World Neurosurgery: X 23 (2024) 100374

Contents lists available at ScienceDirect

World Neurosurgery: X

journal homepage: www.journals.elsevier.com/world-neurosurgery-x

# Laminectomy for acute transverse sacral fractures with compression of the cauda equina: A neurosurgical perspective

Devin A. Nikjou [a,b,j], Chani M. Taggart [b,f,h,i], Salvatore C. Lettieri [b,c,d,h,i], Michael R. Collins [e,h,i], Owen T. McCabe [b,f,h,i], Layne A. Rousseau [b,g,h,i], Iman Feiz-Erfan [a,b,h,i,*]

[a] Division of Neurosurgery, Valleywise Health Medical Center, Phoenix, AZ, USA
[b] Department of Surgery, Valleywise Health Medical Center, Phoenix, AZ, USA
[c] Division of Plastic Surgery, Valleywise Health Medical Center, Phoenix, AZ, USA
[d] Division of Plastic Surgery, Mayo Clinic, Phoenix, AZ, USA
[e] Department of Radiology, Valleywise Health Medical Center, Phoenix, AZ, USA
[f] Division of Trauma, Valleywise Health Medical Center, Phoenix, AZ, USA
[g] Division of Urology, Valleywise Health Medical Center, Phoenix, AZ, USA
[h] Creighton University, School of Medicine Phoenix, Phoenix, AZ, USA
[i] University of Arizona, College of Medicine Phoenix, Phoenix, AZ, USA
[j] Arizona State University, School of Biological and Health Systems Engineering, Tempe, AZ, USA

ARTICLE INFO

*Keywords:*
Fracture of the sacrum
Cauda equina syndrome
Sacral laminectomy
Pelvic trauma
Nerve root repair

ABSTRACT

*Introduction:* Optimal management of transverse sacral fractures (TSF) remains inconclusive. These injuries may present with neurological deficits including cauda equina syndrome. We present our series of laminectomy for acute TSF with cauda equina compression.

*Methods:* This was a retrospective chart review of all patients that underwent sacral laminectomy for treatment of cauda equina compression in acute TSF at our institution between 2007 through 2023.

*Results:* A total of 9 patients (5 male and 4 female) underwent sacral laminectomy to decompress the cauda equina in the setting of acute high impact trauma. Surgeries were done early within a mean time of 5.9 days. All but one patient had symptomatic cauda equina syndrome. In one instance surgery was applied due to significant canal stenosis present on imaging in a patient with diminished mental status not allowing proper neurological examination. Torn sacral nerve roots were repaired directly when possible. All patients regained their neurological function related to the sacral cauda equina on follow up. The rate of surgical site infection (SSI) was 33%.

*Conclusion:* Acute early sacral laminectomy and nerve root repair as needed was effective in recovering bowel and bladder function in patients after high impact trauma and TSF with cauda equina compression. A high SSI rate may be reduced by delaying surgery past 1 week from trauma, but little data exists at this time for clear recommendations.

## 1. Introduction

Fractures of the sacrum have been divided into 3 zones anatomically. These represent fractures that do not include the central sacral canal or neural foramen (Zone I fractures), fractures that do not include the sacral canal but do involve the neural foramen (Zone II fractures), or fractures that include the sacral canal (Zone III fractures).[1] Zone III fractures have been found to carry the highest risk of associated neurological deficit compared to Zone I or II fractures.[1] The sacral canal contains the distal end of the thecal sac as well as the sacral cauda equina and nerve roots, which supply not only parts of the lower extremity sensation and motor function, but also provide neural innervation for bowel, bladder, and sexual function. Therefore, sacral fractures have been associated with acute loss of bowel and bladder (B&B) function in the setting of trauma.[1–4] Neurological deficits associated with sacral fractures have been graded by Gibbons et al into 4 categories

*Abbreviations:* TSF, Transverse sacral fracture; SSI, Surgical site infection; MVA, Motor vehicular accident; B&B, Bowel and bladder; RCC, Roy-Camille classification; SCE, Sacral cauda equina; UTI, Urinary tract infection; CSF, Cerebrospinal fluid; CT, Computed tomography; IRB, Institutional review board.

* Corresponding author. Department of Surgery, Valleywise Health Medical Center, 2601 E Roosevelt Street, Phoenix, AZ, 85008, USA.
*E-mail address:* Iman_Feiz-Erfan@dmgaz.org (I. Feiz-Erfan).

https://doi.org/10.1016/j.wnsx.2024.100374
Received 27 December 2023; Accepted 28 March 2024
Available online 2 April 2024

of increased severity.[2] Grade 1 entails no neurological deficit, grade 2 paresthesia only, grade 3 motor loss with or without paresthesia, and grade 4 bowel and/or bladder dysfunction with or without motor or sensory dysfunction.[2] Transverse sacral fractures (TSF), which comprise a sub-group of Zone III sacral fractures, have been associated with a significant potential for B&B dysfunction.[1–5] TSF are further sub-classified by Roy-Camille et al with additional specification by Strange-Vognsen and Lebech into 4 subcategories.[6,7] These 4 types include type 1 flexion fractures with sacral angulation without cephalad fragment displacement, type 2 flexion fractures with posterior displacement of the cephalad fragment, type 3 fractures with anterior displacement of the cephalad fragment,[6] and type 4 fractures with comminution of the upper sacrum.[7] Going forward in this presentation we will refer to this extended classification as the Roy-Camille classification (RCC).[6,7] Due to the overall rarity of these types of sacral fractures strong guidelines with regards to the management of such fractures have been lacking. Generally, no clear-cut consensus has been established to favor surgical or conservative treatment specifically to address any B&B compromise that may be associated with TSF.[5,8]

The goal of this article was to review our neurosurgical data on direct open decompressive treatment (sacral laminectomy) applied to acute traumatic TSF with compromise of the sacral cauda equina (SCE).

Specifically, the intention has been to focus on the neurosurgical aspects of SCE compromise. Issues with regards to the orthopedic side of pelvic ring stability, lumbo-pelvic instability, pelvic organ injury of the genito-urinary and bowel systems, or lumbo-sacral plexus injury were not the focus of this article.

## 2. Methods

This study reviewed retrospectively all patients that underwent direct sacral decompressive laminectomy for acute traumatic Zone III TSF (fractures involving the sacral canal) with neural deficits related to the sacral cauda equina nerve roots classified per the Gibbons criteria as grade 4[2] or with significant (50% or greater) boney sacral canal stenosis from fracture without known neurological deficits in patients with diminished mental status and with no contraindications for acutely performed sacral laminectomy. Further inclusion criteria were that the fracture had to include a sacral level between S1 to S3 (proximal sacral fracture). Isolated distal sacral fractures (S4-5) were excluded. Presence of canal stenosis was graded as severe (greater than 50% stenosis), moderate up to 50% stenosis, or mild less than 25% stenosis. Moreover, all patients had to have their sacral decompression during the index hospitalization and had their surgery performed by the senior author (IFE). Indirect reduction of sacral angulation or deformity was not attempted. The study period was from 2007 to 2023 at a level one metropolitan trauma hospital.

Patients' records were reviewed retrospectively, follow up was generated from outpatient records as well as phone calls placed to patients. Institutional review board (IRB) approval was obtained for this study.

## 3. Results

A total of nine patients (5 men and 4 women; mean age 36.9 years, range 15–58 years) met the inclusion criteria. Mechanism of injury included 5 vehicular related accidents, 3 falls from height, and one industrial crush injury. None of the trauma mechanisms were due to suicide. Eight patients presented with associated spine injuries (1 case of thoracic chance fracture needing surgery, 1 case of multiple thoracic compression fractures, 1 case of lumbar compression fracture, 1 case of lumbar burst fracture, and four cases of lumbar transverse-process or spinous process fractures). None presented with an associated spinal cord injury or lumbar cauda equina injury. Therefore, we have no patients presenting in spinal shock. Five patients were polytraumas. Four patients also had anterior pelvic ring injuries, with one acetabular fracture. One patient each had an associated bladder and urethra injury or anal tear (Table 1). None presented with an isolated sacral fracture. Fracture morphology included 3 cases of S3 fractures, and each 2 cases involving S1-2 junction, S2 body, and S2-3 junction (Table 1). Based on the RCC, we found one type 1 injury, seven type 2 injuries, and one type 4 injury. We did not have any type 3 injuries (Table 1). Degree of canal stenosis was severe in 3 instances, moderate in 3, and mild in 3 (Table 2).

### 3.1. Neurological findings

All but one patient had symptoms related to sacral cauda equina nerve root compromise (Table 2). In 6 patients there was numbness to light touch over the saddle region. This was consistent with overt SCE syndrome. Two patients had mild SCE syndrome due to the absence of saddle anesthesia. These patients suffered from urinary retention. The final patient was not amenable to exam due to mental status. Five had abnormal anal sphincter exam including diminished rectal tone, absent anal sphincter reflexes (anal wink reflex, bulbocavernosus reflex), and/or absence of voluntary external anal sphincter contraction. Five patients had some degree of urinary retention as evidenced by complete inability to urinate or a post void residual well over 100 cc (Table 2). In one patient a comprehensive exam was not possible due to prolonged diminished mental status from alcohol withdrawal. This patient had a moderate sacral canal stenosis without contraindications for surgery and went on to undergo sacral decompression laminectomy (Fig. 1).

### 3.2. Surgical findings

Levels of laminectomy included S1–S4 in five cases, S2–S4 in three, and L5-S4 in one patient. Timing of surgery was from 1 to 20 days (mean 5.9 days) after admission during index hospitalization (Table 3). Two patients also underwent a lumbo-pelvic fixation along with their sacral decompression for lumbo-pelvic instability, with two other patients undergoing ilio-sacral fixation for stability. Intra-operative findings (Table 3) disclosed contusions to the sacral nerves in all instances, with individual nerve root disruption in 3 cases (two cases with partial or complete nerve root tears needing nerve root repair with end-to-end coaptation and nerve tube placement) (Fig. 1). In all but one patient (case 1), the injury to the sacral nerves appeared bilateral. In case 1, the bruising was overt and involved the right S3 and S4 nerve roots. Although frank bruising was not observed on the left side, subtle nerve root damage could not be excluded (Table 3). In one instance a traumatic spinal fluid leak was repaired (Fig. 1, Table 3).

### 3.3. Patient outcomes

A total of 4 patients had a surgical complication related to their sacral laminectomy (Table 3). Three patients suffered from a surgical site infection (SSI). One of these patients also had a lumbo-pelvic fixation done for pelvic instability from an industrial crush injury. Another patient had a Morel-Lavallée internal degloving injury to the posterior sacral/pelvic soft tissues. One patient suffered from a new onset post-operative coccydynia that spontaneously resolved after 8 months.

Long term follow-up ranged from 15 to 139 months (mean 87.7 months, median 114 months). This was equivalent to 789 person-months. All patients reported normal function of bowel and bladder related to their index trauma (Table 3). One patient 8 years after his trauma had suffered from new diagnosis of prostate cancer and had developed bowel and bladder dysfunction related to the new interval diagnosis and treatment. B&B symptoms improved generally within the index hospitalization after surgery or within 4 months post operatively. One patient (19-year-old-female) had noticed occasional urinary tract infections following the index trauma, but did not complain of incontinence. Interestingly, she noted improved sexual functions with regards to orgasm post-sacral decompression, that even surpassed her pre-injury normal function. One male patient after crush injury complained of post-

**Table 1**
Patient demographics.

| Case (Age & Sex) | Mechanism | Level of Sacral Fracture | Roy-Camille Classification | Associated Injuries |
|---|---|---|---|---|
| 1 (19F) | MVA | S3 | Type 2 | Pelvic ring fracture, rib fracture, lumbar transverse process fracture, kidney laceration |
| 2 (58M) | MCC | S3 | Type 2 | Thoracic chance fracture, upper and lower extremity fracture |
| 3 (56M) | Crush | S1-2 | Type 4 | Bladder and urethra injury, lumbar transverse process fracture, pelvic ring fracture, rib fracture, hand fracture |
| 4 (32F) | Auto vs Pedestrian | S3 | Type 2 | Lumbar transverse process fracture |
| 5 (45M) | Fall from height | S2-3 | Type 2 | Lumbar compression fracture |
| 6 (40F) | Fall from height | S2-3 | Type 1 | Lumbar spinous process fracture |
| 7 (19M) | MCC | S1-2 | Type 2 | Pelvic ring fracture |
| 8 (48 M) | Fall from height | S2 | Type 2 | Lumbar burst fracture, bilateral lower extremity fractures, upper extremity fracture, rib fracture |
| 9 (15F) | MVA | S2 | Type 2 | Thoracic compression fractures, pelvic ring fracture, leg fractures, anal tear, road rashes, Morel-Lavallée |

MVA = Motor vehicular accident.
MCC = Motorcycle crash.

**Table 2**
Neurological assessment of sacral cauda equina function in relation to traumatic sacral canal stenosis.

| Case | Degree of sacral canal stenosis | Neurological assessment of SCE function | Rectal Tone | Post Void Residual |
|---|---|---|---|---|
| 1 | Severe | Saddle anesthesia, absent anal wink reflex, absent bulbocavernosus reflex, no voluntary anal squeeze | Intact | Not obtained |
| 2 | Severe | Saddle anesthesia, urinary retention, stool incontinence | Weak | Not obtained |
| 3 | Mild | Saddle anesthesia, weakness and numbness in both feet, absent anal squeeze | Absent | Not obtained |
| 4 | Severe | Urinary retention | Intact | 820 cc |
| 5 | Mild | Saddle anesthesia, absent bulbocavernosus reflex, urinary retention, stool incontinence | Intact | 600 cc |
| 6 | Moderate | Saddle anesthesia, urinary retention | Intact | Unable to urinate |
| 7 | Mild | Saddle anesthesia | Intact | 160 cc |
| 8 | Moderate | Unknown | Intact | Not obtained |
| 9 | Moderate | Urinary retention | Weak | Unable to urinate |

> 50% stenosis = Severe.
25–50% stenosis = Moderate.
< 25% stenosis = Mild.

trauma sexual dysfunction, but had intact bowel and bladder function. This was thought to be associated with the general pelvic trauma rather than due to sequala from the SCE injury since B&B function were subjectively normal at follow up. This patient also suffered from bilateral foot weakness and numbness that fully recovered on follow up. No other patient had any weakness or numbness of the lower extremities reported prior or after sacral surgery.

## 4. Discussion

Transverse sacral fractures (TSF) have long been associated with compromise to the SCE and dysfunction of B&B.[1–5] Management has been surgical or conservative with generally similar success rates reported to address SCE injury.[5,8] Surgical treatment has been divided into two distinct methods of SCE decompression. Here, a direct decompression with sacral laminectomy, or an indirect decompression of the SCE by reducing the sacral fracture with fixation, as well as a combination of both methods have been shown to successfully alleviate B&B symptoms.[9–16]

Due to the general rarity of TSF focused literature reviews have delivered non-conclusive recommendations with regards to surgical or conservative therapy.[5,8] Generally, it appears that such treatment is left to the managing surgeon. Also, any symptomatic compromise of SCE is very difficult to assess during the acute phase since patients are significantly injured, with involvement of pelvis, extremities, head injury, and injury to the mobile segment of the spine. Deficits in B&B function may not necessarily all stem from compromise to the SCE associated with TSF, but can be the result of pelvic trauma itself with injury to bladder, urethra, rectum, and pelvic floor,[17–21] as well as injury to the lumbo-sacral plexus and peripheral nerves,[22] which can further obscure the neurological outcome assessment after treatment applied to sacral fractures with SCE syndrome. In our series we used saddle anesthesia, the absence of reflexes such as bulbocavernosus and anal wink reflex, weak or absent rectal tone, the inability to voluntarily squeeze the external anal sphincter, any difficulty emptying the bladder, frank stool incontinence, weakness in foot plantar flexion, and numbness on the sole of the feet as symptoms and signs contributing to clinical diagnosis of SCE injury. We used a post void residual of well over 100 cc as our cutoff to define abnormality. Here, one may counter that larger post void residuals of 200 cc would be more appropriate to indicate urinary dysfunction. In our series, the smallest post void volume measured was 160 cc. This instance was also accompanied by saddle anesthesia. Hence, a single deficit alone was rarely used to diagnosed SCE. But rather, we have used multiple clinical findings to substantiate this diagnosis, also incorporating radiographic findings related to sacral canal stenosis and trauma. In the instances (2 patients) with urinary retention being the primary symptoms suggesting SCE involvement, radiographic findings showed moderate and severe degree of canal stenosis of the sacrum, respectively. One patient (case 4) did not have significant pelvic or spinal trauma. Hence, we interpreted the urinary retention to be caused by the severe traumatic canal stenosis. The other patient (case 9) had moderate sacral canal stenosis, but also had suffered from pelvic trauma, anal tear, along with other spinal trauma and extremity injuries. Here, it was only on day 6 after admission that we elected surgery since urinary retention was severe and did not improve conservatively. After the immediate recovery period from surgery, the patient regained the ability to spontaneously void normally. Hence, suggesting that the initial urinary retention may have been due to the sacral canal compromise. Neurologic deficits associated with sacral fractures have been graded by Gibbons et al.[2] In our cohort every patient had a grade 4 deficit (loss of bowel and/or bladder function with or without motor or sensory deficit),[2] except one patient, who was not amenable for examination due to prolonged diminished mental status associated with alcohol withdraw (Fig. 1). Retrospectively, we found saddle anesthesia in this patient at 1 month post-operatively, indicating likely SCE injury at the time of presentation, since it would be otherwise unlikely, that the patient suffered saddle anesthesia due to sacral laminectomy as a surgical complication.

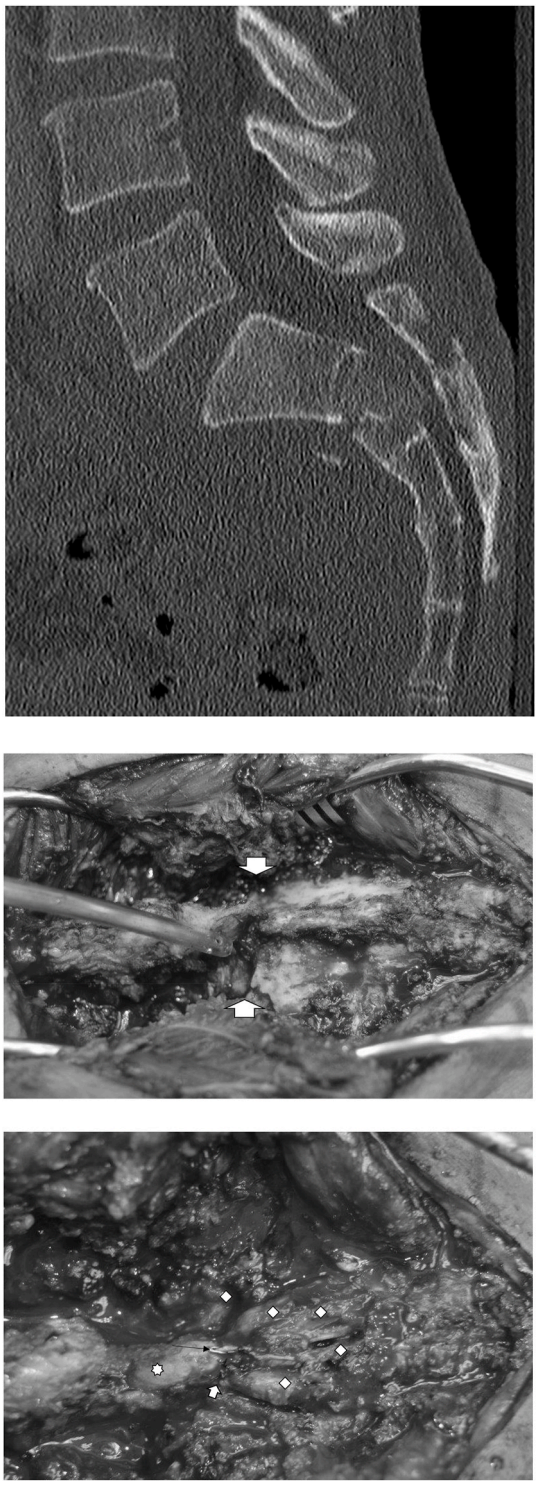

**Fig. 1.** (A) A sagittal bone window computed tomography (CT) of the sacrum is depicted with a TSF, RCC type 2 acute fracture of S2. The sacral canal has a stenosis of 50% approximately. (B) Intraoperative posterior view of a transverse sacral fracture at S2 (white arrows) before decompression. The left side of the image is cranial. (C) After sacral laminectomy has been accomplished, the thecal sac is highlighted by a white star. The sacral nerve roots are marked with a white diamond. The traumatic spinal fluid leak was repaired with a surgical clip (thin black arrow). The severed left S3 nerve root was repaired with 2 sutures (2 dark dot like structures with white arrow pointing to the site of repair).

**Table 3**
Surgical findings and outcomes following sacral laminectomy and decompression for traumatic cauda equina compression.

| Case | Days between admission to surgery (days) | Operative Findings | Complications | Neurological Recovery from SCE syndrome | Length of follow up (months) |
|---|---|---|---|---|---|
| 1 | 1 | Bruised right S3 and S4 nerves | SSI | No incontinence, resolved saddle anesthesia, occasional UTI, improved sexual function | 24 |
| 2 | 20 | Bruised S3 nerves, full and partial tears S4 nerves, torn nerves sutured | – | No incontinence, resolved saddle anesthesia | 139 |
| 3 | 7 | Bruised S2–S5 nerves | SSI | No incontinence, resolved saddle anesthesia, resolved numbness and weakness in feet, sexual dysfunction present | 135 |
| 4 | 4 | Bruised S3–S5 nerves, mild tear left S3 nerve not repaired | – | No incontinence | 120 |
| 5 | 7 | Bruised S2–S4 nerves | – | No incontinence, resolved saddle anesthesia | 117 |
| 6 | 2 | Bruised S2–S3 nerves | Transient coccydynia | No incontinence, resolved saddle anesthesia | 114 |
| 7 | 3 | Bruised S1-5 nerves | – | No incontinence, resolved saddle anesthesia | 89 |
| 8 | 3 | Bruised S2-5 nerves, left S3 torn nerve sutured, Traumatic CSF leak repaired | – | No incontinence, resolved saddle anesthesia | 36 |
| 9 | 6 | Bruised S1-5 nerves | SSI | No incontinence | 15 |

CSF – Cerebrospinal fluid.
SSI – Surgical site infection.

Also, intraoperatively the left S3 nerve root was found torn and was repaired. The remainder of the sacral nerve roots were all bruised. He also had a traumatic CSF leak that was repaired (Fig. 1). All of our patients achieved subjective normal function of bowel and bladder upon last follow up available. In one instance we had recurrent urinary tract infection (UTI) recorded, which may indicate residual SCE dysfunction,

but there was no complaint of saddle anesthesia or incontinence. In this instance the patient reported much better climax intensity since sacral laminectomy, even better than before the accident. This is a unique and interesting finding that has not been reported elsewhere after sacral laminectomy to our knowledge.

Sexual function was significantly diminished in a single patient after crush injury on follow up.

### 4.1. Outcome of B&B function

Generally, the results in the literature vary with regards to B&B function recovery, but a literature review revealed 56% improvement in B&B function in patients with TSF regardless of treatment modality.[8] Our results compare favorably since everyone recovered from their B&B injury. However, our series has a significant short coming by only obtaining subjective reports of B&B function. We did not apply a battery of tests to investigate B&B function more objectively as described elsewhere.[23–25] Therefore, it is fair to state, that residual B&B dysfunction may not have been detected in our series. It has been reported that a significant proportion of patients with objective voiding dysfunction found on urodynamic examinations associated with sacral fractures, did not complain subjectively of urinary problems.[13] Also, it is important to stress that we did not have a formal control group to assess the neurological outcome. Therefore, we cannot comment on the success rate of conservatively managed patients with these injuries.

### 4.2. Morphology of sacral fracture

In our series 55.6% of patients had their transverse fracture at S2-3 junction or S3, with few suffering injuries at S1 or S2. The latter injuries typically are more often associated with significant pelvic trauma in general, and therefore, the results of B&B recovery may be lesser than what we found in our series. Furthermore, our series did not have a RCC type 3 injury. Only 4 of our patients underwent pelvic fixation, when compared to some of the reported series where pelvic fixation was more commonly applied, the sacral injury levels where typically higher (S1 and S2), and RCC type 3 injuries more commonly found.[11,14,26–28] All these differences make direct comparisons of studies very difficult.

### 4.3. Sacral nerve root injury

Sacral nerve root injury, compression, bruising, torn nerves, and traumatic cerebrospinal fluid (CSF) leaks have been observed intraoperatively in patients with TSF.[1,3,5,6,8,9,14,26,29–32] A literature review failed to disclose any improvement in neurological recovery after the repair of torn sacral nerves in TSF.[33] In our series we repaired significantly torn sacral nerve roots routinely if identified and feasible (cases 2 and 8) (Table 3, Fig. 1). Whether this had any impact on neurological improvement, nerve recovery and B&B function is completely speculative. Therefore, we cannot generally advocate for nerve root repair, but we believe, that if it is readily done, one should consider it. In almost all our cases, we could observe bilateral nerve root injuries not allowing us to assess any potential recovery improvement in instances of unilateral injury.

### 4.4. SSI and surgical timing

Lastly, our cohort had a rather high wound infection rate of over 33%, which is within the published range of infection reported in the literature for surgery of TSF, typically from 0 to 37.5%.[9–12,14–16,27–29] Here, we can see a trend to lower SSI around 0–5.6% in late surgeries performed mostly well after 1 week,[11,12] versus surgeries done sooner in usually 7 or less days. Earlier surgeries for TSF tended to have a higher range of SSI of 16–37.5% [14, 27, 28, and present study]. This has been reported elsewhere as well.[34] Here, one may consider delaying sacral decompression beyond a week after injury. A review of the literature could not detect any benefit to early decompression (within 72 h) with regards to neurological recovery.[35] Ultimately, this must be further investigated to better understand risk and benefit of surgical timing. In our experience, it did not appear that the duration of the operation contributed to an increase of SSI since all surgeries were done by the senior author (IFE). However, 2 out of 3 instances of SSI, were associated with severe lumbosacral soft tissue injuries. One instance (case 3) had a severe industrial crush injury to the pelvis. In another instance of SSI (case 9), a Morel-Lavallée internal soft tissue degloving injury was present. We do believe that these severe forms of soft tissue injury may be another reason for our high infection rate.

## 5. Conclusion

TSF can frequently be associated with SCE dysfunction and incontinence of B&B. It is unclear if surgery is superior to conservative treatment. In our experience of clinical SCE dysfunction or significant sacral canal compromise acute direct sacral laminectomy with direct repair of torn sacral nerve roots has resulted in good B&B function in every patient on follow up. This was based entirely on the subjective patient assessment. Therefore, we believe that direct surgical decompression is a reasonable therapy option acutely applied in this patient population. Its associated significant wound infection rate may be lowered by applying the treatment after the first week of trauma.

## CRediT authorship contribution statement

**Devin A. Nikjou:** Writing – original draft. **Chani M. Taggart:** Writing – review & editing. **Salvatore C. Lettieri:** Writing – review & editing. **Michael R. Collins:** Writing – review & editing. **Owen T. McCabe:** Writing – review & editing. **Layne A. Rousseau:** Writing – review & editing. **Iman Feiz-Erfan:** Writing – original draft, Supervision, Investigation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References


1. Denis F, Davis S, Comfort T. Sacral fractures: an important problem. Retrospective analysis of 236 cases. *Clin Orthop Relat Res*. 1988;227:67–81. https://pubmed.ncbi.nlm.nih.gov/3338224/.
2. Gibbons KJ, Soloniuk DS, Razack N. Neurological injury and patterns of sacral fractures. *J Neurosurg*. 1990;72(6):889–893. https://doi.org/10.3171/jns.1990.72.6.0889.
3. Fountain SS, Hamilton RD, Jameson RM. Transverse fractures of the sacrum. A report of six cases. *J Bone Joint Surg Am*. 1977;59(4):486–489. https://pubmed.ncbi.nlm.nih.gov/863942/.
4. Schmidek HH, Smith DA, Kristiansen TK. Sacral fractures. *Neurosurgery*. 1984;15(5):735–746. https://doi.org/10.1227/00006123-198411000-00021.
5. Robles LA. Transverse sacral fractures. *Spine J*. 2009;9(1):60–69. https://doi.org/10.1016/j.spinee.2007.08.006.
6. Roy-Camille R, Saillant G, Gagna G, Mazel C. Transverse fracture of the upper sacrum. Suicidal jumper's fracture. *Spine*. 1985;10(9):838–845. https://doi.org/10.1097/00007632-198511000-00011.
7. Strange-Vognsen HH, Lebech A. An unusual type of fracture in the upper sacrum. *J Orthop Trauma*. 1991;5(2):200–203. https://doi.org/10.1097/00005131-199105020-00014.
8. Kempen DHR, Delawi D, Altena MC, et al. Neurological outcome after traumatic transverse sacral fractures: a Systematic review of 521 patients reported in the literature. *JBJS Rev*. 2018;6(6), e1. https://doi.org/10.2106/JBJS.RVW.17.00115.
9. Ayoub MA. Displaced spinopelvic dissociation with sacral cauda equina syndrome: outcome of surgical decompression with a preliminary management algorithm. *Eur Spine J*. 2012;21(9):1815–1825. https://doi.org/10.1007/s00586-012-2406-9.
10. Tan GQ, He JL, Fu BS, Li LX, Wang BM, Zhou DS. Lumbopelvic fixation for multiplanar sacral fractures with spinopelvic instability. *Injury*. 2012;43(8):1318–1325. https://doi.org/10.1016/j.injury.2012.05.003.
11. Lindahl J, Mäkinen TJ, Koskinen SK, Söderlund T. Factors associated with outcome of spinopelvic dissociation treated with lumbopelvic fixation. *Injury*. 2014;45(12):1914–1920. https://doi.org/10.1016/j.injury.2014.09.003.

12. Li P, Qiu D, Shi H, et al. Isolated decompression for transverse sacral fractures with cauda equina syndrome. *Med Sci Mon Int Med J Exp Clin Res*. 2019;25:3583–3590. https://doi.org/10.12659/MSM.916483. Published 2019 May 15.
13. Tötterman A, Glott T, Madsen JE, Røise O. Unstable sacral fractures: associated injuries and morbidity at 1 year. *Spine*. 2006;31(18):E628–E635. https://doi.org/10.1097/01.brs.0000231961.03527.00.
14. Schildhauer TA, Bellabarba C, Nork SE, Barei DP, Routt Jr ML, Chapman JR. Decompression and lumbopelvic fixation for sacral fracture-dislocations with spino-pelvic dissociation. *J Orthop Trauma*. 2006;20(7):447–457. https://doi.org/10.1097/00005131-200608000-00001.
15. Williams SK, Quinnan SM. Percutaneous lumbopelvic fixation for reduction and stabilization of sacral fractures with spinopelvic dissociation patterns. *J Orthop Trauma*. 2016;30(9):e318–e324. https://doi.org/10.1097/BOT.0000000000000559.
16. Pohlemann T, Gänsslen A, Tscherne H. Die Problematik der Sakrumfraktur. Klinische Analyse von 377 Fällen [The problem of the sacrum fracture. Clinical analysis of 377 cases]. *Orthopade*. 1992;21(6):400–412. https://pubmed.ncbi.nlm.nih.gov/1475126/.
17. Copeland CE, Bosse MJ, McCarthy ML, et al. Effect of trauma and pelvic fracture on female genitourinary, sexual, and reproductive function. *J Orthop Trauma*. 1997;11(2):73–81. https://doi.org/10.1097/00005131-199702000-00001.
18. Aihara R, Blansfield JS, Millham FH, LaMorte WW, Hirsch EF. Fracture locations influence the likelihood of rectal and lower urinary tract injuries in patients sustaining pelvic fractures. *J Trauma*. 2002;52(2):205–209. https://doi.org/10.1097/00005373-200202000-00001.
19. Wright JL, Nathens AB, Rivara FP, MacKenzie EJ, Wessells H. Specific fracture configurations predict sexual and excretory dysfunction in men and women 1 year after pelvic fracture. *J Urol*. 2006;176(4 Pt 1):1540–1545. https://doi.org/10.1016/j.juro.2006.06.044.
20. Bjurlin MA, Fantus RJ, Mellett MM, Goble SM. Genitourinary injuries in pelvic fracture morbidity and mortality using the National Trauma Data Bank. *J Trauma*. 2009;67(5):1033–1039. https://doi.org/10.1097/TA.0b013e3181bb8d6c.
21. Baessler K, Bircher MD, Stanton SL. Pelvic floor dysfunction in women after pelvic trauma. *BJOG*. 2004;111(5):499–502. https://doi.org/10.1111/j.1471-0528.2004.00120.x.
22. Huittinen VM. Lumbosacral nerve injury in fracture of the pelvis. A postmortem radiographic and patho-anatomical study. *Acta Chir Scand Suppl*. 1972;429:3–43.
23. Wyndaele JJ. Correlation between clinical neurological data and urodynamic function in spinal cord injured patients. *Spinal Cord*. 1997;35(4):213–216. https://doi.org/10.1038/sj.sc.3100391.
24. Gunterberg B. Effects of major resection of the sacrum. Clinical studies on urogenital and anorectal function and a biomechanical study on pelvic strength. *Acta Orthop Scand Suppl*. 1976;162:1–38. https://doi.org/10.3109/ort.1976.47.suppl-162.01.
25. Pannek J, Kennelly M, Kessler TM, Linsenmeyer T, Wyndaele JJ, Biering-Sørensen F. International spinal cord injury urodynamic basic data set (version 2.0). *Spinal Cord Ser Cases*. 2018;4:98. https://doi.org/10.1038/s41394-018-0133-0. Published 2018 Nov 1.
26. Sapkas GS, Mavrogenis AF, Papagelopoulos PJ. Transverse sacral fractures with anterior displacement. *Eur Spine J*. 2008;17(3):342–347. https://doi.org/10.1007/s00586-007-0528-2.
27. Gribnau AJ, van Hensbroek PB, Haverlag R, Ponsen KJ, Been HD, Goslings JC. U-shaped sacral fractures: surgical treatment and quality of life. *Injury*. 2009;40(10):1040–1048. https://doi.org/10.1016/j.injury.2008.11.027.
28. Bellabarba C, Schildhauer TA, Vaccaro AR, Chapman JR. Complications associated with surgical stabilization of high-grade sacral fracture dislocations with spino-pelvic instability. *Spine*. 2006;31(11 Suppl):S80–S104. https://doi.org/10.1097/01.brs.0000217949.31762.be.
29. Kim MY, Reidy DP, Nolan PC, Finkelstein JA. Transverse sacral fractures: case series and literature review. *Can J Surg*. 2001;44(5):359–363.
30. Fisher RG. Sacral fracture with compression of cauda equina: surgical treatment. *J Trauma*. 1988;28(12):1678–1680. https://doi.org/10.1097/00005373-198812000-00013.
31. Zelle BA, Gruen GS, Hunt T, Speth SR. Sacral fractures with neurological injury: is early decompression beneficial? *Int Orthop*. 2004;28(4):244–251. https://doi.org/10.1007/s00264-004-0557-y.
32. Lyo IU, Kwon SC, Park JB, Sim HB. Transverse fracture and dislocation at the sacrum. *J Korean Neurosurg Soc*. 2008;43(1):31–33. https://doi.org/10.3340/jkns.2008.43.1.31.
33. Dussa CU, Soni BM. Influence of type of management of transverse sacral fractures on neurological outcome. A case series and review of literature. *Spinal Cord*. 2008;46(9):590–594. https://doi.org/10.1038/sc.2008.59.
34. Vaccaro AR, Kim DH, Brodke DS, et al. Diagnosis and management of sacral spine fractures. *Instr Course Lect*. 2004;53:375–385.
35. Kepler CK, Schroeder GD, Hollern DA, et al. Do formal laminectomy and timing of decompression for patients with sacral fracture and neurologic deficit affect outcome? *J Orthop Trauma*. 2017;31(Suppl 4):S75–S80. https://doi.org/10.1097/BOT.0000000000000951.