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Unplanned extubation in a paediatric intensive care unit: prospective cohort study

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Take-home message: We used a prospectively collected database over 14 years (14,141 ventilation episodes) to verify the suggested benchmark for unplanned extubation of less than 1 episode/100 intubated patient days. However, significant underestimation of the unplanned extubation rate (up to approximately one-third) occurs if ventilated days are calculated using traditional methods (calendar days), rather than recording ventilation to the hour.

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Abstract *Purpose:* Unplanned extubation (UE) is an important paediatric intensive care unit (PICU) quality indicator. Studies on UE have been modest in size, with accurate UE rate calculation potentially hampered by ventilation episodes recorded in calendar days. We wished to document UE rates, outcomes, associated factors and quantify error when calendar days rather than exact timings are used. *Methods:* We recorded prospectively all UE episodes and potential associated factors in our 20-bed PICU for 12,533 admissions (2000–2013). Ventilation episodes were recorded to the minute, with non-invasive and tracheostomy ventilation excluded. Analysis utilised multilevel mixed-effects Poisson regression, adjusting for multiple ventilation episodes in the same patient. *Results:* Overall, 243 UEs occurred within 14,141 ventilation episodes (31,564 intubated days), giving a UE rate of 0.77 (95 % CI 0.67–0.87) episodes per 100 intubated days. If calendar ventilation days were used, the yearly UE rate was underestimated by 27–35 %. UE rates decreased with time, by approximately 0.05/100 intubated days each year. Associations with UE incidence rate included patient age, source of admission, disease severity and diagnostic category, with nasal tubes decreasing the risk. Although UE versus planned extubation was associated with a higher re-intubation rate (43 versus 8 %) and longer median PICU stay (4.6 versus 2.6 days, $p < 0.001$), mortality between the two groups did not differ (3.0 versus 5.1 %, $p = 0.18$). *Conclusions:* This study provides contemporaneous UE rates for benchmarking. Recording ventilation in calendar days underestimates UE rate. Several factors associated with UE may serve as a focus of quality improvement.

Keywords Airway incidents · Unplanned extubation · Accidental extubation · Re-intubation · Paediatric intensive care

Introduction

The importance of benchmarking quality of care in the paediatric intensive care unit (PICU) is widely acknowledged, with the commonest outcome comparator being risk-adjusted mortality [1]. However, validity of this measure is increasingly questioned owing to falling PICU mortality rates. There is subsequently growing emphasis on reporting alternative process-of-care markers, such as refused admissions, unplanned early re-admission, nosocomial infections and unplanned extubation (UE) [2, 3].

UE is the commonest airway-related adverse event in the intensive care environment [4] and is associated with complications such as hypoxaemia, hypercarbia, need for emergency re-intubation and rarely death. UE has been associated with increased nosocomial pneumonia and longer hospital stay in adults [5]. In the PICU setting, UE has been associated with longer stay and increased cost but not mortality [6, 7]. The reported rates of UE vary widely from 0.11 to 2.27 per 100 intubated patient days [8]. A UE rate of less than 1 per 100 intubated patient days has been suggested as a benchmarking tool for PICU [9]. However, quality improvement initiatives have shown potential to reduce the UE rate significantly below this suggested benchmark [10].

A systematic review of UE in PICU found only 11 studies over a 30-year period, with only one-quarter of studies published within the last decade [8]. The inference from the systematic review was further limited by the contributing studies: most were relatively small (median number of patients 500) and had varying aims, such as examining a limited number of potential risk factors or the impact of quality improvement projects. A further limitation relates to calculating the length of a ventilation episode. Many studies report this in either calendar days or in terms of the number of times the ventilation episode crosses midnight. Both methods result in an underestimation of UE rate by inflating the denominator: for example, a ventilation episode of 6 h (0.25 days), from 2300 to 0500 hours would be classed as 2 days by the former definition and 1 day by the latter. This error is pertinent to PICU, where the average duration of ventilation is typically brief [11].

We identified UE as one of several key quality indicators in our multidisciplinary PICU approximately 15 years ago. As part of an ongoing quality improvement initiative, we established a database to monitor UE prospectively, which included timing of UE (recorded to the minute), along with UE outcome and several key patient demographic and other factors which may be associated with UE.

Our primary aim in this report was to document contemporaneous rates of UE using accurate timing for ventilation episodes, and how these have changed over time. We had three secondary aims:

(a) To calculate the error in calculated UE rate if calendar days rather than exact ventilation timings are used.
(b) To quantify the association between selected patient- and care-related factors and UE occurrence.
(c) To report on the outcome of UE in terms of respiratory morbidity and mortality.

Methods

This prospective cohort study utilised routine clinical data collected for quality control, with results reported in a non-patient-identifiable format. As such, it was exempt from the requirement for research ethics committee approval, but was registered as an audit via our institutional reporting mechanism.

Clinical setting

Our PICU is a 20-bed regional referral unit, encompassing all major subspecialties, with the exception of neurosurgery and hepatology. Approximately 40 % of admissions are external (South Thames region), with more than 80 % of these being transported by our integrated transport service (http://www.strs.nhs.uk). Approximately 85 % of admissions are invasively ventilated; such patients typically receive 1:1 nursing care, and 24-h medical cover is provided by dedicated PICU consultants and fellows. Staffing levels increased over the study period, in line with contemporaneous national recommendations [12].

Endotracheal tubes were secured with Elastoplast™ (Beiersdorf UK Ltd) using the "Melbourne strapping" method [13], with nasal tubes being the preferred mode of endotracheal intubation. Tube placement was confirmed by radiograph and adjusted when required. Retaping was done when there was significant mobility of the tubes, or when tapes were wet. Cuffed tubes were not routinely used, but considered when a large leak was present coexistent with lung disease requiring high ventilation pressures. Unit guidelines for analgesia and sedation have not changed significantly during the study period: see electronic supplementary material and [14]. Briefly, this included morphine and oral clonidine as first-line agents, with intermittent lorazepam as required. Neuromuscular blockade (intermittent pancuronium or rocuronium) was infrequently used. Soft limb splints were used as restraints and to secure lines as required.

Definitions and study population

We analysed all UE events in children less than 16 years of age, from January 2000 to December 2013. UE was defined as any displacement of the endotracheal tube occurring at any time other than that chosen for planned extubation by medical or nursing teams [15]. This included (1) self-extubation, (2) accidental extubation due to any other cause (e.g. during procedures) and (3) any event where an endotracheal tube was removed and reinserted as a result of suspected accidental extubation.

We excluded non-invasive and tracheostomy ventilation episodes from the analyses.

Data collection

Data were collected electronically in Microsoft Access format (Microsoft Corporation), using a bespoke database built by one author (AD). Data were typically inputted thrice daily by one of the two on-service consultants. The majority of data were inputted via dropdown lists (using predefined categories) or binary fields (yes/no). Several variables also had limited free text availability, as an adjunct to clarify or elaborate on existing fields. Variables included admitting diagnoses, significant co-morbidity, basic demographics, key therapies (e.g. inotropes, renal replacement) and variables required for calculation of the Paediatric Index of Mortality 2 (PIM-2) score [16]. Ventilation data included timing of all episodes, mode of ventilation, route of endotracheal tube (oral/nasal) and reasons for failed extubation. We were unable to record daily patient clinical status (e.g. organ failure scores), nor the timing of decision to wean towards extubation, including temporal documentation of sedative use or level of sedation.

Internal validation of data was undertaken by a third consultant on a daily basis (e.g. via checking the nursing records for extubation times on the PICU charts), and augmented since 2010 by an automated rule-based system (e.g. ensuring dates of ventilation did not occur beyond date of discharge). A second mechanism for internal validation included reporting all potential UEs (by any member of the multidisciplinary team) as part of our adverse incident monitoring system, which included multidisciplinary review of the event the following working day [17]. External validation of the majority of the database variables (including ventilation timings) occurs as part of the national reporting requirements for the Paediatric Intensive Care Audit Network, details of which are included elsewhere [11].

Data analysis

Statistical analyses were performed using Stata 13.1 (StataCorp LP, Texas, USA). The denominator used for calculating UE rate was intubated patient hours; however, UE rates are expressed in the "Results" section per 100 intubated patient days (by multiplying the hourly rate by 100/24) as per usual convention. Confidence intervals for proportions and rates were calculated using the normal approximation for the binomial distribution. Continuous data are expressed as mean (SD) or median (interquartiles), dependent upon distribution. Univariable comparisons utilised unpaired *t* tests, Mann–Whitney and Fisher's exact tests, as appropriate.

We analysed multivariable associations with UE using a model that contained (a) three patient demographics: age, sex, primary diagnostic category; (b) two proxy markers of illness severity: PIM-2 score and need for inotropes; (c) one tube-related variable (nasal versus oral); and (d) four system-related variables: external versus in-house admission, year of admission, "winter months" and admission during a "high risk month". Winter months (Nov–Feb) reflect the season of highest bed occupancy [11]. High risk months were designated as Feb, Mar, Aug and Sept, as these were when junior medical staff changed over [18]. Multivariable associations were quantified using Poisson regression analysis via a multilevel mixed-effects model to adjust for potential multiple ventilation episodes during the same PICU admission [19]. We tested for possible non-linear relationships between continuous variables and outcome using multivariable fractional polynomials [20]. For all analyses, a p value of less than 0.05 was considered significant.

Results

Unplanned extubation incidence and temporal trends

We analysed 14,141 endotracheal ventilation episodes in 12,533 admissions accounting for 31,564 intubated patient days. During the 14-year study period, the number of yearly ventilated admissions increased from 706 to 1049. The median (interquartile) length of ventilation was 1.2 (0.44–2.9) days and did not change over the study period ($p = 0.29$). In total, 243 UE events occurred in 237 patients (six patients had two UE episodes each). The summated UE rate over the entire study period was 0.77 per 100 intubated patient days (95 % CI 0.67–0.87). In year 1, this was 1.38, and decreased by 0.05 per 100 intubated patient days each year ($r^2 = 0.53$, $p = 0.003$) (Fig. 1). During the latter half of the study period, when the yearly number of intubated patient days had largely plateaued, the mean UE rate was 0.59 (95 % CI 0.48–0.71) per 100 intubated patient days.

Error in unplanned extubation rate using calendar days

The apparent total UE rate decreased from 0.77 to 0.53 per 100 intubated days when calendar days were used, rather than exact ventilation timings. This represented an error of 31.5 %, which fluctuated on a yearly basis between 26.8 and 35.3 %.

Associations with UE

Baseline demographic data and univariable comparison of patients by UE occurrence are shown in Table 1. Patients

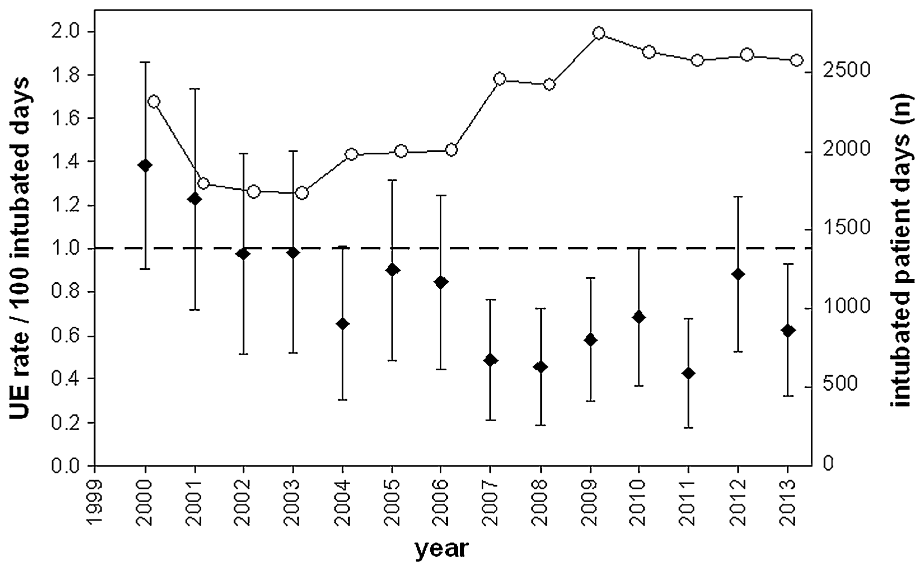

Fig. 1 Unplanned extubation rate and intubated patient days over time. *Diamonds* represent the unplanned extubation rate per 100 intubated days; *circles* represent the number of intubated patient days. *UE* unplanned extubation. The *dashed line* represents the suggested benchmark for unplanned extubation: a rate of 1.0 per 100 intubated days. *Error bars* represent 95 % confidence intervals

Table 1 Patient demographics and univariable comparisons of children according to presence of unplanned extubation

	Unplanned extubation ($N = 237$)	No unplanned extubation[a] ($N = 12{,}296$)	p value
Age (months)	13 (2.8–65)	7.8 (1.2–40)	<0.001
Male	60.3 %	58.9 %	0.69
External admission	57.8 %	39.1 %	<0.001
Diagnostic category			
Respiratory	30.8 %	20.2 %	
Upper airway obstruction	13.5 %	5.2 %	
Neurology	10.6 %	9.6 %	
Sepsis	8.0 %	5.1 %	<0.001
Cardiology	8.0 %	11.0 %	
Cardiothoracic surgery	13.5 %	35.5 %	
Other surgery	9.3 %	7.4 %	
Other	6.3 %	6.0 %	
Total	100 %	100 %	
PIM-2 mortality risk (%)	1.9 (1.0–4.6)	2.0 (1.1–4.9)	0.27
Inotrope use	22.4 %	38.9 %	<0.001
Nasal endotracheal tube	65.4 %	74.4 %	<0.001

Data are median (interquartiles) or percentages

[a] This includes patients who died or were transferred to another unit before extubation

who experienced UE were older, more likely to be admitted from an external hospital, and less likely to receive inotropes or a nasal endotracheal tube. There were also differences in the distribution of admission diagnostic categories, with UE patients having a higher proportion of respiratory illness, upper airway obstruction and a lower proportion of cardiac conditions.

Multivariable associations with UE are shown in Table 2, detailing results from the Poisson model. Many of the univariable relationships were still apparent. Of note, increasing age was associated with an elevated incidence rate ratio (IRR) of UE; however, this relationship was non-linear, with the steepest rise in risk being seen over the first 2 weeks of life, followed by a plateau until approximately 7–8 years of age, after which the risk again rose steeply (Fig. 2). The positive associations between UE and external admissions persisted, as did the negative (protective) association with nasal endotracheal tube use and disease severity (both inotrope use and PIM-2 score were now highly significant).

Of note, the IRR decreased with time, by 6 % per year. There was no association with designated high risk months. The IRR also varied according to diagnostic category at admission (overall variable effect, $p < 0.001$). Using cardiology as the reference group, there was an approximate threefold variation in the IRR, from 0.42 for respiratory admissions to 1.16 for sepsis. The apparent differences in impact of diagnosis and also PIM-2 score between Tables 1 and 2 is explained by the fact that Table 2 takes account of length of exposure (i.e. number

Table 2 Multilevel mixed-effects Poisson regression model examining the association between unplanned extubation and potential risk factors

	Incidence rate ratio	95 % confidence interval	*p* values
Age (months)	Non-linear relationship (see Fig. 2)		0.003
Male	1.10	0.83–1.44	0.51
External admission	1.55	1.08–2.24	0.02
Diagnostic category*			<0.001
Respiratory	0.43	0.24– 0.77	0.005
Cardiothoracic surgery	0.64	0.33–1.22	0.17
Neurology	0.65	0.33–1.30	0.23
Other	0.71	0.34–1.48	0.36
Upper airway obstruction	0.72	0.37–1.39	0.33
Cardiology	Reference		
Other surgery	1.04	0.49–2.17	0.93
Sepsis	1.17	0.57–2.41	0.67
PIM-2 mortality risk[a]	0.50	0.36–0.69	<0.001
Inotrope use	0.41	0.28–0.61	<0.001
Nasal endotracheal tube	0.66	0.47–0.93	0.02
Year of admission	0.94	0.91–0.98	0.002
High risk months[b]	0.99	0.74–1.32	0.94
Winter months[c]	0.94	0.71–1.24	0.65

* Note that the overall *p* value for diagnostic category is <0.001. Subsequent within-category *p* values refer to comparison of individual diagnoses with cardiology (reference)

[a] Change in incidence rate ratio per 10 % increase in mortality risk

[b] High risk months refer to the 4 months (Feb, Mar, Aug, Sep) coinciding with junior medical staff changeover

[c] Winter months include Nov–Feb (inclusive)

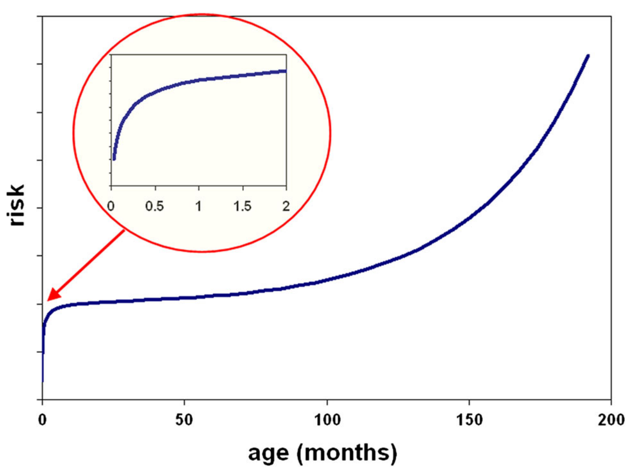

Fig. 2 Multivariable Poisson relationship between age and risk of unplanned extubation. The *circled area* represents a magnification of the relationship between risk and age from 0 to 2 months

of ventilated days) as well as the simultaneous, multivariable relationship between diagnosis and all other variables.

Timing and outcome of UE

The median (interquartile) time to UE was 34 h (11–91) post PICU admission, which was similar for planned extubations, at 37 h (13–86, $p = 0.66$). However, the time of occurrence was markedly different between the two groups, with 80 % of planned extubations occurring between 0800 and 1900 hours, while UEs were evenly distributed throughout the 24 h (Fig. 3).

The re-intubation rate following UE was 43 % ($n = 104/243$), whereas re-intubation only occurred in 8 % of children with planned extubations, giving an unadjusted odds ratio of re-intubation for UE compared to planned extubation of 8.5 (95 % CI 6.4–11.1; $p < 0.0001$). Three quarters of re-intubations occurred within 30 min of UE. The reasons for re-intubation after UE were hypoxia (27.9 %), upper airway obstruction (26.9 %), hypoventilation (24 %), work of breathing (12.5 %), cardiovascular support (3.9 %), procedure (3.9 %) and seizures (1.0 %). This was different for planned extubations, where the commonest reason for re-intubation was upper airway obstruction (36 %), with hypoxia, hypoventilation, work of breathing, cardiovascular support and procedures all exhibiting similar proportions (ranging from 10 to 14 %).

The median (interquartile) length of PICU stay was longer for patients experiencing a UE: 4.6 (1.9–8.9) versus 2.6 (1.2–4.8) days, $p < 0.001$. However, despite this, there were no differences in PICU mortality 3.0 % for UE versus 5.1 % for planned extubation patients, $p = 0.18$.

Discussion

Our main findings are discussed below, structured in terms of our primary and secondary study aims.

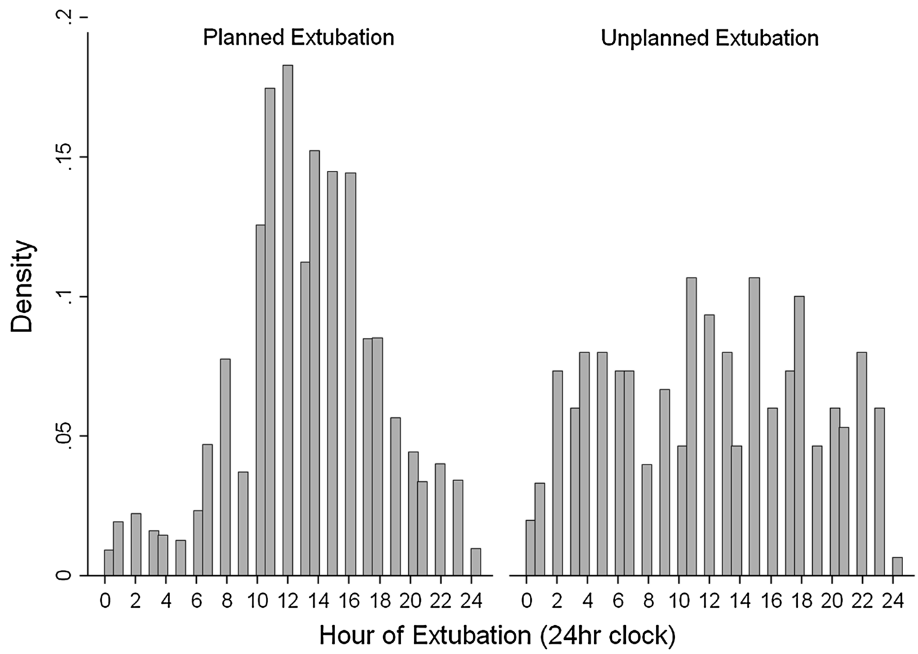

Fig. 3 Comparison of time of day of planned versus unplanned extubations

Benchmarking and data accuracy

The suggested acceptable rate for UE is less than 1 per 100 intubated days [2, 9]. However, there is an approximate 20-fold variation in published UE rates, ranging from 0.11 to 2.7 UE per 100 intubated days, with 38 % (5/13) studies reporting rates greater than 1 [8]. This is likely due, in part, to different care processes between units (e.g. sedation policy, nursing cover). However study size also plays a role, with smaller studies exhibiting greater variation in UE rates. Thus, restricting analysis to the four studies involving more than 1000 patients, the UE rate shows less variation (range 0.92–1.2), which is closer to the suggested benchmark. This is consistent with the rate exhibited during the first half of our study (Fig. 1), which encompasses a similar time period to these published studies. However, our data show a steady decrease in UE over time, which appears to have stabilised in recent years, such that the contemporaneous rate for the latter period (2007–2013) is 0.59 (0.48–0.71) per 100 intubated patient days, with yearly rates consistently below 1 (Fig. 1), which supports the suggested benchmark. Differences in staffing levels over the years may be contributory to this; however, as we did not have data on staffing levels per shift available, we are unable to analyse this further.

The suggested limit of 1 per 100 intubated days is further supported by observing our yearly rates (Fig. 1), which showed an upsurge in 2012, suggesting a process problem. This was indeed the case and was due to a temporary supply problem with the Elastoplast tapes for securing the endotracheal tubes. Once rectified, 2013 rates returned to previous levels (as have 2014 rates, data not shown).

Despite being a single-centre design, our study has two key strengths in terms of providing benchmarking data: size and data accuracy. At 12,533 admissions and 31,564 intubated patient days, it is six times greater than any single study and also larger than all published studies combined [8]. By calculating intubation episodes to the minute, rather than calendar days, we have shown that the latter (traditional) method underestimates UE rates by approximately 32 %. This is important, as many PICUs are transitioning from paper to electronic records, and may thus appear to exhibit an increase in UE rate when this occurs. For units that do not have electronic data capture, we would suggest a reasonable compromise would be to collect ventilation episodes to the nearest hour.

Factors associated with UE

Our findings have added to the understanding of UE-associated factors in several ways. First, we have confirmed the protective association of nasal tubes (IRR 0.66, Table 2), which has been suggested by some previous studies, but not others [21–23]. Although nasal tubes accounted for a majority of all ventilation episodes, there were still a significant number of oral ventilation episodes ($n = 3563$) to provide a statistically meaningful comparison. Second, we have shown an age effect opposite to previous studies [6, 10], which have found youngest patients to be at highest risk. Our data shows greatest risk in older patients (Fig. 2), which may be influenced by our sedation policy, where benzodiazepines and neuromuscular blockade are not routinely used. However this may also be due to differences in the type of analyses used: we modelled age as continuous and non-linear (as opposed to dichotomous in previous studies), and adjusted for different covariates. Third, we have demonstrated a threefold variation in risk according to broad diagnostic categories. This may help inform nurse allocation: for example a nurse–patient ratio of less than 1 may be more appropriate for cohorted respiratory patients (low risk) than stable septic patients (high risk). We also found increased risk with external admissions, which to our knowledge has not been reported before. Although patient transport has been described as a risk factor [8], all UE events occurred after admission to PICU rather than during the transport process, pointing to other contributory factors. We are unable to explain this, but it may reflect subtle differences in case mix not highlighted by the broad diagnostic groupings used in our study. Finally, active, more stable children with longer ventilation episodes have been reported to have a higher rate of UE [24]. Our analysis indirectly supports this, with UE risk halving for each 10 % increase in probability of death (PIM-2), and also with inotrope use.

A limitation was that our analyses involved demographic factors primarily, as we were unable to record important time-varying variables potentially associated with UE in previous studies. These include level of agitation, decision to wean, use of splints, procedures and nursing ratios [9, 15, 17, 25]. We were also unable to record daily patient clinical status (e.g. organ failure scores). Delay in extubation following planned weaning has been postulated as a contributing factor in up to one-half of UE events [6, 26]. Although, we did not document weaning, delayed extubation is unlikely to have been a major contributor, given the similarity of time taken to extubate for planned and unplanned extubations. We have since expanded the database to include daily acuity and nurse–patient ratio, which will inform a future study.

Outcome of UE

A minority (43 %) of patients with UE required re-intubation, similar to that reported elsewhere [6, 10]. Although UE patients had slightly longer PICU stays, there was no appreciable difference in mortality, similar to other studies [6, 23, 26, 27]. Prompt re-establishment of the airway has been described as the main reason for no difference in mortality [26]; this is consistent with our findings, whereby three-quarters of reintubations occurred within 30 min of UE.

In summary, we have validated the suggested benchmark rate of UE (less than 1 per 100 intubated patient days) and shown the magnitude of error introduced by traditional methods of length of ventilation calculation, using this large and accurate prospective cohort study. In addition, we have shown several factors associated with risk of UE, which may be used for resource allocation, further studies as well as focus for quality initiatives in the future.

Conflicts of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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