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Variability in Early Surgery for Acute Cervical Spinal Cord Injury Patients: An Opportunity for Enhanced Care Delivery

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Abstract

Data supporting the benefits of early surgical intervention in acute spinal cord injury (SCI) is growing. For early surgery to be accomplished, understanding the causes of variabilities that effect the timing of surgery is needed to achieve this goal. The purpose of this analysis is to determine factors that affect the timing of surgery for acute cervical SCI within the North American Clinical Trials Network (NACTN) for SCI registry. Patients in the NACTN SCI registry from 2005 to 2019 with a cervical SCI, excluding Acute Traumatic Central Cord Syndrome, were analyzed for time elapsed from injury to arrival to the hospital, and time to surgery. Two categories were defined: 1) Early Arrival with Early Surgery commenced within 24 hours of injury (EAES) and 2) Early Arrival but Delayed Surgery (EADS) with surgery occurring between 24 to 72 hours post-injury. Patients' demographic features, initial clinical evaluation, medical comorbidities, neurological status, surgical intervention, complications, and outcome data were correlated with respect to the two arrival groups. Of the 222 acute cervical SCI patients undergoing surgery, 163 (73.4%) were EAES, and 59 (26.6%) were EADS. There was no statistical difference in arrival time between the EAES and EADS groups. There was a statistical difference in the median arrival time to surgery between the EAES group (9 hours) compared to the EADS group (31 hours) ($p<0.05$). There was no statistical difference in race, sex, age, mechanism of injury, APACHE II scores, or medical comorbidities between the two groups but the EAES group did present with a significantly lower systolic blood pressure ($p<0.05$). EADS patients were more likely to present as an AIS D than EAES ($p<0.05$). Early surgery was statistically more likely to occur if the injury occurred over the weekend ($p<0.05$). There were variations in the rates of early surgery between the 8 NACTN sites within the study, ranging from 57% to 100%. Of the 114 patients with 6-month outcome data, there was no significant change between the two groups regarding AIS grade change and motor/pin prick/light touch score recovery. A trend towards improved motor scores with early surgery was not statistically significant ($p=0.21$). Although there is data that surgery within 24 hours of injury improves outcomes and can be performed safely, there remain variations in care outside of clinical trials. In the present study of cervical SCI, NACTN achieved its goal of early surgery in 73.4% of patients from

2005-2019 who arrived within 24 hours of their injury. Variability in achieving this goal was related to severity of neurological injury, the day of the week, and the treating NACTN center. Evaluating variations within our network improves understanding of potential systemic limitations and our decision-making process to accomplish the goal of early surgery.

Introduction:

Over the last 25 years, the weight of beneficial evidence supporting early surgical intervention in acute traumatic spinal cord injury (SCI) has grown.[1,2,3,4,5] Generally defined as surgery within 24 hours of injury, this benchmark has been recommended as the preferred treatment option given the data that supports improvement in neurological outcomes and cost-effectiveness.[1,6,7 8] In an extensive pooled data analysis of time to surgery and neurological outcomes derived from four prospective datasets containing 1548 patients, Badhiwala et al. treated time to surgery as a continuous variable and found a strong correlation between earlier surgery and improved neurological outcome.[9] While some studies have shown a benefit from surgery occurring within 8 hours of injury, the exact timing of surgery for optimal outcomes has yet to be defined.[2,4,10,11]

To accomplish early surgical intervention in acute cervical SCI, an understanding of the reasons for the variability in the timing of surgery outside of a clinical trial needs to be elucidated. While several studies have attempted to examine factors that delay surgery, including patient characteristics, delay in hospital arrival, and internal hospital delay, further analysis is required.[12,13,14] The purpose of the present study is to analyze the patients treated within the North American Clinical Trials Network (NACTN) for Spinal Cord Injury from 2005-2019 to determine features of patients that undergo early surgery for acute cervical SCI and to learn where variability exists in our network.

Methodology

NACTN is a consortium of adult tertiary medical centers across North America that has existed since 2004. The mission of NACTN is to continually advance the quality of care and life of people with SCI. This is achieved through clinical trials of new therapies that rigorously assess safety and effectiveness.[15,16,17,18] In addition, NACTN maintains a multicenter registry to document and track SCI patients from their time of injury until follow-up at 6 to 12 months. A description of the NACTN registry methodology and data retrieval processes can be found in the companion articles in this edition.

For this specific study, the 989 SCI patients in the NACTN registry injured between 2005 and 2019 was available for analysis. We excluded 484 thoracolumbar injuries resulting in 505 cervical SCIs. From this cervical SCI group, we excluded 1 patient with a missing injury type, 24 patients with a penetrating mechanism of injury, and 45 patients with missing surgical data, resulting in 435 patients. We then excluded 153 patients with a diagnosis of Acute Traumatic Central Cord Syndrome (ATCCS), leaving 282 patients left for additional analysis. ATCCS was defined as a pattern of neurological deficits in AIS C/D cervical SCI injuries in which the upper extremities are weaker, at least 10 points in ASIA Motor Score, than the lower extremities with variable involvement of the sensory system or bladder function.[19] ATCCS patients were excluded from analysis given the differences in recommendations in the current guidelines based on existing literature in the timing of surgical management in these patients.[7] From the 282 cervical SCI patients, 9 were removed for missing injury or arrival time, 32 were removed for arriving to a NACTN center more than 24 hours after injury, and 19 were removed for having their surgical intervention more than 72 hours after injury. The reason these patients were excluded was to homogenize our data set into patients that were eligible for early surgery. This results in 222 cervical SCI for further analysis.

Demographic, initial clinical evaluation, medical comorbidities, AIS grade, initial APACHE score, complications, and discharge information were screened to obtain the characteristics and outcomes of the retained participants. The AIS grade recorded was from the initial ASIA exam before surgery. Time intervals were calculated as the difference in hours between the time of injury, the time of hospital arrival, and the time of surgery. Patients who underwent surgery, but the exact time of surgery was missing from the record were excluded. Early surgery was defined as surgery commencing within 24 hours of injury. Patients who had surgery were classified into two groups: 1) EARLY ARRIVAL and EARLY SURGERY (EAES) if they arrived early enough to have surgery within 24 hours of injury; 2) EARLY ARRIVAL but DELAYED SURGERY (EADS) if they arrived early enough to potentially have early surgery but their surgery occurred more than 24 hours after injury. We examined the relationships between the participants' descriptors and these two surgically treated groups.

Participant descriptors and outcomes that are continuous were tested for normality using the Kolmogorov-Smirnov test. Normally distributed variables were presented with means and standard deviation and compared across groups using Analysis of Variance. Non-normally distributed variables were presented with median and 1st and 3rd quartiles and compared using the Brown-Mood test. Categorical variables were presented with frequency count and percentages and compared across the groups using the appropriate Chi-square test or Fisher's exact test. Two by two comparisons were performed with generalized linear models, one per descriptor or outcome, in which the surgical timing group was included as the only independent variable. The identity link with a normal distribution was used for normally distributed continuous variables, and the logit link with a binary distribution was used for binary variables. For the non-normally distributed continuous variables, the quantile regression to the median was used. The p-values were obtained from linear contrasts, representing the 2-by-2 group comparisons of interests built on this group factor. All tests were 2-sided with a significance level of 0.05. Data analyses were performed in SAS 9.4 (SAS Inc., Cary, NC).

Results

There were 989 patients enrolled in the NACTN registry and eligible to be included in the analysis, of which 282 were found to have cervical SCI without ATCCS. Figure 1 outlines the exclusion criteria. After removing patients who did not undergo surgery (n=9), arrived after 24 hours from their injury (n=32), and those who had surgery more than 72 hours after their injury (n=19), there were 222 patients for analysis treated in 8 different NACTN sites. Over the time course of the NACTN registry, there was a positive trend towards an increasing percentage of patients undergoing early surgery (Figure 2). Of 222 acute cervical SCI patients, 163 (73.4%) had early surgery, while 59 (26.5%) had delayed surgery (Table 1). Of the EAES group, 55.2% (n=90/163) had their surgery commence within 12 hours of injury. Utilizing time as a continuous variable, the highest concentration of surgery occurs between 6 and 12 hours after injury with 50% of patients undergoing surgery within 15 hours of injury (Figure 3). There was no statistical difference in arrival time between the EAES and EADS groups, with the median arrival time between injury and arrival being 1 hour for the EAES group and 2 hours for the EADS group (p=0.1). There was a statistical difference in arrival time to surgery between the EAES group, with a median time of 9 hours, compared to the EADS group, which had a median time to surgery of 31 hours ($p<0.05$) (Table 2).

Between the EAES and EADS categories, there was no statistical difference in race, sex, or age. There was no difference in the mechanism of injury between the two groups (Table 3). There were significant differences between the groups in their presenting systolic blood pressure, which was lower in the EAES group ($p<0.05$), but not in their diastolic blood pressure, mean arterial pressure, or APACHE II score. There was no difference in the following presenting medical comorbidities: hypertension, myocardial infarction, cardiovascular disease, pulmonary disease, malignancy, or smoking status. Regarding neurological status, the EADS group was more likely to present as an AIS D compared to those that had early surgery ($p<0.05$). There was no difference in presenting motor or sensory scores. While each NACTN center had higher rates of early surgery than delayed, three centers showed a significant difference between their early and delayed surgery rates ($p<0.05$) (Table 4). There was a variability observed between the NACTN sites in the rates of early surgery ranging from 57% to 100%.

Saturday was the most common day of the week for an SCI to occur (23%, n=52/222) in both groups: EAES 25% (n=40/163), EADS 23% (n=12/59). There was a statistical difference between the groups if the injury occurred on a weekday (Monday at 6:00 AM thru Friday at 5:00 PM) versus a weekend (Friday at 5:00 PM thru Monday at 6:00 AM) with 54% (n=88/222) of early surgery more likely to occur over the weekend compared to the rest of the week (37%, n=22/59) ($p<0.05$).

Regarding the initial surgical approach, the EADS group was significantly more likely to undergo posterior surgery alone than the EAES group ($p<0.05$). There was no difference regarding the anterior approach or a combined anterior/posterior surgery.

There was no difference in the length of stay or mortality between the two groups (Table 5). The EAES group had a significantly higher rate of discharge to a rehabilitation hospital, while the EADS group had a higher rate of discharge to home ($p<0.05$). Within each AIS grade, there was no difference in hospital disposition between early and delayed surgery. (Table 6). There were no differences in cardiac, pulmonary, gastrointestinal, or urinary complication rates but the EADS group had more complications related to cutaneous infections and pressure injuries (p<0.05).

In terms of follow up, 114 (51.4%) of our initial study group had 6-month outcome data regarding their neurological status, with 67.5% (n=77/114) undergoing early surgery and 32.4% (n=37/114) undergoing delayed surgery. There was no significant change between the groups regarding AIS grade change and motor, pin prick or light touch scores. A trend toward improved motor scores with early surgery was not statistically significant (p=0.21) (Figure 4).

Discussion:

This study is the first published evaluation of NACTN's rate of early surgery for cervical SCI with an attempt to provide a non-clinical trial perspective on the timing of surgery in a network that values early surgical intervention for SCI. In this study, 73.4% of patients received early surgery for their cervical SCI if they arrived within 24 hours of their injury. There was a trend towards a higher rate of early surgery over the time frame of the NACTN registry. Delays in early surgical intervention for 59 patients (26.6%) were related to the process once the patient arrived at a NACTN hospital. Variables that correlated to not achieving early surgery were seen in AIS D SCIs, the NACTN site the patient presented to, and whether the patient was injured on a weekday or weekend. The median time from arrival to the commencement of surgery for those undergoing early surgery was 9 hours. This time period would at least include medical stabilization, radiographic and laboratory evaluation, surgical decision-making, as well as operating room staffing and equipment availability, supporting the feasibility of early surgery. In fact, 40.5% of all patients in this study (n=90/222) had their surgery commence within 12 hours of injury. With the presented median arrival and surgery time at NACTN hospitals, reducing the variability of delays in surgical care of cervical SCI patients after hospital admission may be an area of focus for improvement in patient care.

The timing of surgery for an acute SCI has been a topic that continues to evolve. In 1992, the Surgical Treatment of Acute Spinal Cord Injury Study (STASCIS) trial group was established and advocated for initiating a randomized trial of early surgery for SCI. Its first study was a retrospective review of SCI and cauda equina patients performed in 36 North American Centers. It established the feasibility of initiating a trial of early surgery in acute SCI.[3] In this study, Tator et al. performed a retrospective analysis of 585 patients with acute spinal cord or cauda equina injuries, about half of whom could not have early surgery because of delayed admission. Surgery was ultimately performed on 65.4% of the patients but early surgery, within 24 hours from injury, only occurred in 23.5% of those receiving surgery.

The first prospective STASCIS study was a pilot project published in 1999 by Ng et al. focusing on the ability to obtain appropriate radiographic studies and undergo decompression, either by surgery and/or traction, within 8 hours after a cervical SCI.[5] The authors were able to enroll 26 patients into this first study but noted that less than 10% of eligible SCI patients were enrolled secondary to logistical challenges in meeting the 8-hour decompression goal. The second prospective STASCIS study in 2012 showed that surgery within 24 hours could be performed safely and resulted in an improvement in AIS grade conversion at six months compared to surgery after 24 hours.[1,5] The STASCIS multi-centered, non-randomized prospective observational trial was dependent on the hospital arrival time, time for diagnostic studies, and the discretion of the spine surgeon to determine whether the patient was operated on within 24 hours of injury.

Currently, the AO Spine-Praxis Institute is co-sponsoring revisions of existing guidelines around the role and timing of surgery for acute SCI that will likely strengthen the recommendation for early surgical intervention based on the growing evidence in the literature.[7,20] These recommendations are built on a large amount of pre-clinical and clinical data showing the value of early surgery in acute traumatic SCI.

In a follow-up to the STASCIS trial, Furlan et al. evaluated the reasons for surgery occurring more than 24 hours after injury. They found that time at an outside facility and the time for surgical decision-making were the most significant determinants of early surgery and that patient-related factors did not play a significant role.[12] The statistical difference in our EAES and EADS groups suggests that some patient factors, such as type of SCI, and the day of the week, played a role in the timing of surgery. In a review of the

National Trauma Data Bank (NTDB) Research Data Set from 2011 to 2012, Samuel et al. found that the greatest delay to surgery for acute SCI occurred after the patient was admitted. They also found that high cervical spinal cord injuries and a higher Charlson Comorbidity Index were related to surgery occurring after 24 hours.[13] In a follow-up study, Williamson et al. analyzed the NTDB database between 2011 and 2014. They showed that patients directly admitted to a Level I trauma center were more likely to have surgery.[21] Our findings are similar to Samuel et al., where transport delays only affected a minority of the patients while internal factors to the patient or the hospital system contributed to the largest source of variability to early surgery.

In 2016, Wilson et al. reviewed 1111 acute spinal cord injury patients in Ontario, Canada, between 2002 and 2011. They found that the average injury to arrival time was 8.1 hours, with 88% arriving within 6 hours. The average time to surgery was 49.4 hours, with 53% having surgery within 24 hours. Surgery after 24 hours was associated with older age and intervening care at other hospitals before arriving at the facility where surgery was performed.[22] In 2018, Thompson et al. conducted a prospective study to evaluate the barriers to early surgery at a single Level 1 trauma center in Canada. They found that transfer time from injury to the hospital where surgery occurred was a significant source of delay in achieving early surgery. Additional areas of delay included the time between assessment and finalization of the surgical plan and then getting the patient to the operating room.[14] They found no individual patient characteristics that contributed to the delay in achieving early surgery. In 2022, Kopp et al. found that age was an independent factor to delay in surgical care after an SCI, with older patients more likely to experience a delay in transfer to a tertiary medical center as well as present with more co-morbidities.[23] In the present study, early surgery was achieved in 73.4% of patients arriving at a NACTN hospital within 24 hours of their injury with a median arrival time of 1 hour from injury. Age was not associated with delayed surgical care, but AIS grade did influence the timing of surgery.

The current challenges in achieving surgical management within 24 hours are not likely based on disbelief of the literature supporting early decompression for acute traumatic SCI. Glennie et al. reviewed the Rick Hansen Spinal Cord Injury Registry from

2004 to 2014. They found that despite over 90% of surgeons holding a belief in the benefits of early surgery for both complete and incomplete spinal cord injuries, surgery within 24 hours only occurred in 39% of cervical injuries.[6] Our 73.4% early surgery rate exceeds this, providing an opportunity for improvement given the presenting homogeneity between our EAES and EADS groups. This also raises the question of what a realistic expectation is of the percentage of all cervical SCI patients that can safely and logistically undergo early surgery. While unlikely to be 100%, it is probably more than our current findings.

While our findings are compelling and suggest that characteristics such as a less severe neurologic injury, injury during the weekdays, or the hospital the patient presents to contribute to surgery being delayed for more than 24 hours after an SCI, our study has several limitations. For example, further study is required to determine the exact nature and solutions for other delaying factors, such as access to imaging and operating rooms. As a multi-center consortium, each NACTN hospital team may face unique challenges. Although NACTN is a network of centers with common agreement about the value of early surgery, there was not a rigid protocol, and therefore, the need for and timing of surgery were determined at the local level. While the data showed a significantly higher rate of early surgery over the weekend compared to weekdays, the reason behind this is not clear and represents an area for further study. Another limitation is that patients were excluded from the analysis because of missing or inconsistent data, which may have impacted the results. There are also several areas for improvement in this project that could offer more granular data, such as fracture type and the degree of spinal cord compression coupled with imaging characteristics of the injury. Finally, while our results do not show a statistical neurological benefit to early surgery, we had a limited 6-month follow-up with registry data that spanned 15 years. The causes for this limited follow-up are likely multi-factorial and may reflect health care organization whereby NACTN participants may undergo rehabilitation in other centers.

Conclusion

While the literature supports that early surgery for SCI can improves outcomes and can be performed safely, there remain variations in care. In the present study, NACTN achieved its goal of early surgery in 73.4% of cervical SCI patients from 2005-2019 who arrived within 24 hours of their injury. Delayed arrival was not a major factor in causing delayed surgery. Instead, factors such as a less severe neurological injury, the day of the week, and individual NACTN center management accounted for variability in the timing of surgical intervention. By evaluating the variations within our network, we can better understand not only the potential systemic limitations present within our hospitals but also analyze our decision-making process to accomplish the goal of early surgery.

Transparency, Rigor, and Reproducibility Statement

This is a secondary analysis of a prospective study, North American Clinical Trials Network (NACTN), which was pre-registered at clinicaltrials.gov (NCT00178724). The current analysis plan was not formally pre-registered as, characteristic of secondary studies, it was addressing a question different and not included in the original work. For the same reasons, a formal statistical power and sample size calculations were not formally performed. All available data satisfying this current study's inclusion/exclusion criteria, detailed in the method section, from the original data were included. Figure 1 schematizes the flow of cohort extraction. Data was de-identified. A file of 989 participants, a cleaned analysis file of the original data, was obtained in February 2022, and after preprocessing to specifics of this study, a cohort of 222 was included in the current analysis. Statistical analyses were performed in SAS 9.4 (SAS Inc, Cary, NC). All the assumptions of tests and models were evaluated, and appropriate statistical methods were used, detailed in the last paragraph of the methodology section. Data from this study is not available publicly at the moment because the original study is still ongoing. Analytical codes used in this study are not available to the public because they are commonly known methods. This paper will be published under a 6-month Creative Commons Open Access license, and upon publication will be freely available at https://www.liebertpub.com/loi/neu.

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Disclaimer

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Tables

Table 1: Timing of surgery for 222 acute cervical SCI across 8 NACTN sites.

Surgery after injury	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Within 12 hours	90	40.54	90	40.54
Between 12&24 hours	73	32.88	163	73.42
Between 1&2 days	41	18.47	204	91.89
Between 2&3 days	18	8.11	222	100

Table 2: Categorization of patients based on arrival and surgery time into EAES and EADS. There was no difference in arrival time between the EAES and EADS groups but a significant difference in surgery time (p<0.05).

			Surgery		
			EAES (n=163)	**EADS (n=59)**	**p-value**
Timing in hours	**Injury to Arrival**		***n = 163***	***n = 59***	
		Median [Q1-Q3]	1 [1-3]	2 [1-9]	0.1011
	Arrival to surgery		***n = 163***	***n = 59***	
		Median [Q1-Q3]	9 [6-13]	31 [24-48]	<.0001
	Injury to surgery		***n = 163***	***n = 59***	
		Median [Q1-Q3]	11 [8-17]	40 [28-54]	<.0001

Table 3: Injury Characteristics of the 222 acute cervical SCI patients who arrived at a NACTN center less than 24 hours from their injury comparing those undergoing early and delayed surgery. The only significant difference is EAES having a lower presenting SBP and EADS having a higher proportion of AIS D patients.

			All (n = 222)	EAES (n = 163)	EADS (n = 59)	p-value
Demographics	**Age**		***n = 213***	***n = 156***	***n = 57***	
		Median [Q1-Q3]	45 [29-56]	45 [27-56]	47 [37-56]	0.6139
	Sex		***n=204***	***n=151***	***n=53***	
		Female, n (%)	41 (20%)	29 (19%)	12 (23%)	0.5912
	Race		***n=199***	***n=148***	***n=51***	
		White, n (%)	140 (70%)	104 (70%)	36 (71%)	0.9658
		Black, n (%)	43 (22%)	32 (22%)	11 (22%)	0.9937

		Other, n (%)	16 (8%)	12 (8%)	4 (8%)	1
Injury characteristics	**Mechanism of injury**		***n=220***	***n=162***	***n=58***	
		MVA, n (%)	106 (48%)	75 (46%)	31 (53%)	0.3496
		Fall, n (%)	62 (28%)	47 (29%)	15 (26%)	0.6472
		Sport/Recreation, n (%)	42 (19%)	35 (22%)	7 (12%)	0.1128
		Assault, n (%)	6 (3%)	4 (2%)	2 (3%)	0.6553
		Other, n (%)	4 (2%)	1 (1%)	3 (5%)	0.0571
Initial Clinical state	**SBP**		***n = 222***	***n = 163***	***n = 59***	
		Median [Q1-Q3]	114 [98-132]	112 [96-132]	117 [100-133]	0.0183
	DBP		***n = 222***	***n = 163***	***n = 59***	
		Median [Q1-Q3]	70 [60-81]	70 [60-82]	70 [61-80]	0.9755
	MAP		***n = 222***	***n = 163***	***n = 59***	
		Median [Q1-Q3]	86 [73-99]	86 [73-99]	87 [77-101]	0.7607

	APACHE II		***n = 147***	***n = 112***	***n = 35***	
		Median [Q1-Q3]	5 [2-10]	5 [2-9]	7 [3-12]	0.1689
Comorbidities	**Hypertension**		***n=217***	***n=159***	***n=58***	
		Yes, n (%)	77 (35%)	59 (37%)	18 (31%)	0.408
	Diabetes		***n=216***	***n=158***	***n=58***	
		Yes, n (%)	35 (16%)	25 (16%)	10 (17%)	0.802
	Heart Attack		***n=216***	***n=158***	***n=58***	
		Yes, n (%)	6 (3%)	5 (3%)	1 (2%)	1
	Pulmonary		***n=216***	***n=158***	***n=58***	
		Yes, n (%)	49 (23%)	39 (25%)	10 (17%)	0.2471
	Malignancy		***n=215***	***n=157***	***n=58***	
		Yes, n (%)	3 (1%)	3 (2%)	0 (0%)	0.5651
	Smoker		***n=216***	***n=158***	***n=58***	

		Yes, n (%)	6 (3%)	4 (3%)	2 (3%)	0.6605
	Drug Abuse		***n=217***	***n=158***	***n=59***	
		Yes, n (%)	22 (10%)	16 (10%)	6 (10%)	0.9926
ASIA Measure	**AIS (Initial within the first 7 days)**		***n=184***	***n=137***	***n=47***	
		A, n (%)	101 (55%)	80 (58%)	21 (45%)	0.103
		B, n (%)	30 (16%)	23 (17%)	7 (15%)	0.7616
		C, n (%)	24 (13%)	18 (13%)	6 (13%)	0.9478
		D, n (%)	29 (16%)	16 (12%)	13 (28%)	0.0095
	Motor Score		***n = 181***	***n = 135***	***n = 46***	
		Median [Q1-Q3]	16 [6-33]	16 [6-32]	19 [5-64]	0.4369
	Pin Prick Score		***n = 158***	***n = 118***	***n = 40***	
		Median [Q1-Q3]	24 [14-52]	24 [14-44]	23 [14-101]	1
	Light Touch Score		***n = 165***	***n = 123***	***n = 42***	
		Median [Q1-Q3]	28 [16-69]	28 [16-62]	40 [16-108]	0.4601

Table 4: Surgical timing rates by NACTN site. Of the 8 NACTN sites with cervical SCI patients in this study, 3 sites showed a significant difference between their early and delayed surgical rates.

Site	EAES	EADS	p-value
A (n=42)	57%	43%	0.3545
B (n=19)	58%	42%	0.4913
C (n=12)	67%	33%	0.2482
D (n=43)	84%	16%	<.0001
E (n=39)	82%	18%	<.0001
F (n=44)	82%	18%	<.0001
G (n=19)	63%	37%	0.2513
H (n=4)	100.00%	0%	0.5755

Table 5: Outcome and complications by surgical timing groups. EAES had a significantly higher rate of discharge to a rehab hospital and a lower rate of discharge home compared to EADS. EADS had a significantly higher skin complication rate, including decubitus ulcers and cutaneous infections.

			All (n = 222)	EAES (n = 163)	EADS (n = 59)	p-value
Hospital outcomes	LOS		***n = 212***	***n = 156***	***n = 56***	
		Median [Q1-Q3]	17 [10-31]	17 [10-32]	17 [9-31]	1
	Died		***n=222***	***n=163***	***n=59***	
		Yes, n (%)	8 (4%)	5 (3%)	3 (5%)	0.4409
	Discharge disposition		***n=203***	***n=151***	***n=52***	
		Rehab hospital, n (%)	164 (81%)	127 (84%)	37 (71%)	0.0409
		Home, n (%)	21 (10%)	10 (7%)	11 (21%)	0.003
		Other, n (%)	18 (9%)	14 (9%)	4 (8%)	1
Complications	Cardiac		***n=197***	***n=142***	***n=55***	
		Yes, n (%)	105 (53%)	81 (57%)	24 (44%)	0.0907
	GIGU		***n=186***	***n=133***	***n=53***	
		Yes, n (%)	95 (51%)	66 (50%)	29 (55%)	0.5305
	Pulmonary		***n=199***	***n=145***	***n=54***	
		Yes, n (%)	160 (80%)	117 (81%)	43 (80%)	0.867
	Skin		***n=186***	***n=133***	***n=53***	
		Yes, n (%)	32 (17%)	18 (14%)	14 (26%)	0.0356

Table 6: Discharge disposition based on AIS grade and timing of surgery. There were no differences in discharge disposition based on AIS grade between the EAES and EADS groups.

			All (n = 222)	EAES (n = 163)	EADS (n = 59)	p-value
AIS A			***n=89***	***n=73***	***n=16***	
	Discharge disposition	**Rehab hospital, n (%)**	78 (88%)	65 (89%)	13 (81%)	0.4088
		Home, n (%)	2 (2%)	1 (1%)	1 (6%)	0.3289
		Other, n (%)	9 (10%)	7 (10%)	2 (13%)	0.6616
AIS B			***n=29***	***n=22***	***n=7***	
	Discharge disposition	**Rehab hospital, n (%)**	25 (86%)	20 (91%)	5 (71%)	0.2381
		Home, n (%)	3 (10%)	1 (5%)	2 (29%)	0.136
		Other, n (%)	1 (3%)	1 (5%)	0 (0%)	1
AIS C			***n=22***	***n=16***	***n=6***	
	Discharge disposition	**Rehab hospital, n (%)**	20 (91%)	14 (88%)	6 (100%)	1
		Home, n (%)	0 (0%)	0 (0%)	0 (0%)	
		Other, n (%)	2 (9%)	2 (13%)	0 (0%)	1
AIS D			***n=28***	***n=16***	***n=12***	
	Discharge disposition	**Rehab hospital, n (%)**	14 (50%)	9 (56%)	5 (42%)	0.445
		Home, n (%)	12 (43%)	6 (38%)	6 (50%)	0.5083
		Other, n (%)	2 (7%)	1 (6%)	1 (8%)	1

Figure Legends

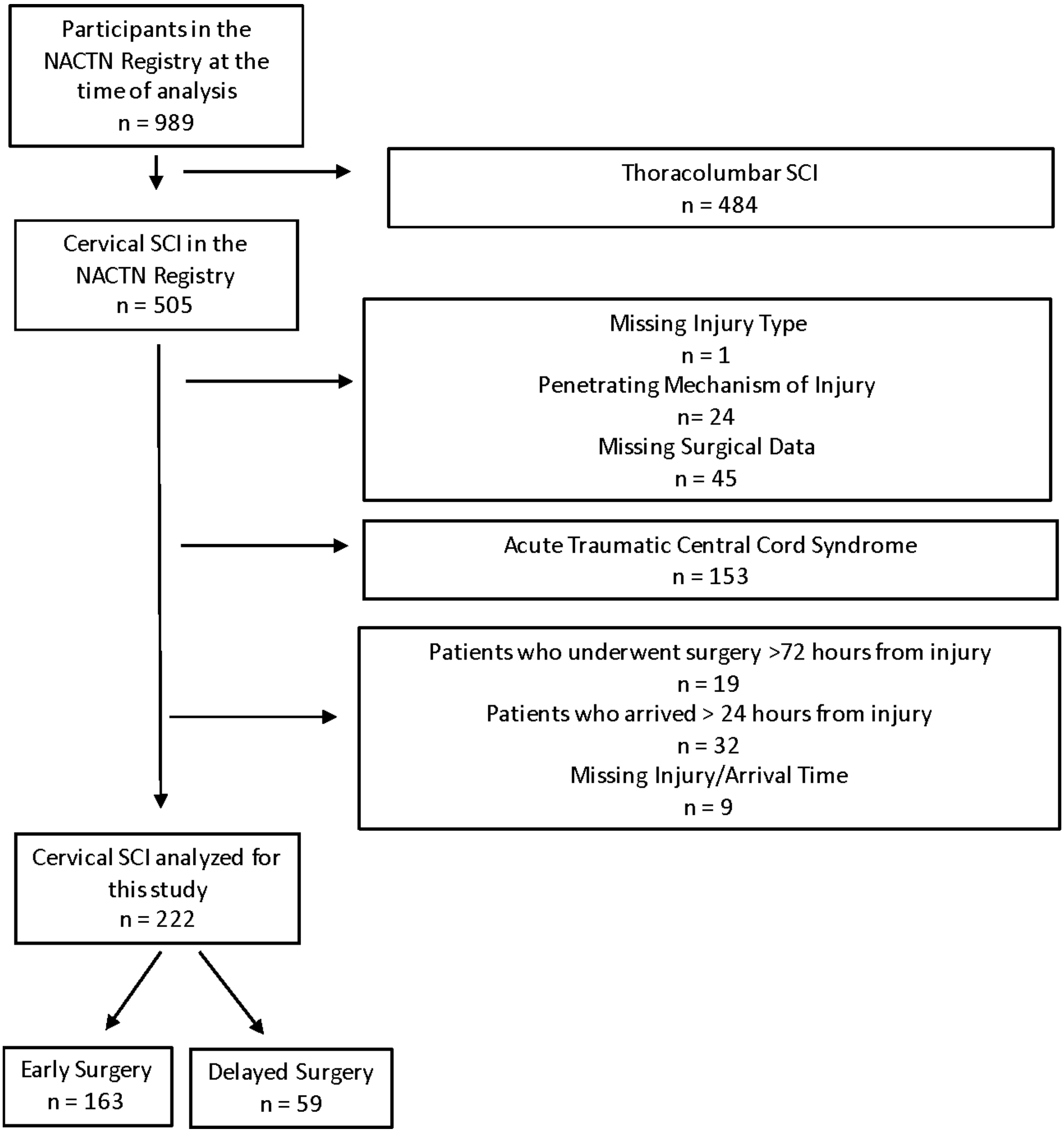

Figure 1: Inclusion and exclusion criteria of patients for this study, identifying acute cervical spinal cord injuries that arrived within 24 hours and underwent surgery within 72 hours of their injury.

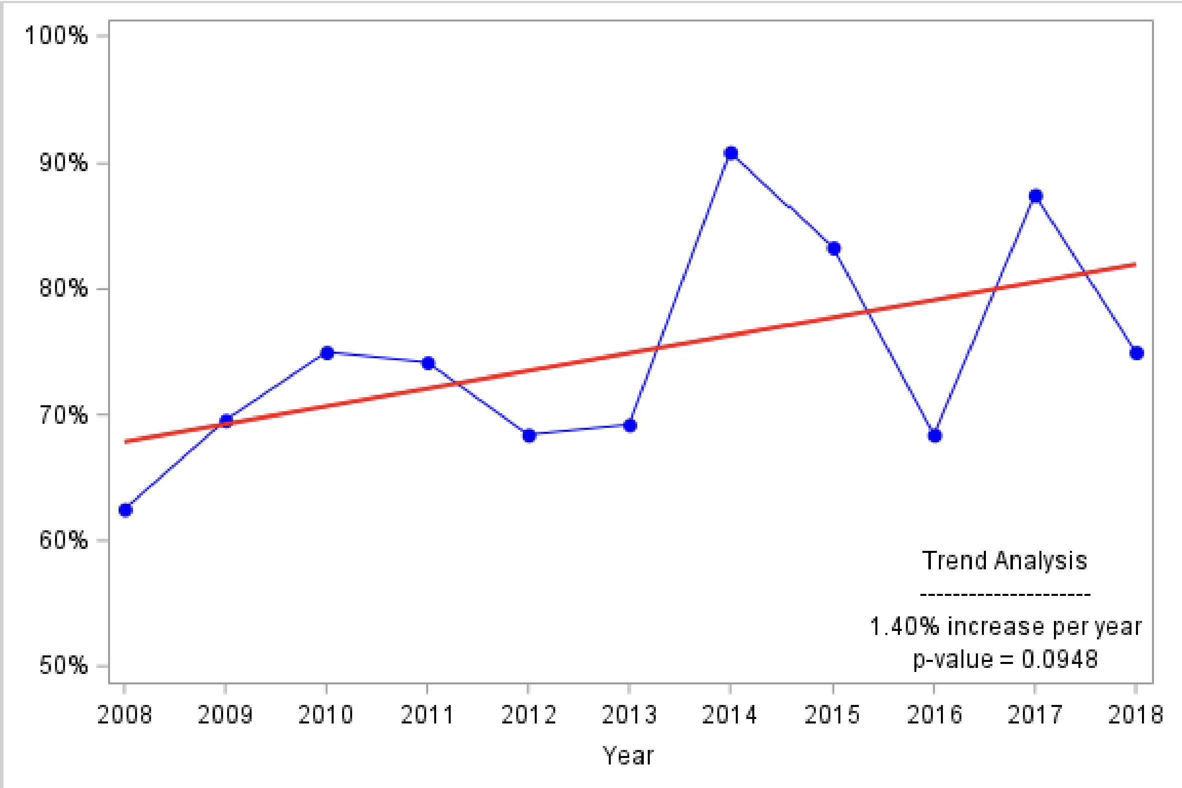

Figure 2: Annual percentage of acute spinal cord-injured patients undergoing surgery within 24 hours after surgery by year from 2005 thru 2019.

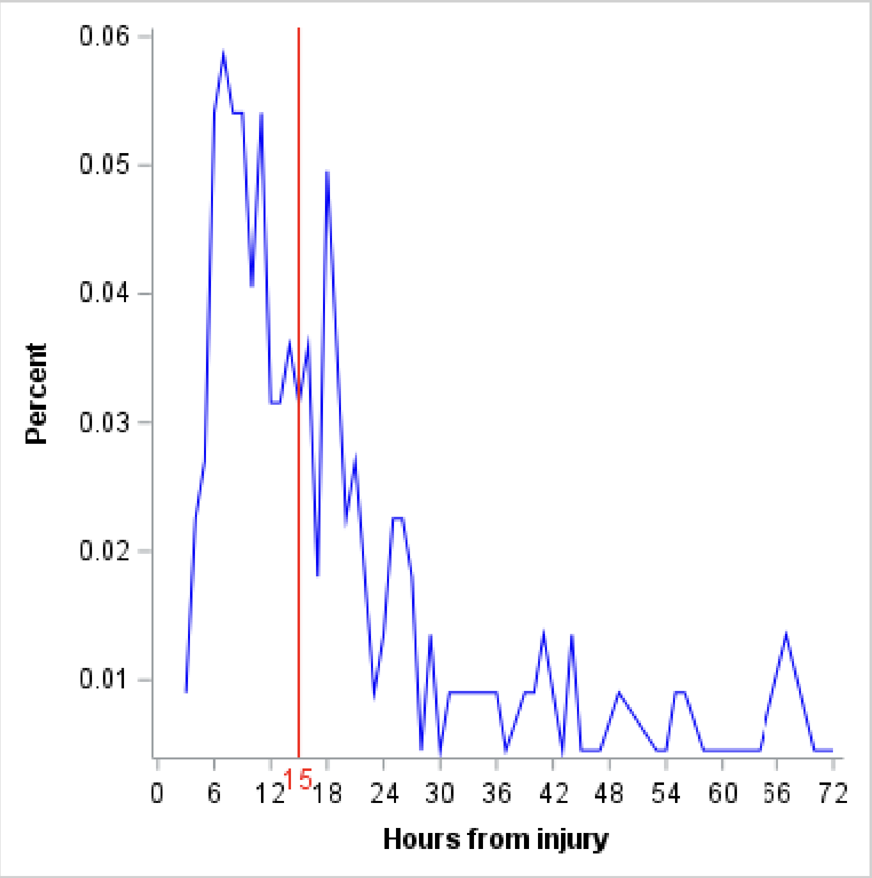

Figure 3: A probability density function plot of surgery with time as a continuous variable showing the timing of surgery from injury in 222 patients analyzed in this study. Fifty percent of patients underwent surgery within 15 hours of injury.

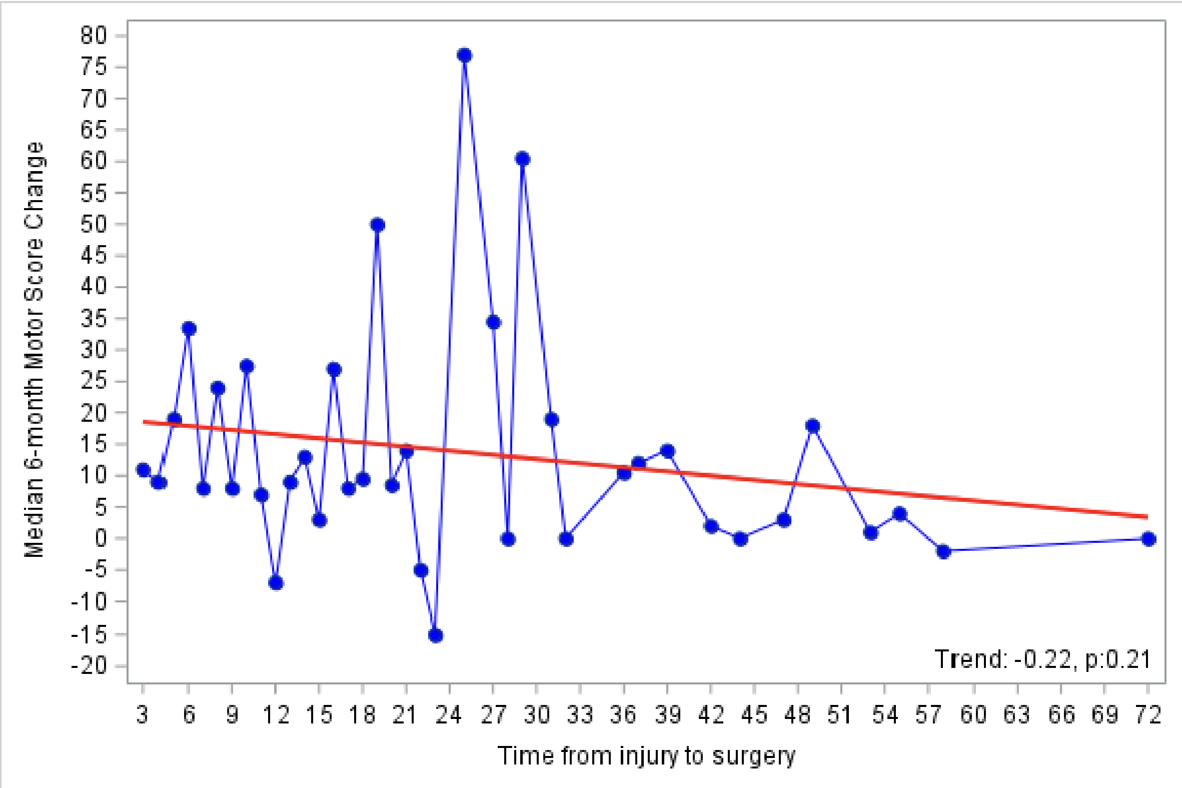

Figure 4: Median motor score change by time from injury to surgery in hours. Over the observed time course from injury to surgery, there was a trend towards improved motor scores with early surgery.

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