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The role of polysomnography in decannulation of children with brain and spinal cord injuries

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Abstract

Objective: The objective of this retrospective review was to determine the utility of polysomnography (PSG) in influencing the decision to decannulate pediatric patients with brain and spinal cord injuries in an inpatient rehabilitation hospital setting.

Methods: Between 2010 and 2016, data were collected on pediatric patients with brain and/or spinal cord injuries who had PSG performed with the goal of decannulation. Patients underwent a decannulation protocol involving toleration of continuous tracheostomy capping and bedside tracheoscopy by otolaryngology. Decision to decannulate was determined with input from multiple disciplines. Associations were examined between decannulation success and findings on PSG as well as demographic factors, injury characteristics, otolaryngology findings, and timeline from initial injury to selected events.

Results: A total of 46 patients underwent PSG, after which 38 (83%) were deemed appropriate and eight (17%) were deemed inappropriate for decannulation. Individuals who were deemed ready for decannulation had significantly lower obstructive apnea hypopnea indexes (AHI) (1.7 vs 5.4 events/h, $P = 0.03$), respiratory disturbance indexes (RDI) (2.4 vs 7.6 events/h, $P = 0.006$), and peak end tidal carbon dioxide (CO₂) levels (50.0 vs 58.7 torr, $P = 0.009$) on PSG compared to those who were not decannulated. There were no complications following decannulation prior to discharge.

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CONFLICTS OF INTEREST

None.

Conclusion: PSG provided important additional information as part of a multidisciplinary team assessment of clinical readiness for decannulation in pediatric patients with brain and spinal cord injuries who underwent a decannulation protocol. Obstructive AHI, RDI, and peak end tidal CO₂ level were associated with successful decannulation prior to discharge from inpatient rehabilitation.

Keywords

inpatient rehabilitation; neuromuscular weakness; sleep study; tracheostomy decannulation

1 | INTRODUCTION

Pediatric patients with brain and spinal cord injuries often require placement of a tracheostomy to manage their respiratory insufficiency and need for prolonged ventilatory support.^{1,2} Protocols for removal of the tracheostomy, or “decannulation,” are not uniform. Some centers require an overnight polysomnogram (PSG) to document readiness for decannulation in order to evaluate dynamic airway factors during sleep when pharyngeal muscle tone is decreased and most vulnerable.^{3,4}

PSG is commonly used in outpatient settings to examine the need for non-invasive ventilation in patients with neuromuscular disease and in titrating up and down respiratory support.⁵ While there is some literature emerging on the utility of PSG in predicting successful decannulation in children, this prior research has focused primarily on patients with chronic lung disease of prematurity and those with craniofacial and airway anomalies.^{6–8} Few studies have assessed the utility of PSG in predicting successful decannulation in pediatric patients with brain or spinal cord injuries in whom underlying neuromuscular weakness or airway hypotonia may complicate the ability to tolerate decannulation.^{5,9} In assessing readiness for decannulation, PSG may be able to identify subtle gas exchange abnormalities or evidence of respiratory insufficiency that would otherwise go undetected by alternative methods such as toleration of continuous tracheostomy capping and otolaryngology evaluation.

Tracheostomy decannulation is a common goal for children with brain and spinal cord injuries admitted to pediatric rehabilitation centers. In examining readiness to successfully tolerate decannulation prior to discharge, the Kennedy Krieger Institute (KKI) inpatient rehabilitation unit (Baltimore, MD) initiated a protocol of short periods of tracheostomy capping progressing to continuous tracheostomy capping, followed by overnight PSG performed with the tracheostomy capped. Following the PSG, the decision to decannulate is then made with input from pediatrics, pulmonology, otolaryngology, speech language pathology, and sleep medicine.

To determine the utility of overnight polysomnography (PSG) in influencing the decision to decannulate and/or success of decannulation to discharge from inpatient rehabilitation, we performed a retrospective review of patients with brain and spinal cord injuries admitted with tracheostomy between 2010 and 2016 who underwent an overnight PSG with the intention to decannulate. We hypothesized that individuals deemed ready to decannulate based on a multidisciplinary team agreement would have significantly lower respiratory

disturbance indexes, lower peak end tidal carbon dioxide levels, and higher oxygen nadirs on PSG than individuals not deemed ready to decannulate. As a secondary objective, we sought to determine what additional factors were associated with the decision to decannulate.

2 | METHODS

2.1 | Study population

Study approval was obtained by the Johns Hopkins Medicine Institutional Review Board (IRB NA_00092069). Informed consent was waived given minimal potential risk to subjects. A retrospective review was performed on all patients with brain and spinal cord injuries who had a PSG performed with the goal of decannulation while participating in inpatient rehabilitation at KKI between 2010 and 2016. The pediatric inpatient rehabilitation unit at KKI provides comprehensive medical management and intensive therapy services to patients with functional deficits related to illness or injury through an interdisciplinary team approach. Consultative services are available including pulmonology, otolaryngology, and sleep medicine.

Inclusion criteria included patients 0–21 years of age, presence of tracheostomy, diagnosis of brain, and/or spinal cord injury on admission, and PSG performed following a tracheostomy capping protocol for the purpose of providing additional information about the safety of decannulation. Patients were excluded on the basis of age greater than 21 years, absence of tracheostomy, diagnosis other than brain or spinal cord injury, or if PSG was performed for a purpose other than the goal of decannulation.

3 | DATA COLLECTION

3.1 | Demographic variables

Demographic data were obtained via chart review including age, sex, race, ethnicity, body mass index (BMI), prior history of obstructive sleep apnea (OSA), prior history of acute respiratory distress syndrome (ARDS), and mechanical ventilation on admission. Admission diagnoses of brain injury and spinal cord injury were reported as well as etiology of injury. For patients with traumatic brain injury (TBI), Rancho Los Amigos Levels of Cognitive Functioning Scale (LCFS) was reported to characterize the level of brain recovery at time of PSG.¹⁰ Spinal cord neurological level of injury (NLI) and American Spinal Injury Association (ASIA) Impairment Scale were identified based on criteria outlined by the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) Revised 2011.¹¹

3.2 | Otolaryngology variables

Data were collected regarding the number of patients who received airway endoscopy by otolaryngology in the office and/or operating room. The timing of initial endoscopy was categorized as prior to tracheostomy capping, after tracheostomy capping and prior to PSG, and after PSG. Relevant findings on airway endoscopy included assessment of vocal cord movement, presence of suprastomal granuloma, and presence of tracheal stenosis. The

number of patients who had tracheostomy downsized to a smaller size prior to decannulation was also recorded.

3.3 | PSG variables

PSG was performed with the tracheostomy capped. Studies were scored by a registered polysomnographic technician and interpreted by physicians board certified in sleep medicine using criteria from the American Academy of Sleep Medicine (AASM).¹² The physicians scoring the studies were not blinded to the team's clinical assessment of readiness for decannulation. An obstructive apnea was defined as a drop in the peak signal excursion by 90% of preevent baseline for at least the duration of two breaths during baseline breathing associated with the presence of respiratory effort throughout the entire period of absent airflow. A central apnea was defined as drop in peak signal excursion by 90% of pre-event baseline and associated with absent inspiratory effort throughout the entire duration of the event and if the event lasted 20 s or if the event lasted at least the duration of two breaths during baseline breathing and was associated with an arousal or a 3% arterial oxygen desaturation. A hypopnea was defined as a drop in peak signal excursion by 30% of pre-event baseline lasting for 2 breaths and if there was a 3% oxygen desaturation from pre-event baseline or the event was associated with an arousal.¹²

The relevant indices that were collected for our study include the obstructive apnea hypopnea index (AHI), central apnea index, respiratory disturbance index (RDI), peak end tidal carbon dioxide (CO₂) level during sleep, oxygen saturation (SpO₂) nadir during sleep, and percentage of total sleep time with SpO₂ less than 92%. For five patients, CO₂ level was alternatively measured transcutaneously. In eight patients, percentage of total sleep time with SpO₂ less than 90% was reported rather than 92%. If a patient had more than one sleep study performed, the first study that had adequate sleep time recorded was used in the data analysis.

3.4 | Timeline variables

Dates were collected for the following events: initial injury, tracheostomy, admission to KKI, capping initiation, 24-h toleration of capping, initial airway endoscopy, PSG, decannulation, and discharge from KKI. The amount of time from date of initial injury to each event was calculated for comparison.

3.5 | Statistics

Descriptive statistics were calculated for demographic, otolaryngology, PSG, and timeline variables with mean and ranges performed for continuous variables and percentages for categorical variables. Due to the small sample size of our study population, non-parametric statistics were utilized to evaluate differences between the successful and no decannulation groups, including the Wilcoxon signed rank test for continuous variables and the Fisher exact test for categorical variables. The level of statistical significance was considered to be $P < 0.05$.

4 | RESULTS

A total of 46 patients with tracheostomy underwent capped PSG during inpatient rehabilitation for the goal of decannulation between 2010 and 2016. Of these, 38 (83%) were deemed appropriate for decannulation based on input from pediatrics, pulmonology, otolaryngology, speech language pathology, and sleep medicine. Eight patients (17%) were deemed inappropriate and decannulation was not attempted during their inpatient rehabilitation stay. All patients deemed appropriate were successfully decannulated prior to discharge except for one patient who was scheduled for a planned neurosurgical intervention following discharge from rehabilitation. There were no complications following decannulation or requirement for replacement of tracheostomy tube in these patients during the inpatient rehabilitation stay.

4.1 | Patient demographics

There were no statistically significant differences in demographics factors between the successful decannulation and no decannulation groups. The mean age of the patient population studied was 13.6 years with 72% male and 28% female. Of the patients studied, 59% identified as white and 26% identified as African American, with 94% identifying as non-Hispanic. The mean BMI was 18.8 kg per square meter (kg/m^2). Only one patient had a history of acute respiratory distress syndrome (ARDS), while no patients had a diagnosis of obstructive sleep apnea (OSA) prior to admission. Twenty percent of our population were on mechanical ventilation on admission, all of whom were eventually decannulated. No patients required supplemental oxygen at time of PSG. There was a trend toward a younger mean age in the no decannulation group compared to the successful decannulation group (10.4 vs 14.3 years), although this did not achieve statistical significance ($P = 0.07$) (Table 1).

4.2 | Brain and spinal cord injury characteristics

Thirty-seven patients (80%) had an admission diagnosis of brain injury of which 25 (68%) were considered traumatic. The Ranchos Los Amigos LCFS for patients with traumatic brain injury ranged from II (generalized response) to VII (appropriate and automatic), with the most common level being VII in 36% ($n = 9$) of patients. There were no statistically significant differences between our successful decannulation and no decannulation groups regarding brain injury diagnosis, etiology of injury, or stage of brain injury recovery (Table 2).

Fourteen patients (30%) had an admission diagnosis of spinal cord injury of which nine (64%) were considered traumatic. Spinal cord injury levels ranged from C1 to T2. Of the four patients with spinal cord injury who were not decannulated, three patients had a spinal cord injury level of C2 while one patient had a level of C5. There were no significant differences regarding diagnosis of spinal cord injury, etiology of injury, neurologic level of injury, or ASIA Impairment Scale (Table 2).

4.3 | Otolaryngology characteristics

Eighty-three percent ($n = 38$) of patients underwent airway endoscopy by otolaryngology. All of the patients ($n = 8$) in the no decannulation group underwent airway endoscopy

compared to 79% ($n = 30$) in the successful decannulation group. Four patients (50%) in the unsuccessful decannulation group required additional endoscopic evaluation in the operating room compared to no patients in the successful group ($P = < 0.01$). Of those who underwent tracheoscopy, 61% ($n = 23$) of patients were evaluated prior to capping trials with no difference between groups.

There was a significantly higher percentage of suprastomal granuloma found on tracheoscopy in the no decannulation group compared to the successful decannulation group (50% vs 7%, $P = 0.01$). Three of the four patients in the no decannulation group had granuloma removal performed in the operating room while the fourth patient had plans for future surgical intervention. For the two patients in the successful decannulation group with granuloma, one patient received medical management while the other had granulation tissue removal performed in the office setting.

Thirty-six of the 38 patients (95%) evaluated by otolaryngology underwent vocal cord assessment. Only one patient in the no decannulation group had abnormal vocal cord movement. No patients in either group were found to have tracheal stenosis. A majority of patients (83%) had tracheostomy tubes downsized during admission, which was not significant between groups (Table 3).

4.4 | Polysomnogram variables

The obstructive AHI was significantly higher in the no decannulation group compared to those who were successfully decannulated (5.4 vs 1.7 events/h) ($P = 0.03$). In addition, the no decannulation group had a significantly higher RDI of 7.6 events/h compared to those who were successfully decannulated at 2.4 events/h ($P = 0.006$). Peak end tidal CO_2 was also significantly higher in the no decannulation group compared to the successful decannulation group (58.7 vs 50.0 torr, $P = 0.009$). There was a trend towards higher percent total sleep time with SpO_2 less than 92% in the no decannulation group compared to the successful decannulation group, however, this did not reach significance (3.4 vs 0.2%, $P = 0.05$). There were no significant differences between the groups for central apneas or oxygen nadir (Table 4).

4.5 | Timeline variables

There were no significant differences in the time from initial injury to selected events in the steps toward decannulation including tracheostomy, admission, capping initiation, toleration of 24-h capping, initial airway endoscopy, PSG, decannulation, and discharge (Table 5).

5 | DISCUSSION

Decannulation is an important step in the rehabilitation course of patients with tracheostomy who have suffered brain and spinal cord injuries. In this retrospective review, we analyzed findings on overnight PSG in patients tolerating continuous capping who were successfully decannulated during inpatient rehabilitation compared to those who were deemed inappropriate for decannulation based on sleep study results. In addition, we examined the relationship between those who were successfully decannulated and patient demographics, etiology of injury, and otolaryngology findings.

We found that the PSG variables of RDI, obstructive AHI, and peak end tidal CO₂ were associated with the decision to decannulate. The difference in RDI was largely driven by the obstructive AHI as the central apneas were similar between groups. Our findings are consistent with other studies^{6–8} that have also demonstrated a significant relationship between absence of obstructive AHI and successful decannulation. Although there was a trend toward a higher percent total sleep time with SpO₂ less than 92% in the no decannulation group ($P = 0.05$), there was no significant difference in oxygen nadir between the two groups. Our results suggest that overnight pulse oximetry monitoring alone may not be sufficient to detect underlying respiratory insufficiency in patients with capped tracheostomies. Given these findings, our study suggests that PSG provides valuable information in determining readiness for decannulation in patients undergoing inpatient rehabilitation.

In addition, we found that the decision to decannulate was associated with the presence of suprastomal granuloma discovered on airway endoscopy by otolaryngology. Granuloma formation is a common complication of long term tracheostomy^{13,14} and may preclude successful decannulation. Previously established guidelines suggest performing airway endoscopy in all pediatric patients being considered for decannulation to assess for airway patency and vocal fold mobility.¹⁵ At our center, airway endoscopy is performed at the bedside or in the office setting, while the operating room is reserved for cases where the airway cannot be visualized adequately or if airway interventions are needed. In addition, young children may require airway endoscopy in the operating room as visualization and/or cooperation may be difficult in an office setting. Airway examination should ideally be performed prior to PSG to evaluate and treat any obvious structural abnormalities before assessing dynamic airway factors. Our findings support that endoscopic evaluation by otolaryngology is an important complimentary tool to PSG in assessing for decannulation readiness.

We did not find an association between successful decannulation and demographic factors, etiology of injury, injury characteristics, or timeline from initial injury to selected events, although there was a trend toward a younger mean age in the unsuccessful decannulation group. We did not look at the relationship between findings on imaging or Glasgow Coma Scale and decannulation, which has been reported in other studies.^{16–18} Given our small sample size, further studies are needed to determine what demographic factors or factors related to underlying diagnosis may be associated with decannulation success as this could help to tailor decannulation protocols to specific patient populations.

Our data help to confirm the role of PSG as an integral component in the decannulation protocol utilized at our center (Figure 1). The final decision regarding decannulation was based on the clinical judgment of the primary physician in conjunction with pulmonology, otolaryngology, sleep medicine, and speech language pathology and on information provided by the PSG. In patients who completed our protocol, 38 out of 46 (83%) were deemed appropriate for decannulation after PSG. There were no complications following decannulation in these patients prior to discharge.

Compared to our study, other investigators have demonstrated the utility of PSG in predicting decannulation success in pediatric patients with tracheostomy.⁶⁻⁸ These studies were not performed in rehabilitation patients and they tended to include younger patients with tracheostomy due to underlying airway abnormalities and pulmonary disorders with only a small proportion having neuromuscular related pathology. Decannulation success rates varied between 54% and 79.5%⁶⁻⁸ and successful decannulation was found to be associated with AHI,⁶⁻⁸ percent of total sleep time with oxygen saturation less than 90%,⁶ oxygen nadir,⁶ and maximal end tidal CO₂.⁸

There have been only a small number of studies regarding decannulation protocols specific to pediatric patients with brain⁹ and spinal cord disorders^{19,20} undergoing inpatient rehabilitation, none of which utilize PSG. In contrast, our results support the use of PSG in this patient population given the association of these disorders with the development of neuromuscular weakness and decreased tone. Decreased respiratory muscle strength and low lung volumes may lead to obstructive sleep apnea by reducing traction and stability of the upper airway.⁵ Bulbar dysfunction, pharyngeal neuropathy, or airway hypotonia may also promote airway obstruction in these patients. Hypoventilation may be seen due to low lung volumes and a weakened respiratory response to hypercarbia in addition to possible disruption of the central drive in patients with brain injuries.⁵ These factors may lead to a higher RDI and place patients at risk for respiratory tract infections and respiratory failure. PSG can help to classify events that may otherwise go undiagnosed by bedside monitoring and can guide interventions such as noninvasive ventilation that may eventually allow for safe decannulation with additional respiratory support. Given the potentially altered respiratory mechanics in patients with brain and spinal cord injuries, our study supports utilizing PSG to assist in determining decannulation readiness in this vulnerable patient population.

Our study has several limitations. It is a retrospective single center study of patients in a specialized inpatient rehabilitation unit with access to sleep medicine, pulmonology, and otolaryngology consultants as well as PSG. Our protocol may not translate to other centers where PSG is not offered or in outpatient situations where patients are not as closely monitored. We had a small sample size of only eight patients in our no decannulation group, which may have made it difficult to detect differences between groups. Another potential limitation to our study is that the physicians scoring the sleep studies were not blinded to the team's clinical assessment of readiness for decannulation. We only included patients with tracheostomy who completed our entire protocol, including PSG. Those who were unable to be weaned off of mechanical ventilation, did not tolerate capping trials, or were deemed inappropriate by otolaryngology prior to PSG would not have been included in our study. Therefore, our success rate of 83% may not reflect the entire population of those with tracheostomy admitted to inpatient rehabilitation. All of the patients in our study who were decannulated were successfully discharged without further complications. However, we did not have long term follow-up to ensure that repeat tracheostomy or other airway interventions were not needed later.

In summary, we found that PSG provides important information regarding readiness for decannulation in patients with brain and spinal cord injuries undergoing inpatient

rehabilitation who are unlikely to have premorbid airway or lung abnormalities. Tolerant of continuous capping and bedside tracheoscopy by otolaryngology alone may not provide sufficient information as 8 out of 46 (17%) of our patients were discovered to have concerning findings on PSG which prevented attempts at decannulation. In particular, PSG parameters including RDI, obstructive AHI and maximum end tidal CO₂ were significantly associated with successful decannulation. Additional studies are needed to establish the optimal way to incorporate PSG into a decannulation protocol as well as long term follow-up strategies to evaluate continued success.

REFERENCES

1. Ogilvie LN, Kozak JK, Chiu S, Adderley RJ, Kozak FK. Changes in pediatric tracheostomy 1982–2011: a canadian tertiary children's hospital review. *J Pediatr Surg*. 2014;49:1549–1553. [PubMed: 25475792]
2. Santus P, Gramegna A, Radovanovic D, et al. A systematic review on tracheostomy decannulation: a proposal of a quantitative semiquantitative clinical score. *BMC Pulm Med*. 2014;14:201 2466–14–201. [PubMed: 25510483]
3. Tunkel DE, McColley SA, Baroody FM, Marcus CL, Carroll JL, Loughlin GM. Polysomnography in the evaluation of readiness for decannulation in children. *Arch Otolaryngol Head Neck Surg*. 1996;122: 721–724. [PubMed: 8663942]
4. Mukherjee B, Bais AS, Bajaj Y. Role of polysomnography in tracheostomy decannulation in the paediatric patient. *J Laryngol Otol*. 1999;113:442–445. [PubMed: 10505158]
5. Aboussouan LS. Sleep-disordered breathing in neuromuscular disease. *Am J Respir Crit Care Med*. 2015;191:979–989. [PubMed: 25723731]
6. Cristea AI, Jalou HE, Givan DC, Davis SD, Slaven JE, Ackerman VL. Use of polysomnography to assess safe decannulation in children. *Pediatr Pulmonol*. 2016;51:796–802. [PubMed: 26919704]
7. Robison JG, Thottam PJ, Greenberg LL, Maguire RC, Simons JP, Mehta DK. Role of polysomnography in the development of an algorithm for planning tracheostomy decannulation. *Otolaryngol Head Neck Surg*. 2015;152:180–184. [PubMed: 25389316]
8. Gurbani N, Promyothin U, Rutter M, Fenchel MC, Szczesniak RD, Simakajornboon N. Using polysomnography and airway evaluation to predict successful decannulation in children. *Otolaryngol Head Neck Surg*. 2015;153:649–655. [PubMed: 26124266]
9. Pozzi M, Galbiati S, Locatelli F, Clementi E, Strazzer S. Performance of a tracheostomy removal protocol for pediatric patients in rehabilitation after acquired brain injury: factors associated with timing and possibility of decannulation. *Pediatr Pulmonol*. 2017;52:1509–1517. [PubMed: 28950420]
10. Flannery J. Using the levels of cognitive functioning assessment scale with patients with traumatic brain injury in an acute care setting. *Rehabil Nurs*. 1998;23:88–94. [PubMed: 9668871]
11. Kirshblum SC, Burns SP, Biering-Sorensen F, et al. International standards for neurological classification of spinal cord injury (revised 2011). *J Spinal Cord Med*. 2011;34:535–546. [PubMed: 22330108]
12. Berry RB, Brooks R, Gamaldo CE, Harding SM, Marcus CL, Vaughn BV. The AASM manual for the scoring of sleep and associated events: Rules, terminology and technical specifications, version 2.0. Darien, Illinois: American Academy of Sleep Medicine 2012.
13. Al-Samri M, Mitchell I, Drummond DS, Bjornson C. Tracheostomy in children: a population-based experience over 17 years. *Pediatr Pulmonol*. 2010;45:487–493. [PubMed: 20425857]
14. Citta-Pietrolungo TJ, Alexander MA, Cook SP, Padman R. Complications of tracheostomy and decannulation in pediatric and young patients with traumatic brain injury. *Arch Phys Med Rehabil*. 1993;74: 905–909. [PubMed: 8379834]
15. Mitchell RB, Hussey HM, Setzen G, et al. Clinical consensus statement: tracheostomy care. *Otolaryngol Head Neck Surg*. 2013;148:6–20. [PubMed: 22990518]

16. Perin C, Meroni R, Rega V, Braghetto G, Cerri CG. Parameters influencing tracheostomy decannulation in patients undergoing rehabilitation after severe acquired brain injury (sABI). *Int Arch Otorhinolaryngol.* 2017;21:382–389. [PubMed: 29018503]
17. Zanata Ide L, Santos RS, Hirata GC. Tracheal decannulation protocol in patients affected by traumatic brain injury. *Int Arch Otorhinolaryngol.* 2014;18:108–114. [PubMed: 25992074]
18. Mitton K, Walton K, Sivan M. Tracheostomy weaning outcomes in relation to the site of acquired brain injury: a retrospective case series. *Brain Inj.* 2017;31:267–271. [PubMed: 28102699]
19. Gundogdu I, Ozturk EA, Umay E, Karaahmet OZ, Unlu E, Cakci A. Implementation of a respiratory rehabilitation protocol: weaning from the ventilator and tracheostomy in difficult-to-wean patients with spinal cord injury. *Disabil Rehabil.* 2017;39:1162–1170. [PubMed: 27339104]
20. Padman R, Alexander M, Thorogood C, Porth S. Respiratory management of pediatric patients with spinal cord injuries: retrospective review of the duPont experience. *Neurorehabil Neural Repair.* 2003;17:32–36. [PubMed: 12645443]

FIGURE 1.
Kennedy Krieger Institute decannulation protocol

TABLE 1

Patient demographics

	Entire study sample (<i>n</i> = 46)	Successful decannulation (<i>n</i> = 38)	No decannulation (<i>n</i> = 8)	<i>P</i> -value
Age (years) (mean ± SD [range])	13.6 ± 5.4 [2.2–20.9]	14.3 ± 5.1 [3.0–20.9]	10.4 ± 5.7 [2.2–18.3]	0.07
Sex (<i>n</i> , % male)	33 (71.7%)	28 (73.7%)	5 (62.5%)	0.40
Race (<i>n</i> , %)				
Caucasian	27 (58.7%)	22 (57.9%)	5 (62.5%)	
African American	12 (26.1%)	10 (26.3%)	0 (0.0%)	1.0
Asian	0 (0.0%)	0 (0.0%)	2 (25.0%)	
Other	7 (15.2%)	6 (15.8%)	1 (12.5%)	
Ethnicity (<i>n</i> , % non-hispanic)	43 (93.5%)	35 (92.1%)	8 (100%)	1.0
BMI (kg/m ²) (mean ± SD [range])	18.8 ± 4.3 [12.3–30.5]	19.1 ± 4.3 [12.3–30.5]	17.3 ± 3.9 [12.9–24.3]	0.22
Past ARDS (<i>n</i> , %)	1 (2.2%)	1 (2.6%)	0 (0.0%)	1.0
Past OSA (<i>n</i>)	0	0	0	-
Ventilator on admission (<i>n</i> , %)	9 (19.6%)	9 (23.7%)	0 (0.0%)	0.15

ARDS, acute respiratory distress syndrome; BMI, body mass index; OSA, obstructive sleep apnea.

TABLE 2

Brain and spinal cord injury characteristics

	Entire study sample (n = 46)	Successful decannulation (n = 38)	No decannulation (n = 8)	P-value
Brain injury diagnosis (n, (%))	37 (80.4%)	31 (81.6%)	6 (75.0%)	0.50
Brain injury type (n)	(n = 37)	(n = 31)	(n = 6)	
Traumatic	25	21	4	
Tumor	1	1	0	
Infectious/autoimmune	3	3	0	0.48
Cerebrovascular accident	3	3	0	
Hydrocephalus	1	1	0	
Anoxic	3	2	1	
Metabolic	1	0	1	
Rancho LCFS in TBI (n)	(n = 25)	(n = 21)	(n = 4)	
II	1	1	0	
III	5	3	2	
IV	4	4	0	0.75
V	4	4	0	
VI	2	2	0	
VII	9	7	2	
Spinal cord injury diagnosis (n, (%))	14 (30.4%)	10 (26.3%)	4 (50.0%)	0.18
Spinal cord injury type (n)	(n = 14)	(n = 10)	(n = 4)	
Traumatic	9	7	2	
Tumor	0	0	0	0.75
Infectious/autoimmune	3	2	1	
Other	2	1	1	
Neurologic level of injury (n)	(n = 14)	(n = 10)	(n = 4)	
C1	1	1	0	
C2	4	1	3	
C3	2	2	0	0.17
C4	2	2	0	
C5	1	0	1	
C6	2	2	0	

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	Entire study sample (<i>n</i> = 46)	Successful decannulation (<i>n</i> = 38)	No decannulation (<i>n</i> = 8)	<i>P</i> -value
T2	2	2	0	
ASIA impairment scale (<i>n</i>)	(<i>n</i> = 14)	(<i>n</i> = 10)	(<i>n</i> = 4)	
A	6	6	0	
B	3	2	1	0.15
C	3	1	2	
D	2	1	1	

ASIA, American Spinal Injury Association; LCFS, Levels of Cognitive Functioning Scale; TBI, traumatic brain injury.

TABLE 3

Otolaryngology variables

	Entire study sample (<i>n</i> = 46)	Successful decannulation (<i>n</i> = 38)	No decannulation (<i>n</i> = 8)	<i>P</i> -value
Airway endoscopy (<i>n</i> , (%))	38 (82.6%)	30 (79.0%)	8 (100%)	0.19
Office	4 (8.7%)	0	4 (50.0%)	0.000
Operating room	(<i>n</i> = 38)	(<i>n</i> = 30)	(<i>n</i> = 8)	
Endoscopy timing (<i>n</i> , (%))	23 (60.5%)	19 (63.3%)	4 (50.0%)	
Before capping	8 (21.1%)	6 (20.0%)	2 (25.0%)	0.63
After capping, before PSG	7 (18.4%)	5 (16.7%)	2 (25.0%)	
After PSG	(<i>n</i> = 36)	(<i>n</i> = 29)	(<i>n</i> = 7)	
Endoscopic findings (<i>n</i> , (%))	35 (97.2%)	29 (100.0%)	6 (85.7%)	0.19
Intact vocal cord movement	(<i>n</i> = 38)	(<i>n</i> = 30)	(<i>n</i> = 8)	
Endoscopic findings (<i>n</i> , (%))	6 (15.8%)	2 (6.7%)	4 (50.0%)	0.01
Suprastomal granuloma	0 (0.0%)	0 (0.0%)	0 (0.0%)	-
Tracheal stenosis	38 (82.6%)	31 (81.6%)	7 (87.5%)	1.0
Tracheostomy downsized (<i>n</i> , (%))				

P values in bold indicate <0.05.

TABLE 4

Polysomnogram variables

	Entire study sample (<i>n</i> = 46)	Successful decannulation (<i>n</i> = 38)	No decannulation (<i>n</i> = 8)	<i>P</i> -value
Obstructive AHI (events/h) (mean ± SD [range])	2.3 ± 3.6 [0.0–18.6]	1.7 ± 2.6 [0.0–13.7]	5.4 ± 6.1 [0.1–18.6]	0.03
Central apneas (events/h) (mean ± SD [range])	1.0 ± 2.2 [0.0–14.3]	0.7 ± 1.0 [0.0–3.8]	2.3 ± 4.9 [0.0–14.3]	0.37
RDI (events/h) (mean ± SD [range])	3.3 ± 4.1 [0.0–18.6]	2.4 ± 2.8 [0.0–14.2]	7.6 ± 6.4 [0.9–18.6]	0.006
Peak End Tidal CO ₂ (torr)	(<i>n</i> = 45)	(<i>n</i> = 38)	(<i>n</i> = 7)	
(mean ± SD [range]) ^a	51.2 ± 7.0 [36.1–79.0]	50.0 ± 5.4 [36.1–60.1]	58.7 ± 9.8 [50.4–79.0]	0.009
Percent TST, SpO ₂ <92% (%) (mean ± SD [range]) ^b	0.7 ± 3.6 [0.0–24.6]	0.2 ± 0.4 [0.0–1.6]	3.4 ± 8.6 [0.0–24.6]	0.05
Oxygen Nadir (%) (mean ± SD [range])	89.6 ± 6.0 [71.0–97.0]	90.3 ± 4.6 [76.0–96.0]	86.0 ± 10.0 [71.0–97.0]	0.32

AHI, apnea hypopnea index; CO₂, carbon dioxide; RDI, respiratory disturbance index; SpO₂, oxygen saturation; TST, total sleep time.

P-values in bold indicate <0.05.

^aFor five patients in the “Successful Decannulation” group, measurement was taken from peak transcutaneous CO₂ rather than peak end tidal CO₂. One patient in the “No Decannulation” group was missing data for peak end tidal CO₂.

^bFor three patients in the “No Decannulation” group and four patients in “Successful Decannulation” group, measurement was made for percent total sleep time in which SpO₂ was <90%.

Time from injury to selected events

TABLE 5

	Entire study sample (<i>n</i> = 46)	Successful decannulation (<i>n</i> = 38)	No decannulation (<i>n</i> = 8)	<i>P</i> -value
Injury to tracheostomy (days) (mean ± SD [range])	18.0 ± 12.4 [4–71]	18.7 ± 13.4 [5–71]	14.5 ± 5.2 [4–19]	0.79
Injury to admission (days) (mean ± SD [range])	75.4 ± 111.8 [13–595]	76.4 ± 117.0 [13–595]	70.4 ± 88.6 [25–285]	0.79
Injury to start capping trial (days)	(<i>n</i> = 45)	(<i>n</i> = 37)	(<i>n</i> = 8)	
(mean ± SD [range])	94.4 ± 108.9 [24–613]	96.4 ± 116.8 [24–613]	84.9 ± 65.0 [39–230]	0.87
Injury to 24 h capping (days) (mean ± SD [range])	107.3 ± 109.4 [32–619]	108.8 ± 117.1 [32–619]	100.3 ± 66.0 [49–240]	1.0
Injury to initial endoscopy (days)	(<i>n</i> = 38)	(<i>n</i> = 30)	(<i>n</i> = 8)	
(mean ± SD [range])	104.1 ± 110.7 [23–613]	107.2 ± 118.7 [23–613]	492.5 ± 78. [35–279]	0.77
Injury to polysomnogram (days) (mean ± SD [range])	117.5 ± 111.0 [36–623]	117.6 ± 116.9 [36–623]	117.1 ± 83.2 [58–305]	0.72
Injury to decannulation (days)	(<i>n</i> = 38)	(<i>n</i> = 38)		
(mean ± SD [range])	124.0 ± 117.0 [43–625]	124.0 ± 117.0 [43–625]	-	-
Injury to discharge (days) (mean ± SD [range])	156.6 ± 109.4 [49–645]	156.9 ± 115.5 [49–645]	155.0 ± 79.9 [67–329]	0.74