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SURGERY

Early Spinal Surgery Following Thoracolumbar Spinal Cord Injury

Process of Care From Trauma to Theater

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Study Design. A retrospective cohort study.

Objective. The aims of this study were to (1) determine the timing of surgery for traumatic thoracolumbar spinal cord injury (TLSCI) between 2010 and 2014 and (2) identify major delays in the process of care from accident scene to surgery.

Summary of Background Data. Early spinal surgery may promote neurological recovery and reduce acute complications after TLSCI; however, it is difficult to achieve due to logistical issues and the frequent presence of other nonlife-threatening injuries.

Methods. Data were extracted from the medical records of 46 cases of acute traumatic TLSCI (AIS level T1–L1) aged between 15 and 70 years. Patients with life-threatening injuries, not requiring spinal surgery or with poor general health, were excluded.

Results. The median time to surgery was 27 hours [interquartile range (IQR): 20–43 hours] and improved from 27 hours in 2010 to 22 hours in 2014. Cases admitted *via* a pre-surgical hospital had a longer median time to surgery than direct surgical hospital admissions (28 *vs*. 24 hours, respectively). The median time from completion of radiological investigations to surgery was 18 hours, suggesting that theater access and organization of a surgical team were the major factors contributing to surgical delay. Number of vertebral levels fractured ($\geq$5) and upper thoracic level of injury (T1–8) were also found to be associated with surgical delay.

Conclusion. Earlier spinal surgery in TLSCI would be facilitated by direct surgical hospital admission and improved access to the operating theater and surgical teams.

Key words: decompression, length of stay, neurological recovery, process of care, spinal cord injury, spine surgery, spine trauma, stabilization, thoracic spine, timing of surgery.

Level of Evidence: 3

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Acute traumatic thoracolumbar spinal cord injury (TLSCI) is a devastating event resulting in severe neurological deficits that greatly impact on general health and functional independence.[1–3] The cost per case of TLSCI in Australia has been estimated to be $5.0 million over a person's lifetime,[4] reflecting a high long-term disease burden.

Time to surgical stabilization is the strongest predictor of in-hospital complications in TLSCI.[5] Stabilization surgery within 72 hours appears to reduce respiratory complications,[6–10] mortality,[6] intensive care unit (ICU), and hospital length of stay (LOS),[7–10] and therefore reduce overall hospital costs.[10] In addition to surgical timing, advanced age ($\geq$65 yrs), comorbidities, and injury severity have also been associated with a higher rate of secondary complications.[5,11,12]

Although spinal surgery within 72 hours is safe, feasible,[13] and recommended to minimize complications in TLSCI, its effect on neurological recovery remains uncertain.[14–17] Limited evidence suggests that decompression within 24 hours may improve outcomes in TLSCI.[13,16,18–21] Expert consensus and clinical practice guidelines recommend the consideration of early surgical decompression, particularly in the presence of deteriorating neurology.[22] Performing early surgery can be difficult due to patient heterogeneity and complexity and delays can occur during any stage of the process of care (*e.g.*, paramedic retrieval, investigations, and organization of theater space).

The aims of this study were to determine the timing of spinal surgery for traumatic TLSCI between 2010 and 2014

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and to establish where major delays occur in the process of care from accident scene to surgery.

MATERIALS AND METHODS

Study Design

A retrospective data audit of TLSCI cases admitted over 4 years (July 2010–July 2014) to the Alfred and Austin Hospitals (Melbourne, Victoria, Australia) was conducted. Low-risk Human Research Ethical Approval was obtained at both institutions.

Inclusion and Exclusion Criteria

Patients were included in the study if they had an acute traumatic spinal cord injury (SCI, resulting in neurological deficit) between the American Spinal Injury Association Impairment Scale (AIS) neurological levels of T1–L1 inclusive and were aged 15 to 70 years.

Patients not requiring spinal surgery, with poor general health (*e.g.*, pre-existing neurological deficits), or where key information (*e.g.*, time of injury and surgery) was unavailable were excluded. Patients sustaining life-threatening injuries, defined as significant head injury at the scene [sustained Glasgow Coma Score (GCS) < 13], significant chest trauma (causing severe hypoxia or hemodynamic instability post-insertion of an intercostal catheter), hemodynamic instability resulting from abdominal or retro-peritoneal bleeding, pelvic fracture, or more than two long bone fractures were also excluded.

Patients with nonlife-threatening injuries (*e.g.*, rib or sternal fractures, hemopneumothoraces, and peripheral limb fractures) and who otherwise fulfilled the inclusion and exclusion criteria were included.

Data Collection

For each included case, the following data fields were collected: demographics, date and time of injury, cause of accident, initial GCS, accident location, date and time of paramedic call, ambulance arrival and departure, date and time of arrival at and departure from first hospital, date and time of surgical hospital arrival and discharge, date and time of spinal computed tomography (CT), and magnetic resonance image (MRI) scans. In addition, injury characteristics (level and type of spinal fracture, other injuries, presence of spinal cord separation on MRI, neurological level of injury, and AIS grade at surgical hospital admission and rehabilitation discharge) and surgical intervention (date and time of initiation of spinal surgery defined as the first anesthetic entry of surgery, date and time of completion of spinal surgery defined as the last anesthetic entry of surgery) were also collected.

Data Analysis

Data were separated into two main periods of interest: pre-hospital (time of injury to first hospital admission) and hospital (first hospital admission to surgical hospital discharge). The following epochs were calculated: time of injury to first ambulance arrival, first ambulance arrival to ambulance departure, ambulance departure to first hospital admission, total paramedic time (time between injury and first hospital admission), pre-surgical hospital LOS (time between first hospital admission and surgical hospital admission), hospital admission and spinal CT scan, hospital admission and spinal MRI scan (time that first spinal CT or MRI was completed, regardless of at which hospital radiology was performed), and surgical hospital admission to midpoint of surgery and acute hospital LOS (time between first hospital admission and surgical hospital discharge).

The time to surgery (spinal cord decompression or stabilization) was defined as the time of injury to the midpoint between initiation and completion of surgery. Data analysis was performed using Igor Pro 6.0 software (WaveMetrics, Portland, OR).

Statistical Analysis

Nonparametric data were compared using Mann-Whitney U t test and significance was set at $P < 0.05$. Data are presented as median $\pm$ IQR (unless otherwise stated). Statistical analyses were performed using Prism software (version 6; GraphPad, CA).

RESULTS

Screening of Patients

A total of 397 cases were screened and 46 cases were included. The reasons for exclusion were absence of T1–L1 neurological deficit (n = 298), life-threatening injuries (n = 24), nontraumatic mechanism (n = 13), key information unavailable (n = 11), age (n = 4), and no surgical intervention (n = 1).

Demographics and Injury Characteristics

The mean ($\pm$SD) age was 36 ± 16 years and the majority (80%) of patients were male. The most frequent injury level was T12–L1 (37%) as a result of a burst fracture (50%) or fracture-dislocation (26%). The majority of cases (67%) were classified as complete (AIS A) SCI and a high proportion of patients (71%) had additional nonlife-threatening injuries. Demographic details of included patients are summarized in Table 1.

Timing of Surgery

The overall median time to spinal surgery was 27 hours (IQR: 20–43, Figure 1). Five (11%) patients had spinal surgery $\leq$12 hours, 17 (37%) $\leq$24 hours, and 45 (98%) $\leq$72 hours. The median time to spinal surgery improved from 27 hours in 2010 to 22 hours in 2014 (Table 2). However, this improvement was not statistically significant ($P = 0.44$).

The median time to spinal surgery of patients admitted with motor complete (AIS A or B) injuries was 28 hours (IQR: 20–44, n = 36), while those with motor incomplete (AIS C or D) injuries underwent surgery at 26 hours (IQR: 18–35, n = 9, $P = 0.52$). Patients presenting with isolated TLSCI had slightly shorter time to surgery than patients

TABLE 1. Demographic Characteristics of Included Patients

Variable	n (%)
Age (mean ± SD)	36 ± 16
Male	37 (80)
Accident category	
Unprotected road users	18 (39)
High fall (≥1 m)	15 (32)
Motor vehicle	8 (17)
Low fall (same level or <1 m)	3 (7)
Struck by or collision with object	2 (4)
Location of accident	
Major cities	24 (52)
Inner regional	14 (30)
Outer regional	6 (13)
Unknown	2 (4)
Neurological level of injury	
T1–8	23 (50)
T9-L1	23 (50)
Acute admission AIS	
A	31 (67)
B	5 (11)
C	4 (9)
D	5 (11)
Unknown	1 (2)
Rehabilitation discharge AIS	
A	25 (54)
B	4 (9)
C	2 (2)
D	14 (30)
E	1 (2)
Unknown	1 (2)
Number of vertebral levels fractured	
≤5	41 (89)
>5	5 (11)
Presence of other injuries	
Poly-trauma	33 (72)
Isolated	13 (28)
Presence of spinal cord transection	
No	42 (91)
Yes	4 (9)

AIS indicates American Spinal Injury Association Impairment Scale; SD, standard deviation.

with TLSCI accompanied by other nonlife-threatening injuries; however, this difference was not significant (23 hours, IQR: 19–37, n = 13 *vs.* 28 hours, IQR: 22–47, n = 33, respectively, $P = 0.32$).

Process of Care

The overall median paramedic time was 1.4 hours (IQR: 1.1–1.9), with the ambulance taking a median of 21 minutes to arrive at the patient. After admission to first hospital (pre-surgical or surgical), spinal CT was completed in a median time of 1 hour (IQR: 0.7–1.8, n = 43) and MRI in 6 hours (IQR: 3–12, n = 40). Overall, patients had a median time to surgery of 18 hours (IQR: 8–27) after completion of all radiological investigations.

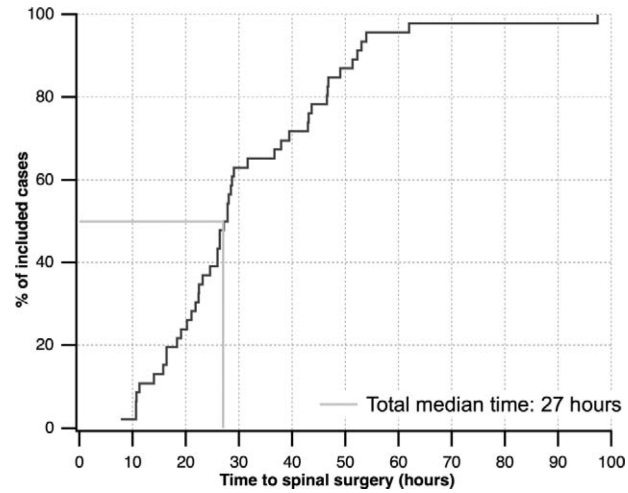

Figure 1. Overall timing of spinal surgery in thoracolumbar spinal cord injury. Cumulative histogram showing the proportion of patients decompressed at different times (dark grey line). The median time of spinal surgery is indicated by the vertical light grey line.

Direct *versus* Indirect Admission to Surgical Hospital

Twenty (43%) patients with TLSCI were transported directly to a surgical hospital and underwent spinal surgery in a median time of 24 hours (IQR: 12–42). However, the majority of patients (n = 26, 57%) were admitted *via* another hospital with a median time to spinal surgery of 28 hours (IQR: 23–44). This result trended toward significance ($P = 0.1$, Figure 2A, B).

The median LOS of cases admitted to a pre-surgical hospital was 8 hours (IQR: 5–11). Most cases (n = 25, 96%) completed spinal CT at a pre-surgical hospital in a median of 1 hour (IQR: 0.7–1.5) after admission. Of the 23 cases where MRI time was available, the majority (n = 17, 74%) had this investigation completed at the surgical hospital in a median time of 7 hours (IQR: 3–12) after surgical hospital admission. The median time to spinal CT and MRI for cases admitted straight to a surgical hospital was 1.2 hours (IQR: 0.7–1.9) and 5 hours (IQR: 3–12), respectively. Once admitted to a surgical hospital, indirect admissions underwent surgery marginally faster than direct admissions (20 hours, IQR: 15–32 *vs.* 21 hours, IQR: 9–41, respectively). This suggests that the timing of spinal surgery is not greatly influenced by the timing of radiological investigations.

Timing of Surgery and Patient Characteristics

The number of vertebral levels fractured and neurological level of injury were associated with surgical delay. When the data were analyzed by the number of vertebral levels fractured, the median time to spinal surgery was significantly lower for patients with five or less (26 hours, IQR: 19–41, n = 41) than those who had more than five vertebral levels fractured (47 hours, IQR: 32–75, n = 5; $P = 0.03$, Figure 3A). All patients with more than five vertebral levels fractured attended a pre-surgical hospital, which may have contributed to this result. There was a trend toward significance when the timing of surgery was analyzed in relation to neurological level of injury ($P = 0.1$, Figure 3B).

Other Early Surgical Characteristics

Data were ranked on the basis of time to spinal surgery and analyzed to evaluate the differences between patients in the upper quartile (Q1, n = 12, median time to surgery of 15 hours) and lower quartile (Q4, n = 12, median time to surgery of 50 hours).

With regard to the neurological level of injury, Q1 comprised a higher proportion of lower thoracic (75%, n = 9) and a lower proportion of upper thoracic (25%, n = 3) injuries. Conversely, Q4 comprised a higher proportion of upper thoracic (58%, n = 7) and lower proportions of lower thoracic (42%, n = 5).

A higher proportion of patients in Q1 were admitted directly to a surgical hospital (75% *vs.* 42%) and cases in Q1 were younger than cases in Q4 (29 *vs.* 44 years, respectively). Fracture type and vertebral injury mechanism did not appear to differ between the two patient groups (data not shown).

Surgical Timing and Acute Hospital Length of Stay

The overall acute hospital LOS was 22 days (IQR: 16–37 days). The median LOS was 21 days in patients with upper thoracic injury (IQR: 17–42, n = 22) and 22 days in lower thoracic injuries (IQR: 15–29, n = 23). The median LOS between different neurological levels of injury was not significantly different.

Patients who had surgery within 12 hours had a median acute LOS of 29 days (IQR: 20–45, n = 5), within 12 to 24 hours a median acute LOS of 20 days (IQR: 14–27, n = 12), and within 24 to 72 hours a median acute LOS of 19 days (IQR: 16–40, n = 27). The one case having surgery at least 72 hours postinjury had the longest LOS (46 days).

DISCUSSION

This study examines the process of care of TLSCI patients from trauma to theater. The median time to spinal decompression and stabilization was 27 hours, with access to theater following admission to a surgical center the major factor delaying surgery. Identifying the principal sources of delay in the care pathway is important to enable improvements in efficiency and the timing of surgical intervention.[23]

Current practice reflects the intent to decompress/stabilize the spine within 72 hours in TLSCI. The majority of our sample (n = 45, 98%) had surgery within this timeframe. Spinal surgery less than 72 hours has been shown to enable mobilisation,[24] reduce respiratory insufficiency,[6–10] mortality,[6] acute hospital LOS,[7–10] and therefore overall hospital costs.[10] However, there is evidence that faster is better, with surgery performed less than 24 hours resulting in the lowest complication rates and acute hospital LOS.[25,26] Only 37% (n = 17) of our sample underwent surgery less than 24 hours and the median LOS for these patients did not differ significantly from those undergoing surgery between 24 and 72 hours (n = 27) postinjury (29 *vs.* 19 days, $P = 0.23$).

Rapid surgery may also have the potential to improve neurological outcome following TLSCI, although data are limited.[13–17] Clinical practice guidelines currently recommend surgical intervention within 24 hours in TLSCI

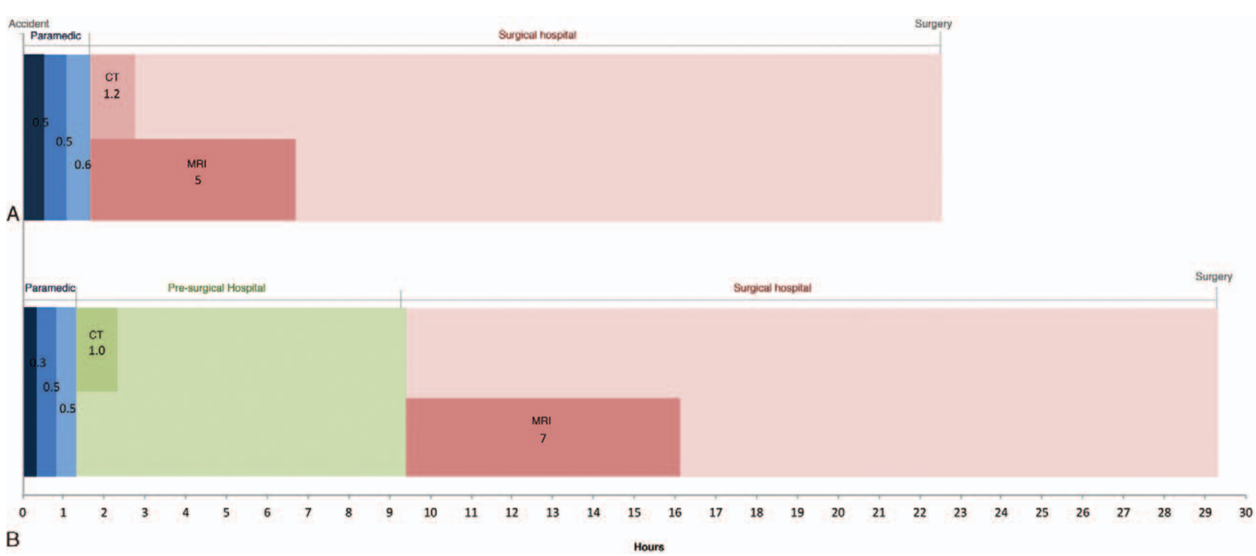

Figure 2. Process of care for direct (**A**) and indirect (**B**) admissions to surgical hospital. The median time of each phase is shown for both groups of patients in different colors. Each stage of paramedic involvement is shown in different shades of blue. The pre-surgical hospital phase is shown in light green and the surgical hospital admission is shown in light pink. The time taken to complete radiological investigations is shown as a darker shade in the respective phase. The overall median time to spinal decompression of cases transported directly to a surgical hospital (24 hours, n = 20) was slightly shorter than cases taken *via* a pre-surgical hospital (28 hours, n = 26). Please note summation of the median times for each segment does not yield the overall median times to spinal decompression for each group.

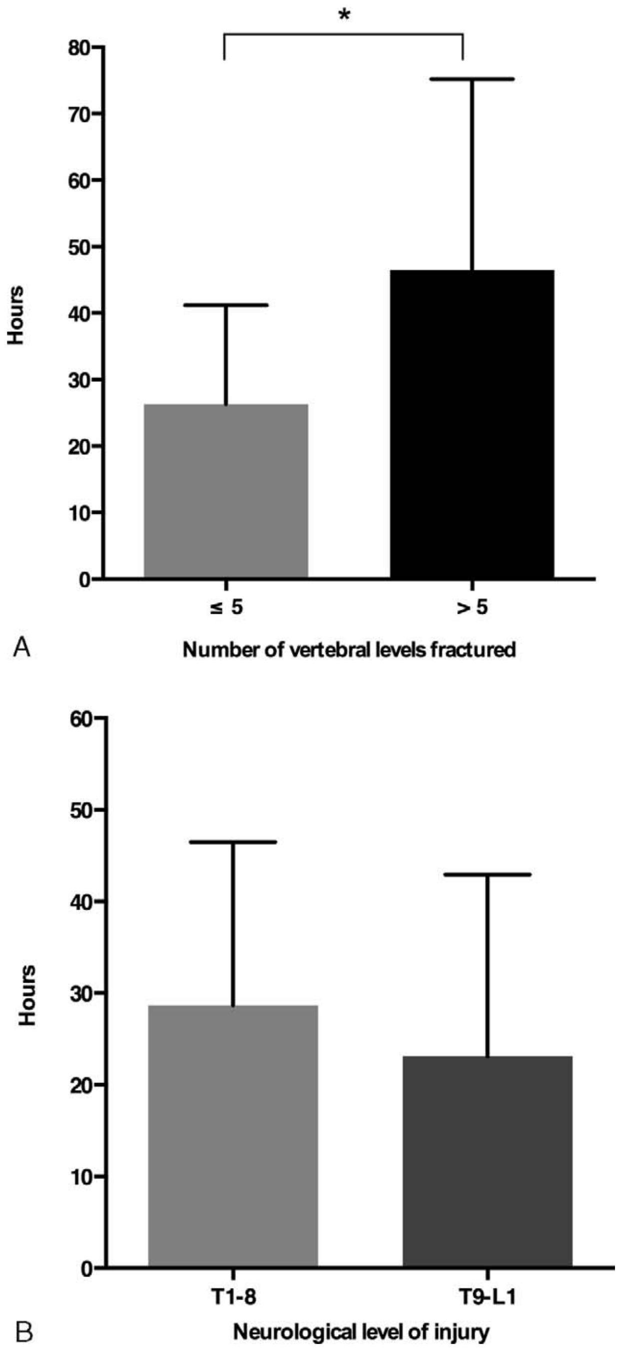

Figure 3. Factors associated with surgical delay. (**A**) Median time (IQR) of spinal surgery for patients with ≤5 vertebral levels fractured *versus* >5 vertebral levels fractured, $^{*}P=0.03$. (**B**) Median time (IQR) of spinal surgery for patients with upper versus lower thoracic neurological levels of injury.

patients with incomplete or deteriorating neurology.[22] In the current study, the median time to surgery was slightly above 24 hours, with a small proportion (n = 5, 11%) undergoing surgery within 12 hours.

Minimizing the Time to Surgery

The main factors influencing the timing of surgery were pre-surgical hospital attendance and the organization of theater after surgical hospital admission. Direct surgical hospital admission following SCI is often challenging due to the patient's medical status and accident location. TLSCI is frequently accompanied by other injuries and concerns about patient stability may necessitate admission to closer centers without spinal surgical expertise, particularly as major trauma guidelines often dictate admission to a medical center for stabilization within 1 hour. In many situations, pre-surgical hospital admission may be unavoidable; however, LOS could potentially be minimized by an awareness of urgency, the application of defined protocols, and early notification of specialist centers.[27,28]

The longest single segment in the process of care in this study was the period from surgical hospital admission to surgical stabilization and/or decompression. A number of factors have been associated with delays to theater in orthopedic and other populations requiring emergency surgery. These include competition for theater access from other services, lack of operating room availability particularly after hours, absence of an experienced surgeon, and lack of best-practice time to theater standards.[29–31] The timing of spinal surgery and its effect on neurological outcome in TLSCI is yet to be convincingly demonstrated, which could result in potential difficulty for surgeons when justifying the prioritization of decompression surgery over other emergency cases. Surgeons may understandably choose to simply schedule operations for the next available list, particularly given the evidence for a reduction in complications when spinal surgery occurs within 24 to 72 hours of TLSCI.[5–10] Possible strategies to improve efficiency include early recognition and referral, increased awareness of urgency, and prioritization of theater at surgical hospitals. The introduction of a pre-hospital notification system ("code spine") similar to the model used in stroke[32] may also be of benefit in reducing time to surgery.

The main barriers to early spinal surgery identified in this study appear consistent with a recent Canadian study.[33] However, the pre-surgical hospital processes in the latter study differed substantially (often involving multiple pre-surgical hospitals), and their study population was cervical SCI. The findings of this study are similar to our recent study[34] that examined the process of cervical SCI care in Australia and New Zealand. Both studies highlight two main factors influencing surgical timing: pre-surgical hospital attendance and access to theater following medical stabilization and imaging. To our knowledge, this is the first study to investigate barriers to early surgery in TLSCI.

TABLE 2. Time to Spinal Surgery by Year

Year (n)	Median Time to Spinal Surgery (IQR)
2010 (8)	27 h (17–38)
2011 (12)	34 h (26–48)
2012 (12)	27 h (19–39)
2013 (9)	29 h (17–47)
2014 (5)	22 h (15–34)

IQR indicates interquartile range.

Other Factors Influencing Surgical Timing

Multiple vertebral fractures were associated with a significantly longer time to surgery. This may reflect the need for more complex surgery in this group, although all patients also underwent pre-surgical hospital admission and this may have contributed. Neurological level of injury was also found to influence surgical timing, with upper thoracic injury levels waiting longer for surgery. Upper thoracic SCIs occur typically as a result of high forces and the presumed futility of these injuries may have lessened their urgency for operative intervention. In future clinical trials examining neurological recovery, differentiating futile from nonfutile injuries may be useful in order to select patients likely to benefit from early surgery.

We found that most (72%) TLSCI patients had nonlife-threatening injuries in addition to their SCI, which required preoperative assessment and management. Although it would seem logical that such injuries would be associated with operative delay, these did not appear to influence surgical timing. In fact, some of the fastest surgical times in our sample were in cases wherein respiratory stabilization with insertion of up to two intercostal catheters was required before surgery. This demonstrates the feasibility of early surgery in the setting of severe chest trauma.

Study Limitations

This study has a retrospective design and limited patient numbers. In addition, our sample was taken from a single area of the western world and the proportion of cases resulting from different injury mechanisms (*e.g.*, penetrating trauma) may vary between regions. Patients sustaining life-threatening injuries were excluded to eliminate the prioritization of more severe injuries as a confounder. Patients aged more than 70 years were excluded due to the potential for comorbidities to delay surgery.

Accuracy of the AIS in the acute setting may be affected by factors such as sedation, medications, pain, fever, and other injuries.[35] It is possible that some early assessments may have been inaccurate, leading to errors in interpreting changes in neurological outcome over time.

In conclusion, the median time to spinal surgery in TLSCI was 27 hours in this study. Major factors associated with operative delay were pre-surgical hospital attendance and access to theater following medical stabilization and imaging. Current surgical timing is appropriate to minimize complications following TLSCI, although emerging evidence favors surgical decompression within 8 hours to maximize neurological recovery. This study suggests the most efficient ways to achieve early surgery would be to facilitate direct admission to a surgical hospital and earlier access to the operating theater.

➢ Key Points

- ❑ Early spinal surgery following thoracolumbar SCI reduces complications and hospital length of stay and may promote neurological recovery; however, it is often difficult to achieve as a result of logistical challenges and the presence of polytrauma.
- ❑ Surgical delay following thoracolumbar SCI is associated with pre-surgical hospital admission and poor theater access, as well as upper thoracic level of injury and number of vertebral levels fractured.
- ❑ Early spinal surgery in patients with traumatic thoracolumbar SCI may be facilitated by direct surgical hospital admission, rapid organization of a surgical team, and earlier access to the operating theater.

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