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Decreasing Unplanned Extubation in the Neonatal ICU With a Focus on Endotracheal Tube Tip Position

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BACKGROUND: Unplanned extubation (UE) is an important quality metric in the neonatal ICU that is associated with hypoxia, bradycardia, and risk for airway trauma with emergent re-intubation. Initial efforts to reduce UE in our level 4 neonatal ICU included standardized securement of the endotracheal tube (ETT) and requiring multiple providers to be present for ETT adjustments and patient positioning as phase 1 interventions. After an initial decline, the UE rate plateaued; an internal retrospective review revealed that the odds of UE were 2.9 times higher in the setting of an ETT tip at or above T1 (high ETT) on chest radiograph just prior to UE. The team hypothesized that advancing ETT tips to below T1 would reduce UE risk in infants of all gestational ages. METHODS: Over a period of 32 months, we compared pre-intervention and post-intervention UE rates in our neonatal ICU after a 2-step initiative that focused initially on ETT securement and assessment, with a subsequent addition of a single intervention to advance ETT tips below T1. To determine if the decrease in UE rate could be secondary to our intervention, data were analyzed from 3 cohorts: a control group of 40 infants with 185 chest radiographs and no UEs, 46 infants with chest radiographs prior to 58 UE events before the intervention, and 37 infants with chest radiographs prior to 48 UE events following the intervention. RESULTS: Advancing ETT tips below T1, in addition to the use of a standard UE-prevention bundle, led to a significant decrease in the UE rate from 1.23 to 0.91 UEs per 100 ventilator days, with 14% of postintervention UEs attributed to ETT advancement. CONCLUSIONS: High ETTs are significantly associated with UEs in the neonatal ICU. Optimizing ETT position may be an underrecognized driver in the provider's toolbox to reduce UEs. Because ETT repositioning carries risk of UE, extra caution should be taken during advancement. *Key words: intensive care unit; neonatal; quality improvement; airway extubation; intubation; intratracheal; risk factors; infant; newborn.* [Respir Care 0;0(0):1–●. © 0 Daedalus Enterprises]

Introduction

Unplanned extubation (UE), defined by Children's Hospitals' Solutions for Patient Safety as "any dislodgement of an endotracheal tube from the trachea that is not intentional," is an important quality measure of preventable harm in the neonatal ICU (https://www.solutionsforpatientsafety.org, *Accessed September 1, 2019*). UEs are associated with significant risk for adverse events, including hypoxia, hypercarbia, bradycardia and code events, increased risk of intracranial hemorrhage, and trauma to the larynx, pharynx, and trachea with emergent re-intubation.[1] Often discussed strategies for decreasing UE rates include standardizing

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securement of the endotracheal tube (ETT), frequent assessment of securement, requiring multiple providers to be present for all ETT adjustments and patient moves, use of sedation and analgesia, and respiratory weaning protocols to facilitate early extubation.[2] Yet high-quality studies assessing the effectiveness of individual interventions to reduce UEs are scarce, with most studies instead reporting the incidence of risk factors associated with UE at their individual institutions.[2-7] One literature review found only 15 articles over a 62-y period that it deemed of sufficient quality to analyze as part of a systematic review on risk factors and preventive strategies in neonatal ICUs nationwide. Included study designs were cohort, case-control, and cross-sectional; there were no relevant systematic reviews or randomized controlled clinical trials.[8] Disagreement over the best way to define UE, along with a lack of standardization in neonatal ICU practices such as ETT securement or patient sedation, has further hampered study of UE across institutions as well as strategies to prevent it.[9]

Despite increasing awareness of the dangers of UE and the implementation of similar prevention bundles across multiple units, UE rates tend to plateau at a rate greater than zero after an initial decline, suggesting that there are other contributory factors not addressed in current bundles.[2,4,5] In this study, we sought to understand whether high ETT tip, defined as at or above T1 on a standard chest radiograph, was an additional risk factor that could contribute to UE. Furthermore, we wondered whether intervening by actively advancing a high tube would decrease the risk for UE and whether the benefits of this intervention would outweigh the risks of actively manipulating and re-securing the tube, a risk factor in itself for UE. Although there are no previous studies in UE literature individually investigating the position of the ETT tip on UE rates, institutional guidelines recommend keeping the ETT tip at mid-trachea. A report from Primary Children's Hospital noted that its neonatal ICU team did replace tubes following UE at a deeper depth than they noted them to be on chest radiograph prior to the event, suggesting that their team, too, was suspicious that high ETT was a significant risk factor in their patients' subsequent UE.[2] The primary aim of this study was to determine if a single intervention to advance ETT tip past T1 would reduce the UE rate to a best-in-class target of < 1 UE per 100 ventilator days, beyond what was achieved by the standard UE-prevention bundle implementation alone.[4]

QUICK LOOK

Current knowledge

Unplanned extubation (UE) in the neonatal ICU is associated with hypoxia, bradycardia, and risk for airway trauma with emergent re-intubation. Disagreement over the best way to define UE, along with a lack of standardization in endotracheal tube (ETT) securement practices, has hampered the study of UE-prevention. Despite implementation of similar prevention bundles across multiple units, UE rates tend to plateau at a rate after an initial decline, suggesting there are other contributory factors not addressed in current bundles.

What this paper contributes to our knowledge

High ETTs contribute significantly to UEs in the neonatal ICU. Optimizing ETT tip position to below T1 can reduce UEs in the neonatal ICU. Because manipulating the ETT comes with a risk of UE, extra caution should be taken during the intervention.

Methods

Context

From April 2016 to November 2018, we conducted our study at St. Louis Children's Hospital, a level 4 referral neonatal ICU with an annual average of 1,200 neonatal ICU admissions and 5,600 mechanical ventilator days per year. Institutional review board approval was obtained for data collection in this project. UE was defined as any dislodgement of an ETT from the trachea that is not intentional. A multidisciplinary UE committee was formed, and every UE event was reviewed to identify risk factors and precipitating events. If an ETT was intentionally removed due to decompensation and unresponsiveness to bag-valve-tube ventilation, and prior to extubation the tube was not directly visualized in the trachea or following extubation the ETT was not noted to be blocked (plugged), the event was counted as an UE.

Interventions

In January 2017, as phase 1, we implemented a typical neonatal ICU ETT care bundle. This bundle focused on the method of ETT securement, its regular assessment as part of nursing cares, and the use of 2 providers for all patient repositioning. All nurses and respiratory therapists were educated on this first initiative through in-person trainings. Flyers and educational materials were placed prominently throughout the unit and surrounding break areas. Rotating physicians and first-line caregivers were reminded of the new ETT care guidelines at twice-daily huddles.

By August 2017, the neonatal ICU respiratory care bundle had been in place for 7 months. An initial decline in unit UE rate was observed, but this reached a subsequent plateau (Fig. 1). To achieve further decline in the UE rate in phase 2, the decision was made to add the single intervention to actively advance high ETT tips past the T1

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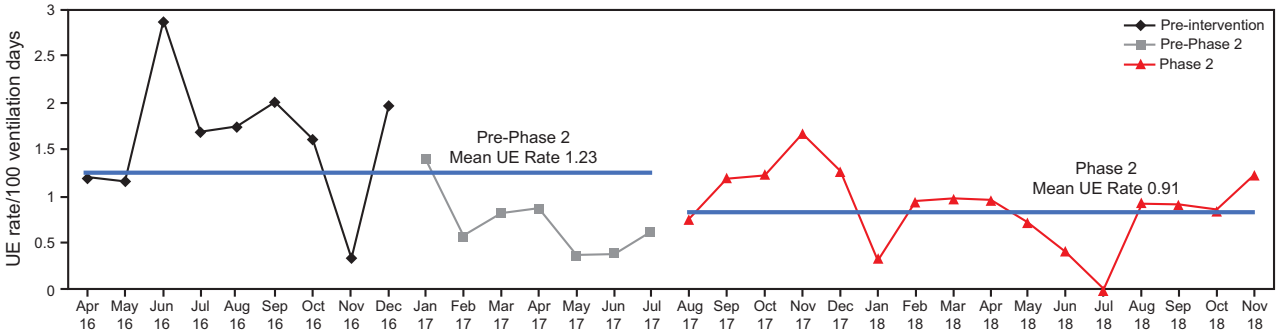

Fig. 1. Unplanned extubation (UE) rate in the neonatal ICU.

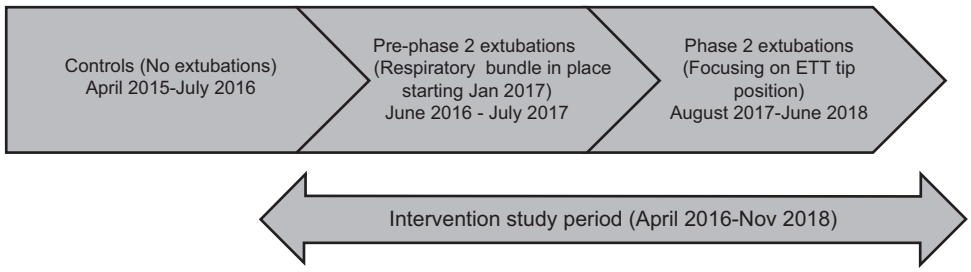

Fig. 2. Timeline of data collected from subject cohorts. ETT = endotracheal tube.

vertebra as standard practice. We implemented 2 major changes as "nudges" for care teams to remember to advance the ETT. First, a script change was added to the twice-daily huddles attended by all attending physicians, fellows, respiratory therapists, and nursing leadership, reminding providers to note whether the ETT position on subject chest radiographs was below T1. Daily rounding sheets, which act as nursing scripts for morning rounds on every patient in the unit, were also updated to prompt discussion on ETT position. We recommended advancement of all tubes that were not below the T1 vertebra on chest radiograph, although it was the clinical decision of the primary team whether to intervene. With advancement, the targeted ideal position of ETT was midway between T1 and the carina; we did not name a specific vertebra to target given the slight variations in each patient's carina relative to the vertebrae and patient position. To reduce radiation exposure, neither regularly scheduled chest radiographs nor chest radiographs following ETT advancement were recommended unless clinically indicated.

Data Collection

Between April 2016 and November 2018, we collected data on all intubated subjects with both planned and UEs during the study period. Demographic and clinical information, including gestational age, birthweight, presence or absence of neck flexion and head direction during chest radiograph (facing left or right), phase of treatment (acute or chronic), and whether extubation led to a code event or re-intubation, were collected. Data gathering also focused on investigating circumstances around the extubation; any case that did not have a clearly defined reason or where there was any uncertainty was classified as UE after review by the multidisciplinary team.

The first stage of the analysis was a case-control comparison of the effect of ETT placement on UE rate using preintervention data (April 2015–July 2017). These data were analyzed using one-way analysis of variance, chi-square test of independence, and logistic regression in SPSS 24 (IBM, Armonk, New York). When the first stage of the analysis suggested that a high ETT may in fact be a significant risk factor for UE, phase 2 of the project was initiated with a focus on maintaining ETT tips below T1. To evaluate the impact of this intervention, the statistical significance of high ETT was again tested in this second epoch. We used statistical process control charts and P-charts to evaluate the impact of our interventions over the designated time course of our project.

Three cohorts of subjects were analyzed as a part of this study (Fig. 2). The first was a group of 40 intubated subjects without UE events and with 185 chest radiographs over the course of their hospitalizations in our neonatal ICU prior to the implementation of this initiative (April 2015–July 2016). The second cohort of subjects consisted of 46 subjects with 58 UEs prior to phase 2 of the study, when ETT position on chest radiograph was not yet a focus in the project (June 2016–July 2017). The final cohort

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Table 1. Subject Characteristics

	Control Group	Phase 1 Cohort	Phase 2 Cohort	*P*
Subjects	40	46	37	
Chest radiographs examined	185	58	48	
Estimated gestational age, wk	27 ± 1.6	27.5 ± 4.9	27 ± 4.8	.56
Birthweight, g	951 ± 266	1,172 ± 876	945 ± 915	.033
Right facing	47 (25)	16 (28)	17 (36)	.34
Neck flexion	94 (51)	25 (43)	25 (53)	.55
High endotracheal tube	35 (19)	23 (50)	11 (23)	

Data are presented as *n*, *n* (%), or mean ± SD.

consisted of 37 subjects with 48 UE events following the intervention to actively advance ETTs found to be above T1 on chest radiograph (August 2017–June 2018). Baseline characteristics were collected regarding mean gestational age, birthweight, and neck flexion and direction for each cohort.

One-way analysis of variance indicated that a clinically insignificant difference in mean weight was the only statistically significant difference between cohorts (Table 1). The final analysis included 32 months of UE data surrounding phase 2 of the project (April 2016–November 2018).

Outcome Measures

Our primary outcome measure was UE rate per 100 ventilator days, a commonly used metric that allows comparison of UE rates across institutions. Ventilator days excluded patients with tracheostomies. The statistical significance of high ETT as a risk factor for UE was also measured both prior to and after our intervention, along with other potential risk factors including gestational age, birthweight, and neck flexion and direction on chest radiograph. Because the process of untaping, advancing, and retaping an ETT carries a risk of UE, we also collected data on the number of UEs associated with ETT repositioning due to a high ETT in phase 2 of the project.

Results

ETT Tip Position as a Risk Factor for UE

We retrospectively compared the historic UE and control cohorts to determine if position of ETT tip on chest radiograph was a significant factor in the rate of UE. A chi-square test of independence was performed to examine the relation between high ETT and UE; the relation between these variables was significant [chi-square (1, $n = 243$) = 10.45, $P = .001$], with a likelihood ratio of 9.71 ($P = .002$) (Fig. 3). Comparing the infants with no UE to the infants with UE, this significant relationship was maintained in logistic regression when controlling for estimated gestational age, birthweight, head direction, and neck flexion, wherein the odds of UE were found to be 2.9 times higher in the setting of a high ETT (95% CI 1.4–5.8, $P = .002$) (Table 2).

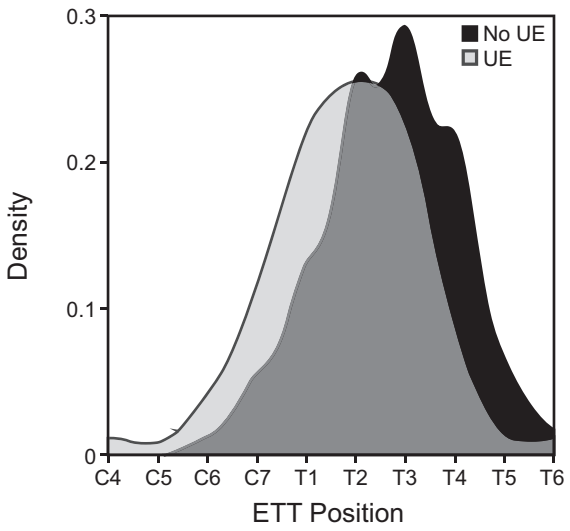

Fig. 3. Density function mapping the probability of UE based on ETT position. UE = unplanned extubation; ETT = endotracheal tube.

Active Advancement of ETT Tip Below T1 as a Modifier of Unit UE Rate

After the results of the case-control study definitively demonstrated the importance of ETT position, phase 2 of the initiative was implemented, wherein we actively advanced ETT tips past T1. Following implementation of this intervention, data were then analyzed to determine whether the UE rate did in fact decrease and whether high ETT was removed as a significant risk factor for UE. For this analysis, we compared preintervention and postintervention infants with UE. In the 16 months before and the 16 months following the implementation of phase 2, 152 events met criteria for UE. In the 16 months prior to the intervention, the UE rate was 1.23 per 100 ventilator days, with 40% of UEs occurring in the setting of high ETT. In

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Table 2. Historic Significance of Variables Associated With Unplanned Extubations

	Odds Ratio (95% CI)	*P*
High endotracheal tube	2.93 (1.47–5.83)	.002
Estimated gestational age	0.67 (0.52–0.87)	.003
Birthweight	1.00 (1.00–1.00)	.000
Neck flexion	0.87 (0.45–1.68)	.68
Right facing	0.86 (0.41–1.80)	.69

Table 3. Significance of Variables Associated With Unplanned Extubations Following Intervention to Actively Advance Endotracheal Tube Tip Past T1

	Odds Ratio (95% CI)	*P*
High endotracheal tube	1.87 (0.72–4.85)	.20
Estimated gestational age	0.45 (0.33–0.62)	.000
Birthweight	1.01 (1.00–1.01)	< .001
Neck flexion	0.70 (0.31–1.56)	.38
Right facing	1.02 (0.43–2.41)	.97

the 16 months following the intervention, the UE rate decreased to 0.91 per 100 ventilator days, with 25% occurring in the setting of high ETT (Fig. 1). In addition, while the UE cohort in phase 1 was 2.9 times more likely to have a high ETT (95% CI 1.4–5.8, $P = .002$), following the intervention in phase 2 both univariate analysis [chi-square (1, $n = 233$) =.88, $P = .35$] and binary logistic regression ($P = .20$) found that a high ETT was no longer significantly associated with UE (Table 3). Only 14% of UEs following the intervention were associated with the process of ETT advancement.

Discussion

UE is an important quality metric and a measure of preventable harm in the neonatal ICU, with a risk profile of associated adverse events that requires active and persistent attention toward its elimination. In this study, we first quantified the relationship between high ETT tip position and the risk of UE through a defined case-control study after the implementation of a respiratory care bundle that significantly reduced but did not fully eliminate risk of UE in the neonatal ICU. When the study team confirmed that high position of ETT tip on chest radiograph was in fact a significant risk factor for UE, we enacted an intervention to actively advance ETT tips below T1 with the goal of decreasing the UE rate to a best-in-class target of < 1 UE per 100 ventilator days. We measured the impact of this intervention and noted that prophylactically advancing high ETTs led to a statistically significant decrease in the unit's UE rate.

Despite widespread agreement that UE in the neonatal ICU is a significant risk factor for patient harm, common interventions, including 2-person patient moves, regular assessment of ETT securement, and standardized taping methods, have failed to eliminate UE as one of the most common adverse events in the neonatal ICU. One study looking to identify and measure potentially preventable harm to neonatal ICU subjects found UE to be the fourth most common adverse event in the neonatal ICU, accounting for 8.3% of all adverse events, with nearly a quarter of adverse events resulting in permanent harm, requiring intervention to save the subject's life, or contributing to the subjects' death.[10]

There is no doubt that the risk of UE is increased by circumstances both unique and often unavoidable in the neonatal ICU population. These include patient agitation without routine use of sedation or muscle relaxation, the need for tape to stick to small, often moist, faces, the frequent requirement for bedside procedures, patient repositioning required for kangaroo care, prolonged time on mechanical ventilation, and standard use of noncuffed ETTs.[1,11-14] Neonatal ICU providers also work with little margin for error on the ideal ETT placement, which decreases risk for UE without increasing risk for bronchial intubations and regional atelectasis. Anatomically, the newborn larynx is positioned higher in the neck, extending from C3 to C5 to the carina between T3 to T5. T1–T2 should therefore be the midpoint of the trachea. However, the midpoint and carina may only be millimeters apart, and when providers are working with estimated weights, particularly in emergent situations, the correct insertion depth may be difficult to target using common practices such as "weight + 6 = targeted depth."[15]

Moreover, investigation into factors that increase risk for UE has been hampered by an ongoing disagreement about what should be considered an UE and a lack of research into what independent factors may have the greatest impact on UE prevention.[9] Both issues hinder the ability to track a single intervention's effects consistently across units. Although multiple case reports on the implementation of various bundles in individual neonatal ICUs exist, whether the individual interventions in the bundle or just the awareness of and attention to the issue of UE with the implementation of any bundle leads to the subsequent improvement in UE rate is sometimes less clear.[3,4,16]

With this in mind, following the implementation of a prevention bundle that initially led to a decline in our neonatal ICU UE rate but with subsequent plateau, we proposed the addition of a single intervention: to actively advance ETT tips past T1. Maintaining a goal ETT position on chest radiograph has been considered in the literature at least once before; one neonatal ICU, as part of their own UE-prevention bundle, required all patients to have heads held neutrally during chest radiographs, and

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targeted an ETT depth of mid- to lower trachea. They were able to reduce their UE rate by 53% from 1.15 to 0.54 UEs per 100 ventilator days.[2] Because the recommendation to assess ETT tip on chest radiograph was implemented at the same time point as at least 6 other recommendations, it was difficult to determine how much of the unit's improvement in their UE rate could be attributed to each individual factor.

Our study is unique in its study design, in that we were able to evaluate the impact of a single intervention in this 2-phase study. Nonetheless, this project did present some limitations. First, this was an observational, sequentially designed project, not a randomized controlled trial. When the single intervention to advance ETTs was instituted, the initial UE-prevention bundle was still in place and could be a confounding factor in attributing the decline in unit UE rate solely to the new focus on ETT advancement. A second limitation of this study is that all chest radiographs were read by a single reviewer. Finally, this study design lacked a regularly prescribed daily chest radiograph, an intentional decision so as to avoid radiation exposure in patients often intubated for extended periods of time. This decision, however, creates varying intervals between chest radiograph and UE and introduces the possibility that the position of ETT at the time of the chest radiograph was not in fact the same as at time of UE, a dilemma that could both underestimate or overestimate the effect of ETT tip position on UE. Similarly, the study did not require a follow-up chest radiograph after repositioning of a high ETT, which limited the ability to measure such respiratory complications as atelectasis or deep ETTs secondary to repositioning ETT tips. The best measure of respiratory complications for this project, therefore, is the measure of the number of UE due to the process of ETT advancement. Risk of UE during ETT advancement was low, with only 14% of the total UEs attributed to the process of ETT advancement. Although any risk of UE should prompt extra caution during the intervention, the relatively low risk is reassuring and should not preclude the addition of this intervention to neonatal ICU respiratory bundles.

Ultimately, the reduction in neonatal ICU UE rates is likely driven by multiple factors working in conjunction. Given the paucity of literature on the impact of ETT tip position on UE rate, our project indicates that it may be an important but underutilized component of the neonatal ICU provider's toolbox to reduce UEs.

Conclusions

High ETTs are significantly associated with UE in the neonatal ICU. Optimizing ETT tip position to below T1 is an underutilized but valuable driver in a provider's toolbox to reduce UEs in the neonatal ICU. Because there is a finite, though low, risk of UE during ETT advancement, extra caution should be taken during the intervention.

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