Mechanical ventilation weaning and extubation after spinal cord injury: A Western Trauma Association multicenter study

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BACKGROUND: Respiratory failure after acute spinal cord injury (SCI) is well recognized, but data defining which patients need long-term ventilator support and criteria for weaning and extubation are lacking. We hypothesized that many patients with SCI, even those with cervical SCI, can be successfully managed without long-term mechanical ventilation and its associated morbidity.

METHODS: Under the auspices of the Western Trauma Association Multi-Center Trials Group, a retrospective study of patients with SCI at 14 major trauma centers was conducted. Comprehensive injury, demographic, and outcome data on patients with acute SCI were compiled. The primary outcome variable was the need for mechanical ventilation at discharge. Secondary outcomes included the use of tracheostomy and development of acute lung injury and ventilator-associated pneumonia.

RESULTS: A total of 360 patients had SCI requiring mechanical ventilation. Sixteen patients were excluded for death within the first 2 days of hospitalization. Of the 344 patients included, 222 (64.5%) had cervical SCI. Notably, 62.6% of the patients with cervical SCI were ventilator free by discharge. One hundred forty-nine patients (43.3%) underwent tracheostomy, and 53.7% of them were successfully weaned from the ventilator, compared with an 85.6% success rate among those with no tracheostomy ($p < 0.05$). Patients who underwent tracheostomy had significantly higher rates of ventilator-associated pneumonia (61.1% vs. 20.5%, $p < 0.05$) and acute lung injury (12.8% vs. 3.6%, $p < 0.05$) and fewer ventilator-free days (1 vs. 24 $p < 0.05$). When controlled for injury severity, thoracic injury, and respiratory comorbidities, tracheostomy after cervical SCI was an independent predictor of ventilator dependence with an associated 14-fold higher likelihood of prolonged mechanical ventilation (odds ratio, 14.1; 95% confidence interval, 2.78–71.67; $p < 0.05$).

CONCLUSION: While many patients with SCI require short-term mechanical ventilation, the majority can be successfully weaned before discharge. In patients with SCI, tracheostomy is associated with major morbidity, and its use, especially among patients with cervical SCI, deserves further study. (*J Trauma Acute Care Surg*. 2013;75: 1060–1070. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Prognostic study, level III

KEY WORDS: Spinal cord injury; mechanical ventilation; tracheostomy.

Traumatic spinal cord injury (SCI) represents an injury with devastating sequelae and limited treatment options, affecting 12,000 new patients every year in the United States; less than 1% of patients have complete recovery at hospital discharge.[1] Given dismal prospects for complete functional recovery, the treatment of SCI is focused on preventing secondary injury and maximizing residual function. In keeping with this principle, airway and pulmonary management are of paramount importance in preventing morbidity, minimizing mortality, and promoting meaningful recovery. Multiple studies have addressed respiratory challenges related to SCI, which constitute the most common cause of morbidity and mortality[2–6] and the highest acute costs[2,4,7,8] related to these injuries.

A well-established respiratory rehabilitation profession has evolved to facilitate long-term recovery from SCI. However, few data exist to guide acute ventilator management during the index hospitalization, and whether extubation of these patients can or should be attempted during initial hospitalization remains unknown. This has led to widespread variability in approach to and timing of tracheostomy placement, long-term acute care use, and

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TABLE 1. Patient Demographics/Outcomes

	N = 344
Age, median (range)	43 (18–90)
Male, n (%)	277 (80.5)
Blunt mechanism, n (%)	295 (85.8)
ISS, mean (SD)	32 (16)
Head AIS score, mean (SD)	3 (2)
Chest AIS score, mean (SD)	2 (2)
Arrival GCS score, median (IQR)	14 (8–15)
Cervical injury, n (%)	222 (64.5)
Thoracic injury, n (%)	90 (26.2)
Lumbar injury, n (%)	32 (9.3)
Complete injury, n (%)	172 (20.0)
TBI, n (%)	72 (20.9)
Other injury, n (%)	209 (60.8)
Operative stabilization, n (%)	229 (66.6)
VAP, n (%)	131 (38.1)
ALI, n (%)	26 (7.6)
ARDS, n (%)	30 (8.7)
ICU days, median (IQR)	12 (6–22)
Hospital days, median (IQR)	20 (11–32)
Ventilator-free days (to 28 d), median (IQR)	15 (0–25)
Extubation attempted, n (%)	187 (54.4)
Successfully extubated, never received tracheostomy, n (%)	168 (48.8)
Tracheostomy, n (%)	149 (43.3)
Not mechanically ventilated at discharge, n (%)	247 (71.8)
Cause of death secondary to respiratory failure, n (%)	6 (1.7)
Expired, n (%)	32 (9.3)

Patient demographics for the 344 mechanically ventilated, spinal cord injured patients. For not normally distributed, variables reported as median with IQRs. Ventilator-free days are counted to 28 days.

overall outcomes in this patient demographic. Our group has previously published a single-center study reporting that 74% of patients who survive to discharge after SCI tolerated extubation and did not require tracheostomy. Specifically, more than half of patients with cervical SCI were successfully extubated, leading to shorter intensive care unit (ICU) and hospital stays and a decreased incidence of ventilator-associated pneumonia (VAP).[9] These preliminary findings highlight the possibility that many patients with cervical SCI may not require long-term mechanical ventilation (MV) and may benefit from aggressive weaning and extubation. While intriguing, the small sample size and single-center nature of that study prompted skepticism from the trauma and critical care community, given the prevalent but not necessarily evidence-based teaching that most patients with cervical SCI should undergo tracheostomy during the index hospitalization. Inspired by these data, we hypothesized that many patients with SCI, even those with cervical SCI, can be successfully managed without long-term MV and its associated morbidity. To test this, we performed a multicenter cohort study to examine the predictors of ventilator dependence at discharge in patients with acute SCI.

PATIENTS AND METHODS

The Western Trauma Association Multi-Center Trials Group performed a retrospective cohort study of patients with SCI requiring MV at 14 US trauma centers. Institutional review board approval was obtained from the University of California San Francisco and at all contributing sites. SCI was defined as radiologically confirmed injury to the cervical, thoracic, or lumbar spinal column, combined with clinical signs and symptoms consistent with SCI at that level. Comprehensive injury, demographic, clinical, and outcome data on patients with acute SCI were compiled from medical records, ICU databases, and trauma registries. Ventilator and respiratory therapy data were collected for patients at the time of intubation, extubation (if attempted), and tracheostomy (if performed). Failed extubation was defined as unplanned reintubation or tracheostomy at any point after initial removal of the endotracheal tube. The primary outcome variable was the need for MV at discharge. Secondary outcomes included the use of tracheostomy, acute lung injury (ALI), and VAP based on consensus definitions.[10–13]

All data are presented as mean (SD), median (interquartile range [IQR]), or percentage. Percentages are calculated out of subgroup total (N) for each subgroup analysis. Univariate comparisons were made using Student's *t* test for normally distributed data, Wilcoxon rank-sum testing for skewed data, and Fisher's exact test for proportions. For multiple group univariate comparisons, analysis of variance was used for normally distributed and Kruskal-Wallis testing for skewed data. Multivariate comparisons were performed by logistic regression and adjusted for baseline demographics, injury severity, and respiratory comorbidities (smoking, asthma, chronic obstructive pulmonary disease, or other respiratory disease). Missing predictor data were multiply imputed using standard multivariate normal (for continuous) and logistic (for binary data) methods. For reporting purposes, missing outcome data were presumed negative to reflect the minimum possible incidence. An α of 0.05 was considered significant. All data were analyzed using Stata version 12 (StatCorp LP, College Station, TX).

RESULTS

A total of 360 patients with SCI requiring intubation and MV at 14 trauma centers from 2005 to 2009 were evaluated. Sixteen patients who died within the first 2 days of hospitalization from nonrespiratory causes were excluded. Of the 344 patients analyzed, the majority (80.5%) were male, with a median age of 43 years (range, 18–90 years), and severely injured with a mean (SD) Injury Severity Score (ISS) of 32 (16). Blunt mechanism of injury accounted for the preponderance of SCI (85.8%). The level of SCI was primarily cervical (64.5%, 222 patients, Table 1). Although 72 patients (20.9%) had a concomitant traumatic brain injury (TBI) diagnosis, this did not differ by level of SCI (Table 2, $p = 0.17$). More than half of the patients had additional injuries (60.8%); this differed by level of cord injury, with the highest percentage of additional injuries occurring in patients with thoracic SCI (68.9%, $p < 0.05$, Table 2).

Of the 344 patients included, the majority (71.8%) did not require MV at the time of discharge. Although extubation was only attempted in half of the patients overall, it was successful in the majority of attempts (89.8%, Table 1). This was

TABLE 2. Demographics by Injury Group: Cervical, Thoracic, Lumbar

	Cervical (n = 222)	Thoracic (n = 90)	Lumbar (n = 32)	*p*
Age, median (range)	47 (18–90)	38 (19–83)	37 (18–83)	0.0001
Male, n (%)	175 (78.8)	76 (84.4)	26 (81.3)	0.5460
Blunt mechanism, n (%)	204 (91.9)	64 (71.1)	27 (84.4)	<0.0001
ISS, mean (SD)	31 (17)	36 (13.0)	36 (16.0)	0.0160
Head AIS score, mean (SD)	4 (2)	2 (2)	1 (2)	<0.0001
Chest AIS score, mean (SD)	1 (2)	4 (1)	2 (2)	<0.0001
Arrival GCS score, median (IQR)	14 (6–15)	14 (9–15)	15 (14–15)	0.0311
Complete injury, n (%)	111 (50.0)	53 (58.9)	8 (25.0)	0.0050
TBI, n (%)	47 (21.2)	20 (22.2)	5 (15.6)	0.1720
Other injury, n (%)	137 (61.7)	62 (68.9)	10 (31.3)	<0.0001
Operative stabilization, n (%)	161 (72.5)	47 (52.2)	21 (65.6)	0.0070
VAP, n (%)	100 (45.1)	29 (32.2)	2 (6.3)	<0.0001
ALI, n (%)	17 (7.7)	7 (7.8)	2 (6.3)	0.1140
ARDS, n (%)	22 (9.9)	7 (7.8)	1 (3.1)	0.4990
ICU days, median (IQR)	14 (7–24)	9 (5–21)	6 (3–8)	0.0001
Hospital days, median (IQR)	20 (12–32)	18 (11–33)	16 (9–27)	0.3557
Ventilator-free days (to 28 d), median (IQR)	10 (0–23)	21 (6–26)	26 (19–26)	0.0001
Extubation attempted, n (%)	95 (42.8)	65 (72.2)	27 (84.4)	<0.0001
Successfully extubated, n (%)	80 (36.0)	60 (66.7)	28 (87.5)	<0.0001
Tracheostomy, n (%)	122 (55)	24 (26.7)	3 (9.4)	<0.0001
Not mechanically ventilated at discharge, n (%)	139 (62.6)	78 (86.7)	30 (93.8)	<0.0001
Cause of death secondary to respiratory failure, n (%)	5 (2.3)	0 (0.0)	1 (3.1)	0.4410
Expired, n (%)	22 (9.9)	8 (8.9)	2 (6.3)	0.9180

Patient demographics, injury characteristics, ventilatory status at discharge or transfer, and outcomes for patients by level of SCI. Significance assessed by Kruskal-Wallis for continuous and Fisher's exact test for dichotomous outcomes among groups. For not normally distributed, variables reported as median with IQRs. Ventilator-free days are counted to 28 days.

consistent even in the cervical SCI subpopulation, in which only 42.8% of patients underwent attempted extubation, with 84.2% ultimately successful (Table 2). In addition, extubation occurred early: the median time to extubation for cervical SCI patients was 2 days. The overall cohort had a high rate of VAP (38.1%), and patients with cervical SCI had significantly higher rates of VAP than those with thoracic or lumbar injuries (cervical, 45.1%; thoracic, 32.2%; lumbar, 6.3%; $p < 0.05$; Table 2). The rates of ALI and adult respiratory distress syndrome (ARDS) did not differ significantly by injury level (Table 2). Distribution of injuries by anatomic level and extent of motor deficit is shown in Figure 1.

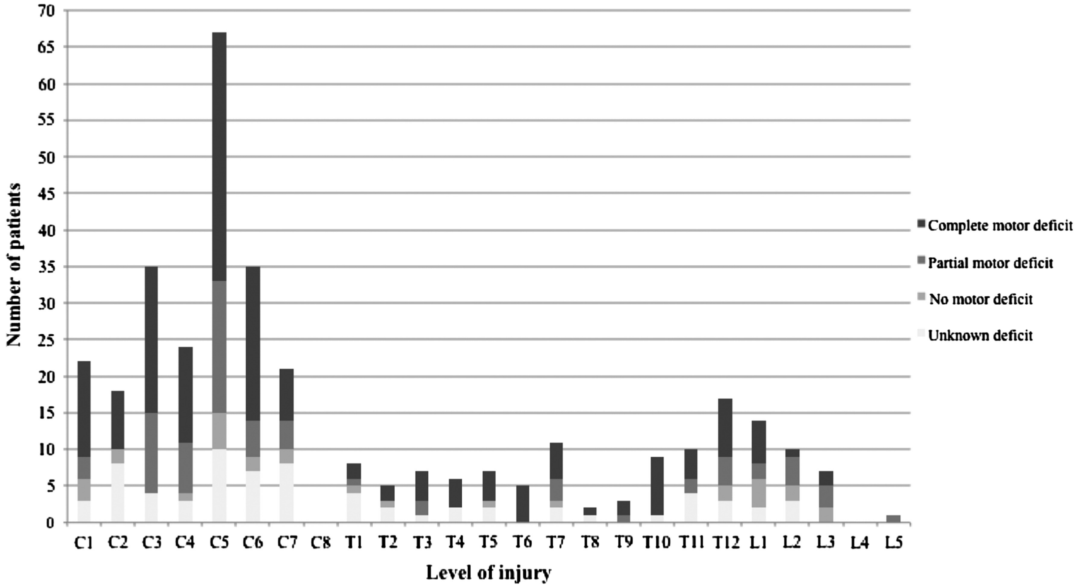

Figure 1. Injuries by anatomical and functional level. Number of patients with each level of spinal cord injury. Stacked bars represent extent of motor loss.

TABLE 3. Demographics/Outcomes for Tracheostomy Versus No Tracheostomy

	Tracheostomy (n = 149)	No Tracheostomy (n = 195)	*p*
Age, median (range)	43 (18–82)	44 (18–90)	0.9355
Male, n (%)	122 (81.9)	155 (79.5)	0.6800
Blunt mechanism, n (%)	129 (86.6)	166 (85.1)	0.7570
ISS, mean (SD)	34 (17)	31 (15)	0.0553
Head AIS score, mean (SD)	4 (2)	3 (2)	0.0006
Chest AIS score, mean (SD)	2 (2)	3 (2)	0.0297
Arrival GCS score, median (IQR)	13 (3–15)	15 (10–15)	0.0029
Cervical injury, n (%)	122 (81.9)	100 (51.3)	
Thoracic injury, n (%)	24 (16.1)	66 (33.9)	<0.0001
Lumbar injury, n (%)	3 (2.0)	29 (14.9)	
Complete injury, n (%)	93 (62.4)	79 (40.5)	<0.0001
TBI, n (%)	35 (23.5)	37 (19.0)	0.0220
Other injury, n (%)	96 (64.4)	113 (58.0)	0.0150
Operative stabilization, n (%)	101 (67.8)	128 (65.6)	0.2490
VAP, n (%)	91 (61.1)	40 (20.5)	<0.0001
ALI, n (%)	19 (12.8)	7 (3.6)	0.0020
ARDS, n (%)	18 (12.1)	12 (6.2)	0.0650
ICU days, median (IQR)	22 (16–33)	6 (4–11)	0.0001
Hospital days, median (IQR)	30 (20–41)	13 (8–23)	0.0001
Ventilator-free days (to 28 d), median (IQR)	1 (0–11)	24 (15–26)	0.0001
Extubation attempted (before tracheostomy), n (%)	23 (15.4)	164 (84.1)	<0.0001
Not mechanically ventilated at discharge, n (%)	80 (53.7)	167 (85.6)	<0.0001
Cause of death secondary to respiratory failure, n (%)	2 (1.3)	4 (2.1)	0.1910
Expired, n (%)	9 (6.0)	23 (11.8)	0.0910

Patient demographics, injury characteristics, ventilatory status at discharge or transfer, and outcomes for patients by tracheostomy versus no tracheostomy. Significance assessed by Kruskal-Wallis for continuous and Fisher's exact test for dichotomous outcomes among groups. For not normally distributed, variables reported as median with IQRs. Ventilator-free days are counted to 28 days. For patients who received tracheostomy, median time to tracheostomy was 7.5 days (IQR, 5–11 days).

TABLE 4. Demographics/Outcomes for Patients With Tracheostomy and off MV at Discharge Versus No Tracheostomy and off MV at Discharge

	Tracheostomy and off MV at Discharge (n = 80)	No Tracheostomy and off MV at Discharge (n = 167)	*p*
Age, median (range)	40 (18–82)	41 (18–83)	0.7793
Male, n (%)	66 (82.5)	130 (77.8)	0.5110
Blunt mechanism, n (%)	67 (83.8)	140 (83.8)	0.2490
ISS, mean (SD)	32 (16)	30 (13)	0.1769
Head AIS score, mean (SD)	3 (2.0)	2 (2)	0.0197
Chest AIS score, mean (SD)	2 (2)	3 (2)	0.2652
Arrival GCS score, median (IQR)	14 (3–15)	15 (11–15)	0.0069
Cervical injury, n (%)	60 (75)	79 (47.3)	
Thoracic injury, n (%)	18 (22.5)	60 (35.9)	<0.0001
Lumbar injury, n (%)	2 (2.5)	28 (16.8)	
Complete SCI, n (%)	45 (56.3)	64 (38.3)	<0.0001
TBI, n (%)	15 (18.8)	29 (17.4)	0.0690
Other injury, n (%)	51 (63.8)	93 (55.7)	0.0080
Operative stabilization, n (%)	50 (62.5)	115 (68.9)	0.4920
VAP, n (%)	39 (48.8)	32 (19.2)	<0.0001
ALI, n (%)	8 (10.0)	4 (2.4)	<0.0001
ARDS, n (%)	10 (12.5)	6 (3.6)	0.0060
ICU days, median (IQR)	21 (14–28)	6 (4–11)	0.0001
Hospital days, median (IQR)	30 (22–41)	14 (9–25)	0.0001
Ventilator-free days (to 28 d), median (IQR)	10 (1–16)	25 (21–26)	0.0001

Significance assessed by Kruskal-Wallis for continuous and Fisher's exact test for dichotomous outcomes among groups. For not normally distributed, variables reported as median with IQRs. Ventilator-free days are counted to 28 days.

TABLE 5. Demographics/Outcomes for Patients off MV at Discharge Versus On MV at Discharge

	Off ventilation at Discharge (n = 247)	On Ventilation at Discharge (n = 63)	*p*
Age, median (range)	41 (18–83)	45 (18–80)	0.0744
Male, n (%)	196 (79.4)	50 (79.4)	0.2630
Blunt mechanism, n (%)	207 (83.8)	56 (88.9)	0.2080
ISS, mean (SD)	31 (14)	36 (17)	0.0129
Head AIS score, mean (SD)	3 (2)	4 (2)	<0.0001
Chest AIS score, mean (SD)	3 (2)	2 (2)	0.0109
Arrival GCS score, median (IQR)	15 (10–15)	13 (8–15)	0.1009
Cervical injury, n (%)	139 (56.3)	59 (93.7)	
Thoracic injury, n (%)	78 (31.6)	4 (6.4)	<0.0001
Lumbar injury, n (%)	30 (12.2)	0 (0.0)	
Complete injury, n (%)	109 (44.1)	47 (74.6)	<0.0001
TBI, n (%)	44 (17.8)	19 (30.2)	0.0570
Other injury, n (%)	144 (58.3)	39 (61.9)	0.1030
Operative stabilization, n (%)	165 (66.8)	49 (77.8)	0.0040
VAP, n (%)	71 (28.7)	49 (77.8)	<0.0001
ALI, n (%)	12 (4.9)	11 (17.5)	0.0010
ARDS, n (%)	16 (6.5)	8 (12.7)	0.1300
ICU days, median (IQR)	10 (5–18)	25 (17–36)	0.0001
Hospital days, median (IQR)	19 (11–31)	28 (18–40)	0.0002
Ventilator-free days (to 28 d), median (IQR)	22 (11–26)	0 (0–0)	0.0001
Extubation attempted, n (%)	177 (71.7)	7 (11.1)	<0.0001
Successfully extubated (never received tracheostomy), n (%)	167 (67.6)	0 (0.0)	<0.0001
Tracheostomy, n (%)	80 (32.4)	59 (93.7)	<0.0001

Patient demographics, injury characteristics, ventilatory status at discharge or transfer, and outcomes for patients on and off MV at discharge. Significance assessed by Kruskal-Wallis for continuous and Fisher's exact test for dichotomous outcomes among groups. For not normally distributed, variables reported as median with IQRs. Ventilator-free days are counted to 28 days.

TABLE 6. Ventilatory Parameters/Arterial Blood Gas Values at Time of Extubation for Patients who Failed Extubation Versus Tolerated Extubation

	Failed Extubation (n = 38)	Successful Extubation (n = 142)	*p*
PH at extubation	7.41 (0.05)	7.42 (0.04)	0.0921
$Paco_2$ at extubation, mm Hg	41 (6)	39 (6)	0.1485
Pao_2 at extubation, mm Hg	114 (53)	130 (65)	0.1786
HCO^3 at extubation, mmol/L	25 (4)	25 (4)	0.9744
Base deficit at extubation	0.4 (3.4)	1.1 (3.8)	0.4557
GCS score at extubation	10 (9–12)	10 (10–11)	0.4830
FIO_2 at extubation	0.39 (0.08)	0.41 (0.13)	0.2984
Respiratory rate at extubation, bpm	19 (7)	18 (6)	0.3547
Ventilator rate at extubation, bpm	12 (7)	10 (5)	0.2734
Tidal volume at extubation, mL	570 (185)	568 (177)	0.9580
Minute volume at extubation, L/min	8.6 (1.6)	8.0 (2.8)	0.2306
Peak pressure at extubation, cm H_2O	22 (16)	19 (8)	0.4095
Plateau pressure at extubation, cm H_2O	16 (7)	17 (7)	0.7241
PEEP at extubation, cm H_2O	5 (1)	5 (1)	0.2872
Spo_2 at extubation, %	99 (97–100)	99 (98–100)	0.0565
Mean airway pressure at extubation, L/cm H_2O	9 (3)	9 (3)	0.8398
Compliance at extubation, L/cm H_2O	0.055 (0.012)	0.049 (0.018)	0.2927
P/F ratio at extubation	338 (224)	314 (116)	0.6045

Ventilator parameters and arterial blood gas values at time of extubation for patients who tolerated versus failed extubation. Significance assessed by Kruskal-Wallis for continuous outcomes among groups. Data are mean (SD) for normally distributed data or median (IQR) for not normally distributed data. Parameters at time of initial extubation attempt. Nineteen patients additionally had a second extubation attempt (of which 4 failed and 15 were successfully extubated).

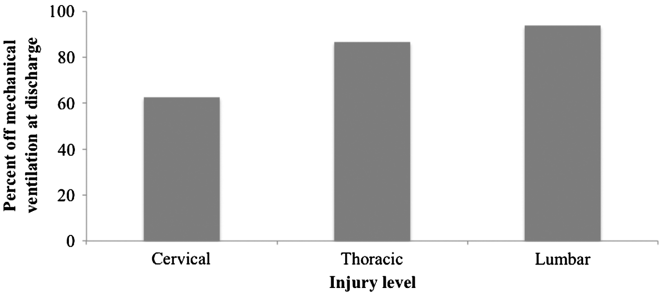

Figure 2. Freedom from mechanical ventilation at hospital discharge by injury level. Percentage of patients who did not require mechanical ventilation on hospital discharge classified by level of spinal cord injury. *p < 0.05 by two-sided Fisher's exact testing comparing the rate of ventilator independence on discharge between cervical vs. thoracic vs. lumbar injury.

In addition, analysis of patients with cervical SCI grouped by high (C1–3) versus low (C4–7) level of injury demonstrated that the 75 patients (33.8%) with high cervical SCI were older, were more severely injured, had a higher percentage of blunt injuries, and had lower Glasgow Coma Scale (GCS) scores. However, they had a lower rate of VAP compared with those with low cervical SCI (41.3% vs. 46.9%, $p < 0.05$). The patients with high cervical SCI underwent tracheostomy 57.3% of the time, compared with 53.7% of the time in low cervical SCI patients ($p < 0.05$), a statistically but not clinically significant difference. Impressively, more than half of the patients with high cervical SCI were off the ventilator at discharge (53.3%), and of the 34.7% who had extubation attempted, 88.4% were successfully extubated (Supplemental Digital Content 1, http://links.lww.com/TA/A316).

We next examined patients who underwent tracheostomy versus those who did not. Median time to tracheostomy was 7.5 days (IQR 5–11 days, Table 3). Patients who underwent tracheostomy had less severe thoracic injury (mean chest Abbreviated Injury Scale [AIS] score, 2 vs. 3; $p < 0.05$) but a higher incidence of TBI (23.5% vs. 19%, $p < 0.05$; mean head AIS score, 4 vs. 3, $p < 0.05$; median GCS score, 13 vs. 15, $p < 0.05$; Table 3). Patients who underwent tracheostomy had higher rates of VAP (61.1% vs. 20.5%, $p < 0.05$) and ALI (12.8% vs. 3.6%, $p < 0.05$, Table 3) as well as significantly longer median ICU stay (22 days vs. 6 days, $p < 0.05$), hospital stay (30 days vs. 13 days, $p < 0.05$), and fewer ventilator-free days (1 day vs. 24 days, $p < 0.05$; Table 3). Only 15.4% of tracheostomy patients had an extubation attempt, versus 84.1% of those patients who never underwent a tracheostomy (Table 3, $p < 0.05$). Tracheostomy was not associated with discontinuation of MV: a higher percentage of patients were on MV at discharge in the tracheostomy group compared with those who never underwent a tracheostomy (85.6% vs. 53.7%, $p < 0.05$). No statistical difference in death caused by respiratory complications ($p = 0.191$) or overall mortality ($p = 0.091$, Table 3) was found. Analysis of patients who underwent early tracheostomy (<7 days, 48%) versus late (>7 days, 52%) found no major clinical differences in demographics. Those who underwent late tracheostomy had higher rates of VAP (70.5% vs. 59.7%, $p < 0.05$), ALI (18.0% vs. 8.8%, $p < 0.05$), and ARDS (16.4% vs. 10.5%, $p < 0.05$). However, they had no difference in ventilator-free days. Only 10.5% of patients who underwent early tracheostomy ever had an extubation attempt. Early tracheostomy was not associated with freedom from MV at discharge as only 52.6% of the patients who underwent early tracheostomy were off the ventilator by discharge compared with 45.9% in the late tracheostomy group,

TABLE 7. Demographics/Outcomes for Patients With Cervical SCI, off MV at Discharge Versus on MV at Discharge

	Off Ventilation at Discharge (n = 138)	On Ventilation at Discharge (n = 59)	*p*
Age, median (range)	44 (18–82)	44 (18–80)	0.9584
Male, n (%)	107 (77.0)	46 (78.0)	0.2820
Blunt mechanism, n (%)	127 (91.4)	53 (89.8)	0.3430
ISS, mean (SD)	27 (14)	36 (17)	0.0002
Head AIS score, mean (SD)	4 (2)	4 (2)	0.0356
Chest AIS score, mean (SD)	1 (2)	2 (2)	0.5217
Arrival GCS score, median (IQR)	14 (6–15)	13 (8–15)	0.9085
Complete injury, n (%)	55 (39.6)	44 (74.6)	<0.0001
TBI, n (%)	24 (17.3)	18 (30.5)	0.0410
Other injury, n (%)	86 (61.9)	35 (59.3)	0.9730
Operative stabilization, n (%)	103 (74.1)	46 (78.0)	0.0220
VAP, n (%)	43 (31.0)	48 (81.4)	<0.0001
ALI, n (%)	7 (5.0)	9 (15.3)	0.0060
ARDS, n (%)	12 (8.6)	7 (11.9)	0.7770
ICU days, median (IQR)	12 (6–19)	27 (17–37)	0.0001
Hospital days, median (IQR)	19 (11–30)	29 (18–41)	0.0004
Ventilator-free days (to 28 d), median (IQR)	20 (11–25)	0 (0–0)	0.0001
Extubation attempted, n (%)	85 (61.2)	7 (11.9)	<0.0001
Tracheostomy, n (%)	60 (43.2)	55 (93.2)	<0.0001

Patient demographics, injury characteristics, ventilatory status at discharge or transfer, and outcomes for cervical SCI patients on and off MV at discharge. Significance assessed by Kruskal-Wallis for continuous and Fisher's exact test for dichotomous outcomes among groups. For not normally distributed, variables reported as median with IQRs. Ventilator-free days are counted to 28 days.

TABLE 8. Predictors of Ventilator Dependence for Patients With Cervical Spinal Cord Injuries

	OR	95% CI	*p*	OR Adjust	95% CI	*p*
Age	1.00	0.99–1.01	0.938	1.00	0.99–1.01	0.935
Sex	1.05	0.44–2.57	0.901	0.95	0.49–1.86	0.885
Blunt mechanism	1.19	0.38–3.74	0.756	0.55	0.09–3.34	0.516
Body mass index	1.00	0.96–1.05	0.883	1.01	0.97–1.05	0.725
ISS	1.04	1.02–1.05	<0.0001	1.05	1.03–1.08	<0.001
AIS head	1.29	0.65–2.52	0.465	1.10	0.62–1.93	0.746
AIS chest	1.06	0.86–1.31	0.568	0.85	0.67–1.06	0.154
GCS score on arrival	0.99	0.91–1.07	0.756	0.99	0.92–1.05	0.686
TBI	1.96	0.83–4.60	0.124	1.57	0.64–3.82	0.323
Other injury	0.98	0.42–2.28	0.957	0.66	0.15–2.83	0.578
Operative stabilization	1.34	0.67–2.69	0.412	1.60	0.78–3.28	0.196
Respiratory comorbidities	1.14	0.56–2.33	0.714	1.10	0.29–4.19	0.886
Tracheostomy	18.10	5.53–59.22	<0.0001	14.11	2.78–71.67	0.001
PH at intubation	0.44	0.01–15.10	0.651	0.92	0.01–67.72	0.970
$Paco_2$ at intubation	0.99	0.96–1.02	0.495	0.99	0.94–1.04	0.715
Pao_2 at intubation	1.00	1.00–1.00	0.917	1.00	1.00–1.00	0.633
HCO^3 at intubation	0.95	0.85–1.07	0.414	0.99	0.85–1.15	0.892
Base deficit at intubation	0.97	0.89–1.05	0.458	0.99	0.89–1.11	0.911
GCS score at intubation	1.03	0.96–1.10	0.477	1.07	0.98–1.15	0.113
FIO_2 at intubation	2.64	0.93–7.5	0.068	1.15	0.23–5.78	0.867
Respiratory rate at intubation	1.04	0.98–1.11	0.186	1.05	0.96–1.15	0.322
Ventilator rate at intubation	1.02	0.91–1.14	0.706	1.03	0.84–1.25	0.809
Tidal volume at intubation	1.00	1.00–1.00	0.082	1.00	1.00–1.00	0.440
Minute volume at intubation	0.99	0.88–1.12	0.921	0.82	0.69–0.97	0.022
Peak pressure at intubation	1.02	0.95–1.10	0.514	1.03	0.97–1.09	0.291
Plateau pressure at intubation	1.07	0.95–1.20	0.298	1.09	0.96–1.24	0.188
PEEP at intubation	0.87	0.70–1.07	0.188	0.83	0.57–1.21	0.336
Spo_2 at intubation	1.06	0.96–1.18	0.225	1.06	0.97–1.16	0.198
Mean airway pressure at intubation	0.99	0.95–1.03	0.535	0.89	0.69–1.14	0.366
Compliance at intubation	1.34	0.64–2.82	0.436	1.58	1.12–2.46	0.045
P/F ratio at intubation	1.00	1.00–1.00	0.462	1.00	1.00–1.00	0.966

OR and OR adjust for compliance for a change of 0.1 L/cm H_2O.
OR adjust, OR adjusted for age, arrival GCS score, ISS, chest AIS score, and respiratory comorbidities; PEEP, positive end-expiratory pressure; P/F ratio, ratio of arterial oxygen concentration to fraction of inspired oxygen, PaO_2/FiO_2.

a statistically significant but clinically insignificant difference (Supplemental Digital Content 2, http://links.lww.com/TA/A317).

Next, in the subset of patients who were free from MV at discharge, the role of tracheostomy was investigated. There were no demographic differences between those with and without tracheostomy (Table 4); however, tracheostomy was associated with higher rates of VAP (48.8% vs. 19.2%, $p < 0.05$), ALI (10% vs. 2.4%, $p < 0.05$), and ARDS (12.5% vs. 3.6%, $p < 0.05$), as well as longer median ICU stay (21 days vs. 6 days, $p < 0.05$), hospital stay (30 days vs. 14 days, $p < 0.05$), and fewer ventilator-free days (10 days vs. 25 days, $p < 0.05$; Table 4).

Because tracheostomy was not associated with improved respiratory outcomes, we then examined potential predictors of the need for MV at discharge. The 63 patients requiring ventilation at discharge had higher ISS (36 vs. 31, $p < 0.05$) compared with the 247 ventilator-free patients, had higher mean head AIS scores (4.0 vs. 3, $p < 0.05$), but lower mean chest AIS scores (2 vs. 3, $p < 0.05$, Table 5). As expected, patients requiring MV at discharge had significantly higher rates of VAP (77.8% vs. 28.7%, $p < 0.05$) and ALI (17.5% vs. 4.9%, $p < 0.05$) and longer ICU stay (25 days vs. 10 days, $p < 0.05$) and hospital stay (28 days vs. 19 days, $p < 0.05$, Table 5). Tracheostomy was performed in 93.7% of the patients still requiring ventilation on discharge, with initial extubation attempted in only 11.1% (Table 5). No major differences in respiratory parameters at the time of intubation were identified for patients on and off MV at discharge (Supplemental Digital Content 3, http://links.lww.com/TA/A318). More importantly, we found no statistically significant differences in ventilatory parameters or arterial blood gas values at the time of extubation for patients who tolerated extubation versus those who failed (Table 6). The vast majority of patients (93.7%) requiring MV at discharge had cervical SCI (Table 5); yet, more than half (62.6%) of the 222 patients who presented with cervical SCI were off MV at discharge (Table 2, Fig. 2).

Given the surprising incidence of freedom from MV in patients with cervical SCI, we then specifically analyzed this subgroup. Although similar in age, sex, and mechanism of injury, patients with cervical SCI who required MV at discharge had higher mean ISS (36 vs. 27, $p < 0.05$) and higher rates of TBI (30.5% vs. 17.3%, $p < 0.05$, Table 7); no significant differences in severity of thoracic injury existed (Table 7). Notably, only 11.9% of cervical SCI patients who still required MV at discharge ever had extubation attempted, compared with 61.2% of ventilator-free patients ($p < 0.05$, Table 7). Not surprisingly, ventilator-free cervical SCI patients had lower rates of VAP (31.0% vs. 81.4%, $p < 0.05$) and ALI (5.0% vs. 15.3%, $p < 0.05$) as well as shorter median ICU stay (12 days vs. 27 days, $p < 0.05$) and hospital stay (19 days vs. 29 days, $p < 0.05$) and more ventilator-free days (20 days vs. 0 day, $p < 0.05$; Table 7).

The cervical SCI cohort was then analyzed for independent predictors of ventilator dependence using logistic regression analysis. In both unadjusted and adjusted analysis, the most notable predictor of ventilator dependence was the presence of tracheostomy. When controlled for injury severity, thoracic injury, and respiratory comorbidities (smoking, asthma, chronic obstruction pulmonary disease, or any other respiratory disease), we found tracheostomy to be associated with a 14.1-fold higher odds of prolonged MV (odds ratio [OR], 14.1; 95% confidence interval [CI], 2.78–71.67; $p < 0.05$, Table 8).

DISCUSSION

Here, we show that a high number of patients with cervical SCI and respiratory failure can successfully be weaned and extubated without empiric tracheostomy and describe the association of tracheostomy with increased respiratory morbidity. These findings have important implications for improving the outcome of cervical SCI patients. In 2012, up to 370,000 people in the United States were estimated to be living with SCI, and the lifetime costs of cervical tetraplegia are estimated at nearly \$2.5 million.[1] SCI carries significant morbidity, mortality, and hospital costs associated with short- and long-term ventilator dependence;[2,4,8,14] as such, careful airway management and avoidance of pulmonary complications are central focuses of appropriate management.[2,3]

Although chronic respiratory care, ventilator management, and respiratory rehabilitation for patients with SCI have been broadly explored in the literature, successful acute weaning and extubation strategies have not been elucidated.[2–6,8,14] Two small studies have examined weaning and extubation attempts in this setting. Chiodo et al.[15] demonstrated in a small series of 26 tetraplegic patients that negative inspiration force diaphragm needle electromyography was the best predictor of the ability of patients with SCI to wean from the ventilator; however this small study did not examine standard clinical predictors. Claxton et al.[7] demonstrated in another small series of 72 patients that copious sputum production and pneumonia were independent predictors of the need for MV after SCI, but they did not examine predictors of ventilator weaning or extubation. Combined with the pervasive clinical teaching that cervical SCI will always result in ventilatory paralysis, many trauma centers do not consider weaning or extubation before tracheostomy in patients with cervical SCI. Contrary to this belief, we previously demonstrated in a small single-center study that the majority of patients with SCI who survived to discharge tolerated extubation and never required tracheostomy.[9] We therefore hypothesized that many patients with cervical SCI can be successfully managed without long-term MV and its associated morbidity and sought to identify predictors of ventilator dependence in this population.

Our data here confirm the previous result that many patients with SCI and respiratory failure can be successfully extubated during their acute hospitalization.[9] Despite the prevalence of cervical SCI in this cohort, the majority of patients were free from MV at discharge. Specifically, extubation attempts were successful 84.2% of the time in cervical SCI patients. Despite this impressive successful extubation rate, there remains a pervasive clinical bias toward avoiding attempts at extubation and proceeding directly to tracheostomy. Clinical intuition would seem to dictate that not all SCI patients are appropriate for attempts at extubation. However, our study did not demonstrate statistical differences in ventilator settings or arterial blood gas values at the time of extubation in those who were successfully extubated versus those who were not, highlighting the paucity of objective data available to support this clinical decision.

An area of respiratory management in SCI patients that has been well-studied is the use of tracheostomy. Several studies have examined tracheostomy in SCI with regard to potential benefits, timing, and resource use and sought to identify predictors of the need for tracheostomy.[16–21] Despite identifying that early tracheostomy led to shorter duration of MV and ICU stay, Romero et al.[16] were unable to demonstrate that tracheostomy protected against VAP or decreased mortality rates. In contrast, we demonstrate here that tracheostomy was a significant independent predictor of ventilator dependence at discharge. Not surprisingly, more than half of cervical SCI patients in this cohort underwent tracheostomy, remained ventilated at discharge, and had concerning rates of VAP. Of those patients, few had any documented weaning or extubation attempts before tracheostomy. In fact, 90% of patients who underwent an early tracheostomy never had an extubation attempt before, and more than half of them remained MV on discharge. Specifically in patients with cervical SCI, tracheostomy was the *only* notable predictor of ventilator dependence (OR, 14.1; 95% CI, 2.78–71.67; $p < 0.05$), while no demographics, ventilator parameters, or arterial blood gas measurements at the time of extubation were predictive of ventilator dependence. We interpret this result as an injunction to rethink the clinical paradigm of empiric tracheostomy after cervical SCI. We believe that there are patients with SCI who do require tracheostomy but that further study may identify evidence-based criteria for patient selection, allowing a reduction in empiric tracheostomy and an associated decrease in morbidity and costs associated with SCI.

This study shares the limitations inherent to all retrospective and multicenter studies. We did not identify differences between successfully extubated SCI patients and those who were not, despite the fact that bedside gestalt often clearly identifies patients who are poor candidates for weaning; in a retrospective cohort, these unmeasured confounders seen by the experienced clinical eye cannot be accounted for. In fact, the clearly poor candidate for trial extubation is not who we are interested in; our overall aims were to identify patients whose clinical appearance and objective data are indeterminate and to elucidate clinical parameters to provide decision support for assessment in determining appropriateness of trial extubation versus empiric tracheostomy. The critical lack of weaning data from individual sites could be caused by a clinical bias toward not performing any weaning attempts in patients with SCI before tracheostomy or caused by missing data. In addition, the timing of the development of VAP in relation to tracheostomy and the clinician reason for tracheostomy are unknown. Although our data suggest that patients did not undergo tracheostomy based on objective differences, the answer to this is unknown. These data are crucial to conclusively answering our objective, and the serial standardized data collection of a prospective study would elucidate these.

In conclusion, while many patients with SCI require short-term MV, we demonstrate that the majority can be successfully weaned from ventilation before discharge without the use of empiric tracheostomy. This is of paramount importance because we also identified that tracheostomy is associated with major morbidity in this population, especially among patients with cervical SCI. Tracheostomy and its use in cervical SCI patients deserve further study to identify the subset best served by this procedure. These data do not suggest that empiric tracheostomy should be abandoned in all patients with cervical SCI. We believe that there are cervical SCI patients who do require early tracheostomy but that there is need for a prospective trial to identify optimal clinical guidelines for weaning and extubation attempts in patients with SCI. Clinical equipoise is supported for such a trial by the high rates of successful extubation, the lack of clear differences between patients who succeed and fail, and the morbidity associated with tracheostomy shown here.

AUTHORSHIP

L.Z.K., M.E.K., and M.J.C. performed the literature search. L.Z.K., M.E.K., M.J.C., and B.J.R. provided the study design. L.Z.K., M.E.K., R.A.C., B.J.R., C.K.H., T.H.C., C.C.Ba., M.L.S., C.C.Bu., K.L.K., M.A.D., J.M.H., C.H.K., S.J.Z., S.D.G., D.V.S., D.B.P., and M.J.C. performed the data collection. L.Z.K., M.E.K., R.A.C., B.J.R., and M.J.C. performed the data analysis. L.Z.K., M.E.K., R.A.C., and M.J.C. performed the data interpretation. L.Z.K., M.E.K., R.A.C., B.J.R., and M.J.C. wrote the manuscript. L.Z.K., M.E.K., R.A.C., B.J.R., C.K.H., T.H.C., C.C.Ba., M.L.S., C.C.Bu., K.L.K., M.A.D., J.M.H., C.H.K., S.J.Z., S.D.G., D.V.S., D.B.P., and M.J.C. provided critical revision.

DISCLOSURE

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EDITORIAL CRITIQUE

In their well-written paper, the authors provide a cogent argumentl that it is time to abandon the practice of empiric tracheostomy in patients with spinal cord injury. They note that the majority of patients with spinal injuries were able to be liberated from the ventilator prior to discharge from the hospital. What they fail to do is truly elucidate the stated goal of determining the predictors of ventilator dependence at discharge in acute spinal cord injury. The authors state that the only significant predictor of ventilator dependence at the time of discharge was the presence of a tracheostomy. Isn't this at least somewhat a which "came first the chicken or the egg argument"? Did the inability to be liberated from the ventilator lead to placement of a tracheostomy or did placement of a tracheostomy lead to inability to be liberated from the ventilator? Were the clinicians just really adept at predicting which patients would need long-term mechanical ventilation or did placement of a tracheostomy lead to abandoning weaning attempts? In the absence of data on weaning parameters, such as the rapid shallow breathing index, it is difficult to ascertain. If a prospective study is performed, information on weaning parameters would be very helpful.

It would also be interesting to see the groups "low" and "high" cervical spine injury further subdivided into actual level of injury. There is clearly a significant difference between C1 and C7 injuries. But are there significant differences in ability to be liberated from the ventilator at the cervical spinal levels where diaphragmatic innervation enters the equation? It there a significant difference between injuries at the level of the second cervical vertebrae as compared to the third? What about between the third and the fourth? Stratification by level of injury would have been an informative addition to the analysis.

As the authors note, the paper is limited by its retrospective nature and they call for future study. Additional work should focus on cervical spine injury, stratify by level of injury and include the use of objective weaning parameters to answer the interesting questions raised by this paper.

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