reinsert the tube when needed (2, 28). After an unplanned extubation, neither may be available. A model that could adequately predict the patients who may need reintubation could support clinical decision-making and facilitate clinician preparedness in the event of an unplanned extubation. With unplanned extubations being a fairly rare event (0.5 events per 100 ventilation days in this sample of PICUs), clinicians may not anticipate an unplanned extubation occurring, or further, what the outcome might be after the unplanned extubation. A prediction tool that could be integrated into the electronic medical record, pulling variables that are gathered as part of routine care, could flag the patients who are at high risk of requiring immediate reintubation after unplanned extubation, ensuring that clinicians are more prepared. Furthermore, if a patient was identified as extremely low risk of requiring reintubation following an unplanned extubation, clinicians could consider whether intubation and mechanical ventilation are still required. Intubation and mechanical ventilation are not innocuous interventions; approximately 40% of intubated patients experience complications, including atelectasis, pneumothorax, ventilator-associated pneumonia, and increased risk of delirium related to sedation (29–31). Removing the endotracheal tube as early as possible is associated with decreased risk of complications, earlier discharge from PICU and hospital, and decreased admission costs (32, 33).

The association between age and requiring reintubation after unplanned extubation has been observed in the existing literature. In a sample of 36 unplanned extubations over 1 year, Tripathi et al (6) found that 62.9% of patients less than 1 year required reintubation, compared with 33.3% of patients greater than or equal to 1 year. This study was underpowered due to the small sample size; thus, the association was not statistically significant. Fitzgerald et al (7) conducted a multisite study across 11 PICUs with a sample size of 189 unplanned extubations. They found that 68.0% of patients less than 1 year required reintubation, compared with 50.0% of patients greater than or equal to 1 year ($p = 0.016$). We were unable to explore if there was a difference in patients less than or equal to 1 year, compared with patients greater than or equal to 1 year and less than 2 years, as the age groups were precategorized by VPS; however, our findings support preexisting evidence that younger patients have increased odds of requiring reintubation, compared with older patients in pediatric critical care.

Existing literature and biological plausibility also support the association between respiratory diagnosis and increased odds for reintubation. A 2018 retrospective study by Al-Abdwani et al (5) found that after unplanned extubation, patients intubated for respiratory indications had increased odds of requiring positive-pressure ventilation within the first 24 hours. Researchers have found that the reasons for reintubation after unplanned extubation include stridor or wheezing, increased work of breathing, apnea, hypoxia, hypoventilation, and hypercapnia, which are all symptoms or complications associated with common pediatric respiratory diagnoses (7–9). Patients admitted to PICU for respiratory support would have higher odds of experiencing these complications upon unplanned extubation. Future research in this field should continue to explore how patient diagnoses are associated with the risk of requiring reintubation after unplanned extubation.

These findings should motivate clinicians to increase vigilance when caring for intubated patients that fall into the higher-risk categories (younger age, respiratory diagnosis, unscheduled admission). As described in the introduction, the process of intubation is not innocuous. If we anticipate that a patient will require reintubation after unplanned extubation, clinicians should protect the patient and prevent the endotracheal tube from being accidentally removed. Based on supporting literature, preventing unplanned extubations may include 1:1 nurse-to-patient ratios, maintaining adequate sedation, ensuring the endotracheal tube is securely affixed, and the patient and tube are carefully monitored throughout procedures (3, 4, 34, 35). From a unit level, PICUs should explore the local contributing factors for unplanned extubations and design quality improvement interventions to target the factors. At the bedside, nurses can increase their vigilance when caring for children at higher risk of reintubation after unplanned extubation, as well as working collaboratively with the care team to advocate for appropriate staffing ratios and adequate sedation. The nursing assessment should also involve endotracheal tube assessment (including fixation) and proper monitoring and securement during procedures. Engaging in appropriate prevention practices, especially when caring for patients with the highest risk of requiring

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reintubation after unplanned extubation, may increase patient safety and the quality of care provided.

This study is not without limitations. One of the major limitations of using an observational database, such as VPS, is the inability to obtain certain clinically relevant variables that may be required to answer research questions. Previous studies exploring the risk of reintubation have found that variables such as the volume of airways secretions (3, 6, 8), ventilatory support (3, 4), sedation assessment score (8), and recent administration of a sedative or paralytic medication (3) prior to the unplanned extubation were associated with increased risk. Unfortunately, these variables and others that may be predictive of reintubation were not captured in the VPS database, and thus, were not able to be included in our model. Furthermore, we were unable to describe the clinical trajectory of the patients that did not require reintubation after unplanned extubation, and it is likely that this group is highly heterogeneous. The patients ready for extubation likely followed a similar trajectory to those who had planned extubations, whereas others may have had a precarious course with threatened reintubation and vigilant bedside monitoring. It is important to consider this when interpreting the findings from our study. With the expansion of electronic medical records, and the integration of novel methodological techniques such as natural language processing (36, 37), there is an opportunity to analyze mass amounts of routinely collected data that can support future investigations. We suggest that when collecting information about adverse events, such as unplanned extubations, clinically relevant variables such as ventilator settings or sedative medications at or before the time of the event are also collected to support large-scale analysis and prediction.

The findings from this study are more generalizable than single or small multisite studies, analyzing data from more than 5,700 patients across 149 PICUs in North America. However, results must be interpreted with caution. Participating in the VPS database is voluntary; units choose to participate because of a shared desire to collectively enhance pediatric outcomes through patient safety and quality improvement (16). There could be patient, staff and environmental factors that differ between VPS-participating sites and non-VPS-participating sites that could impact the odds of reintubation after unplanned extubation, such as patient acuity, staff training and comfort with noninvasive ventilation methods, nurse-to-patient ratios and equipment availability (38, 39). However, the variables we identified as being associated with an increased or decreased odds of unplanned extubation (age, weight, respiratory diagnosis, and type of admission) are broadly applicable across PICU sites.

This is the largest sample of unplanned extubations in the literature to date, which was only possible using a large-scale database like VPS. Another strength of using the VPS database is the validity and reliability of the information gathered. Admission characteristics, diagnoses and interventions are documented by trained analysts within a PICU, achieving over 95% inter-rater reliability. This decreases the risk of misclassification bias; however, there is still a possibility that variables were misclassified (40). After observing that the rate of reintubations in our sample was lower than what has been previously found in the literature (4, 7, 34, 41), we connected with VPS to verify the coding and calculations we used appropriately captured the events as documented. The VPS data management team confirmed the findings were correct based on the available data.

We aimed to develop and validate a model that would have clinical utility to identify patients requiring reintubation after unplanned extubation. When developing models for clinical use, it is important to consider clinician preference, knowledge translation, implementation, and impact assessment (15, 20, 42). Acknowledging that our model is not ready for clinical use, we urge future researchers to consider these features if a valid and operational predictive tool is ever developed. Future research in this area would benefit from obtaining clinically relevant variables, such as oxygen and ventilator requirements at the time of unplanned extubation, which, when combined with the findings from this research, could lead to powerful models with higher predictive capabilities.

CONCLUSIONS

Quality improvement and patient safety require measurement and understanding of the complex relationships between variables and outcomes. This study provides a broad overview of unplanned extubations, exploring some of the variables that are associated with an increased risk of intubation. Associated variables included age and a respiratory primary diagnosis. This study also provides an example of how LASSO

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regression can be used as a prediction tool in the setting of pediatric critical care. Future research should include clinically relevant variables that may enhance the predictive ability of this model.

1 *Department of Community Health Sciences, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada.*

2 *Faculty of Nursing, University of Calgary, Calgary, AB, Canada.*

3 *Alberta Children's Hospital Research Institute, Calgary, AB, Canada.*

4 *Alberta Children's Hospital, PICU, Calgary, AB, Canada.*

5 *Maternal Newborn Child and Youth Strategic Clinical Network, Alberta Health Services, Calgary, AB, Canada.*

6 *Department of Critical Care Medicine, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada.*

7 *Department of Pediatrics, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada.*

8 *Department of Medicine, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada.*

9 *Department of Obstetrics and Gynecology, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada.*

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All those designated as authors (to Drs. Wollny, McNeil, Moss, Sajobi, Parsons, Benzies, and Metcalfe) have met all four International Committee of Medical Journal Editors criteria for authorship: 1) substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; 2) drafting the work or revising it critically for important intellectual content; 3) final approval of the version to be published; and 4) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Drs. Wollny, McNeil, and Metcalfe were the core team leading the study. Dr. Wollny obtained, reviewed, and cleaned the data. Drs. Wollny and Moss analyzed the data. Drs. Wollny, Moss, and Metcalfe interpreted the evidence. All authors provided advice at different stages and approved the final version of the article. Dr. Wollny is the guarantor and attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. Dr. Wollny affirms that this article is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

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For information regarding this article, E-mail: krista.wollny@ucalgary.ca

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The data that support the findings of this study are available from Virtual Pediatric Systems, LLC. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from authors with the permission of Virtual Pediatric Systems, LLC.

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