Robot-Assisted Thoracolumbar Fixation After Acute Spinal Trauma: A Case Series

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Abstract

Background: Pedicle screw fixation has become the workhorse for the stabilization of the thoracolumbar spine. Since accurate pedicle screw placement is necessary for a successful surgery, three-dimensional navigation has become a mainstay for placing pedicle screws. However, the published studies have an overrepresentation of lumbar screws despite the prevalence of thoracic fractures. Furthermore, no robotic-assisted pedicle screw study has focused solely on traumatic fractures. The goal of this study was to address whether (1) robot-assisted pedicle screw placement had comparable accuracy in the thoracic and thoracolumbar region and (2) robot-assisted spine surgery was feasible in an acute, traumatic setting.

Methods: We performed 14 consecutive, thoracolumbar spinal stabilization procedures in which 126 pedicle screws were placed using the Globus ExcelsiusGPS® spine robot in an acute, traumatic setting. Operative times were measured, and the accuracy of pedicle screws was assessed with the Gertzbein and Robbins classification system by two board-certified neuroradiologists.

Results: A total of 60 thoracic (T3-T11), the 24-thoracolumbar junction (T12-L1), 40-lumbar (L2-L5), and two-sacral pedicle screws were placed. Pedicle screw placement was accurate with a < 1% (1/126) pedicle breach rate. Thoracolumbar robotic spine surgery in an acute, traumatic setting was demonstrated to have a good safety profile with only one minor neurological deficit which was related to positioning. Furthermore, surgical times were inversely related to the case number.

Conclusions: These results together suggest that robot-assisted spine surgery is accurate in the thoracic spine. Furthermore, placement of thoracolumbar screws in an acute trauma is non-inferior to other methods when based on accuracy.

Introduction

Over 160,000 spine traumas occur yearly in North America with over 90% of those being localized to the thoracolumbar spine [1,2]. Factors increasing the rates of fracture include risky behavior, lower bone density, alterations in vertebral biomechanical range, and increased falls [3-6]. When necessary, operative intervention utilizing pedicle screws has become the treatment of choice for thoracolumbar spine stabilization. During thoracolumbar fusion procedures, minimizing the risk of screw pullout and strength are important modifiable factors. While screw strength is proportional to the inner (minor) screw diameter, the outer (major) diameter is proportional to screw pullout resistance. A common modifiable factor maximizing screw strength and screw pullout resistance is the accurate placement of the thoracic screw in pedicles in addition to the intrinsic properties of the screw [7].

Thoracic spine pedicle fixation can be particularly difficult due to the kyphosis in the thoracic spine producing vertebra-specific optimal trajectories [8]. Robot-assisted pedicle screw fixation seems ideal in the thoracic scenario due to the previously demonstrated superb accuracy [9,10]. However, most published robot-assisted pedicle screw reports are heavily biased toward lumbosacral fusions. In our own data, only 163/402 of the screws placed with robot assistance have been in the thoracic area (unpublished data). Other studies either report an over representation of lumbar pedicle screws [9,10] or have no data on the instrumented level [11]. Such information will lead to an underrepresentation and possibly inaccurate picture of thoracic robot-assisted pedicle screw placement.

Additionally, despite spinal trauma accounting for a significant portion of potential spinal procedures, robot-assisted surgery remains largely untested in acute, spinal trauma. In a sample of studies with a large number of robot-assisted pedicle screws, trauma only represented a small number of the cases representing 0% up to 18% of cases [10,11]. This small representation of trauma cases in large studies dilute the statistics and impede proper conclusion about acute, traumatic cases. Furthermore, the timing for these trauma surgeries is unclear in many studies as timing for trauma surgeries was outside the scope of the papers. Understanding the feasibility of robot-assisted pedicle screw placement in acute trauma is of the utmost importance as recent research has suggested early decompression (<8 hours) and instrumentation after a spinal cord injury is optimal [12,13].

Despite the evidence emphasizing the accuracy of robot-assisted spine surgery, the adoption of these techniques has been slow. Reasons for not using a robot include lack of accessibility to a robot, familiarity with older techniques, and increased setup time. However, these disadvantages need to be balanced against the advantages of robot-assisted spine surgery including dual point registration/verification, a rigid arm to help support, and guide tools, which translate to less deformity on the unstable spine, and pre-operative planning with intraoperative plan modification. These factors have led robotic-assisted spine surgery to be more accurate than other methods outside of acute spine traumas [14] and may lead to increased fusion rates with improved outcomes in the acute, traumatic setting as has been demonstrated outside of acute, traumatic settings [15].
Given the advantages of navigated, robot-assisted surgery, we performed a case series to determine the feasibility of robot utilization for stabilization of acute, thoracolumbar spine injuries. We investigated the accuracy of a robotic system, the amount of blood loss, the length of hospital stays, and the duration of surgery to address the feasibility of robot-assisted spine surgery in a thoracic-biased setting of an acute, traumatic setting. We hypothesized that robot-assisted pedicle screw fixation would be non-inferior to other pedicle screw fixation techniques.

Materials And Methods
This study is a case series of acute, thoracolumbar spinal fracture patients collected from May of 2020 to February of 2022 at a single institution. Each patient was evaluated by a neurosurgeon to determine the individual’s pathology as well as the best operative course. Patients were taken to the operating room within 24 hours of presentation. All surgeries were performed by a single neurosurgeon with resident assistance. All thoracolumbar pedicle screws were planned and placed using a robotic navigational system (ExcelsiusGPS®, Globus, Audubon, PA). Chart reviews were conducted for demographics, operative reports, and perioperative complications. Post-operative CT scans were obtained either intraoperatively or post-operatively. The post-pedicle screw placement scans were evaluated in the axial and sagittal cuts for screw breaches in Centricity imaging software by two board-certified neuroradiologists. Any difference of opinion on pedicle screw breach was discussed among the radiologists until a consensus was reached independently of the surgeons. The cut with the largest deviation was measured by the neuroradiologists. The Gertzbein and Robbins system (GRS) was utilized for grading the pedicle screw breaches. A screw was considered accurate if the screw had an acceptable trajectory (in the pedicle or with an in-out-in trajectory) without a neurological deficit. Operative times were defined as when the time of the initial incision to the closure of the skin. Blood loss was estimated for each procedure by the attending neurosurgeon. This study was approved via the University of Oklahoma Health Sciences Center Institutional Review Board (2/2020/IRB #11641).

Workflow
After a thin-cut (0.65-mm) CT scan was obtained, screw trajectories were planned in all three planes and loaded into the ExcelsiusGPS® system. Patients were sedated, intubated by the anesthesiologist, and positioned on an open Jackson table. The patients were prepped and draped. The area of surgery was identified via fluoroscopy. The dissection of the bony elements surrounding the corresponding level of injury was performed. The surveillance frame was clamped to a spinous process. A second surveillance point was placed into the PSIS through a stab incision. Anterior/posterior and lateral images were obtained using a special attachment with a C-arm x-ray machine. Close attention was paid to the stability of the clamp to optimize navigation and the merging of pre-operative and intraoperative images. A breath hold was utilized during imaging based on the utility of the breath hold in unpublished experience. The CT-planned images were merged with the pre-operative radiographs. The construct was verified by the surgeon ensuring the screw trajectories were merged appropriately with the fluoroscopic images using the merge scores. Landmarks were verified before proceeding. The robot was draped in a sterile fashion and brought into the field. The robot arm was aligned with the potential screw hole. The hole was drilled and tapped with concurrent breath holds. The corresponding pedicle screw was placed. Intraoperative neuromonitoring was conducted on all surgeries. After the screws were placed, the corresponding fusion was performed as well as any additional procedures.

Results
There were 14 acute, spinal column trauma patients who were included in this single-center study for a total of 126 pedicle screws (Table 1).
Table 1: Complete list of patients.
A complete list of patients and individual patient characteristics. IOI denotes an in-out-in trajectory.

| Patient | Height (m) | Weight (kg) | BMI | Age | Injury | AO Spine Classification | Glascow coma scale | ASIA Scale | Neurological deficit Present | Neurological deficit Present | Respiration | [T40] | No. of Breaches | Location of breach | Geriatric Fractures | Highest Den [mm] | Screws | Additional Procedures | Duration (min) | Levels fused | Time/level (min) |
|---------|------------|-------------|-----|-----|--------|-------------------------|-------------------|------------|----------------------------|----------------------------|-------------|-------|----------------|-------------------|------------------|------------------|---------|--------------------------|--------------|-------------|------------------|
| 1       | 1.7        | 79.0        | 27.34 | 26  | L1/2 burst with superior vertebral endplate fracture | B1N3          | 15                     | E          | None                        | None                        | N             | 0     | 8               | Thrombotic CEP leak, L1L5 56.8 | 205 | 3   | L1L5 56.8       |
| 2       | 1.8        | 70.0        | 20.02 | 08  | L1 burst | A4N5          | 15                     | D          | 80-80 HP 4-15                | Bred                        | N             | 0     | 8               | Laminaectomy | 235 | 3   | T11-L5 66.8       |
| 3       | 1.6        | 93.7        | 35.43 | 56  | L1 burst | A4N5          | 15                     | E          | None                        | None                        | N             | 0     | 8               | Laminaectomy | 289 | 3   | T11-L5 56.8       |
| 4       | 1.7        | 69.1        | 37.26 | 60  | L1 burst | A4N5          | 15                     | E          | None                        | None                        | N             | 0     | 2               | L1, L2                  | D, NA 5, 2 | 8   | Laminaectomy | 300 | T11-L5 66.8       |
| 5       | 1.6        | 77.2        | 33.61 | 61  | T12 Chance | A5N5          | 15                     | E          | None                        | None                        | N             | 1     | 5               | Laminaectomy | 200 | 3   | T11-L5 66.8       |
| 6       | 1.7        | 83.1        | 27.77 | 79  | T9/10 Chance | A5N5          | 15                     | E          | None                        | None                        | N             | 0     | 8               | Laminaectomy | 387 | 3   | T3-T7 67.4        |
| 7       | 1.8        | 94.0        | 23.37 | 27  | T12 burst | A5N5          | 15                     | E          | None                        | None                        | N             | 0     | 10              | Laminaectomy, drainage of CSF | 217 | 3   | T10-L2 43.4       |
| 8       | 1.7        | 104.0       | 35.15 | 57  | L4 burst | A5N5          | 15                     | E          | None                        | None                        | N             | 0     | 8               | Laminaectomy | 252 | 3   | L2-3T 43.4        |
| 9       | 1.6        | 59.8        | 23.01 | 52  | T12 superior vertebral endplate, L1 burst | A5N5          | 15                     | E          | None                        | None                        | N             | 1     | 5               | Laminaectomy | 281 | 3   | T11-L5 66.8       |
| 10      | 1.6        | 59.1        | 22.35 | 50  | L3 burst | A5N5          | 15                     | E          | None                        | None                        | N             | 1     | 3               | Laminaectomy, L1L5 34.6 | 227 | 3   | T2-T4 63.4       |
| 11      | 1.8        | 81.0        | 20.15 | 50  | T9/10 -plus | Not applicable | 15                     | D          | 80-80 HP 4-15                | R50 pedicles                | N             | 0     | 4               | Capemanectomy | 226 | 3   | T5-T8 55.3       |
| 12      | 1.6        | 75.0        | 25.89 | 85  | T12-L1 burst | A5N5          | 15                     | E          | None                        | None                        | N             | 0     | 12              | Laminaectomy | 290 | 7   | T9-L3 66.8       |
| 13      | 1.8        | 97.8        | 28.08 | 63  | T9 burst | A5N5          | 15                     | E          | None                        | None                        | N             | 0     | 4               | Laminaectomy, L1L5 50.5 | 171 | 3   | T9-T10 39.8       |
| 14      | 1.8        | 85.7        | 27.05 | 38  | T9-T10 Hyperextension | A5N5          | 15                     | E          | R8-8.50 pedicles            | None                        | N             | 0     | 12              | Laminaectomy | 187 | 6   | T9-T12 28.8       |
patient population are summarized in Table 2 and the characteristics of the procedures are summarized in Table 3. The average blood loss was calculated to be 191 mL with the average hospital stay being 13.5 days.

| Parameter                  | Overall |
|----------------------------|---------|
| Number of patients         | 14      |
| Gender                     |         |
| Female, n (%)              | 7 (50%) |
| Male, n (%)                | 7 (50%) |
| Mean age (years)           | 52.1 ± 19.8 |
| Mean mass (kg)             | 76.9 ± 15.0 |
| Mean BMI                   | 27.3 ± 4.8 |

**TABLE 2: Patient demographics.**

| Parameter                          | Overall |
|------------------------------------|---------|
| Indication for surgery, n (%)      |         |
| Burst fracture                     | 9 (64%) |
| Chance fracture                    | 2 (14%) |
| Hyperextension                     | 1 (7%)  |
| Facet fracture                     | 1 (7%)  |
| Traumatic disc                     | 1 (7%)  |
| Number of levels treated, n (%)    |         |
| 3                                  | 1 (7%)  |
| 4                                  | 0 (0%)  |
| 5                                  | 9 (63%) |
| 6                                  | 2 (14%) |
| 7                                  | 1 (7%)  |
| 8                                  | 1 (7%)  |
| Mean number of screws per case, n  | 9.0 ± 2.1 |
| Mean surgery time (min)            | 254.1 ± 55.8 |
| Mean blood loss (mL)               | 190.7 ± 119.1 |
| Mean post-operative stay (days)    | 13.5 ± 15.1 |

**TABLE 3: Procedure characteristics.**

Twenty-six percent (4/15) of patients had pre-operative deficits with three out of four improving after surgery (Table 1). One person had new, post-operative thigh tingling in the lateral femoral cutaneous nerve distribution, (1/14) which was related to positioning and resolved over time. Operative time was graphed against case number which demonstrated the total amount of operative time and the amount of operative time per level that decreased as the surgeon became more experienced (Figure 1).
Operative times include any intervening procedures such as laminectomies.

Pedicle screw placement was accurate with a <1% (1/126) pedicle breach rate when discounting the pre-planned in-out-in trajectories. Pedicle screw breaches which occurred due to an in-out-in trajectory were noted in Table 1 with “IOI.” Images of each screw breach, as denoted by the neuroradiologists, are provided (Figures 2–9).

**FIGURE 2:** Axial CT radiographs of the right T12 pedicle screw on patient 4.

Axial CT radiographs demonstrating the right pedicle screw placement on patient 4 at T12 with an in-out-in (IOI) trajectory. Screw placement progresses from A to D. The pedicle of interest is outlined in red. The blue arrow denotes the largest deviation of the screw. Please note all CT images are in radiographic orientation.
FIGURE 3: Axial CT radiograph of the left L2 anterior cortex breach on patient 4.

An axial CT radiograph of the anterior cortex breach of the left L2 screw on patient 4. The anterior cortex is lined in red. A blue area denotes the screw deviation.
FIGURE 4: Axial CT radiographs of the left T6 pedicle screw on patient 5.

Axial CT radiographs demonstrating the left T6 pedicle screw placement on patient 5 with a medial breach. Screw placement progresses from A to D. The pedicle of interest is outlined in red. The blue arrow denotes the largest deviation of the screw. Please note all CT images are in radiographic orientation.
FIGURE 5: Axial CT radiographs of the left T11 pedicle screw on patient 9.

Axial CT radiographs demonstrating the left T11 pedicle screw placement on patient 9 with an in-out-in (IOI) trajectory. Screw placement progresses from A to D. The pedicle of interest is outlined in red. The blue arrow denotes the largest deviation of the screw. Please note all CT images are in radiographic orientation.
FIGURE 6: Axial CT radiograph of the left T12 anterior cortex breach on patient 10.

An axial CT radiograph of the anterior cortex breach of the left T12 screw on patient 10. The anterior cortex is lined in red. A blue area denotes the screw deviation.
FIGURE 7: Axial CT radiographs of the right T6 pedicle screw on patient 13

Axial CT radiographs demonstrating the right T6 pedicle screw placement on patient 13 with an in-out-in (IOI) trajectory. Screw placement progresses from A to D. The pedicle of interest is outlined in red. The blue arrow denotes the largest deviation of the screw. Please note all CT images are in radiographic orientation.
FIGURE 8: Axial CT radiographs of the T7 pedicle screws on patient 13.

Axial CT radiographs demonstrating the T7 pedicle screws on patient 13 with an in-out-in (IOI) trajectory. Screw placement progresses from A to D. The pedicle of interest is outlined in red. The blue arrow denotes the largest deviation of the screw. Please note all CT images are in radiographic orientation.
FIGURE 9: Axial CT radiographs of the left T10 pedicle screw on patient 13.

Axial CT radiographs demonstrating the left T10 pedicle screw placement on patient 13 with an in-out-in (IOI) trajectory. Screw placement progresses from A to D. The pedicle of interest is outlined in red. The blue arrow denotes the largest deviation of the screw. Please note all CT images are in radiographic orientation.

None of the screws required replacement. The average anterior vertebral body screw breach was 2 mm. The only true pedicle breach (when discounting IOI trajectories) was 2 mm (Figure 4) and was not associated with a change of either neuromonitoring, intraoperatively, or neurological exam, post-operatively. The GRS for each screw was graphed against the vertebral level (Figure 10).
FIGURE 10: Gertzbein-Robbins screw classification based upon vertebral body level.

The number of pedicle screws graphed via the Gertzbein-Robbins classification for each spinal pedicle level. * denotes the true pedicle breach (1 GBS grade C) and a breach due to an IOI trajectory (IOI) trajectory. # denotes all GBS grades > A are due to IOI trajectories.

Discussion

This case series demonstrates the feasibility of utilizing robotic assistance for thoracolumbar pedicle screw placement in acute, traumatic spine surgery. In this paper, after placing 126 pedicle screws in 14 patients we demonstrated the feasibility and safety of robot-assisted spinal fixation. Of the 126 pedicle screws placed, 84 screws were placed from T1-L1 with only a single breach (1.2% breach rate). Our breach rate was comparable to previous studies utilizing O-arm navigation demonstrating the non-inferiority of the robot-assisted pedicle screws in the thoracic spine.

Our secondary findings of this case series include the feasibility of robotic assistance in an acute, traumatic setting. We demonstrated a good safety profile with a single new neurological deficit unrelated to robot use. In fact, three of the four pre-operative neurological deficits improved with surgery. Additionally, blood loss was low (191 mL), and operative times were decreased with a case number.

Pedicle screw placement accuracy is critically important for not only improved fusion rates/strength of the fusion construct but also for patient safety. Previous work has demonstrated that intraoperative navigation improves pedicle screw placement accuracy from 68% to 95% [16]. The addition of a rigid robotic arm further increases pedicle screw placement accuracy to about 99% [14]. However, thoracic pedicle screw placement requires acknowledgment of several anatomical nuances. The sagittal and coronal angulation of the pedicle transitions throughout the thoracic spine. The sagittal pedicle angle increases from 0 degrees at T1 to 10 degrees at T8. The sagittal pedicle angle decreases from T8 to 0 degrees at T12 [8]. In the coronal plane, pedicle angulation decreases from 10-15 degrees at T1 to 5 degrees at T12 [8]. Additionally, the transverse process, an anatomic landmark for the lumbar pedicle, does not align with the thoracic pedicle in the axial plane. The transverse process progresses from the rostral to the pedicle at T1 to the caudal to the pedicle at T12 with the T6 or 7 transverse processes aligning with the pedicle [8]. The morphing anatomical landmarks throughout the thoracic spine creates a scenario ideal for navigation as navigation provides an additional check to known anatomical landmarks. In this study, robot-assisted pedicle screw placement was accurate in the thoracic spine with a breach rate of 1.2% without any new neurological deficits. While <2% of screws were not in the optimal trajectory, the screws did not need to be replaced, and no issues were caused by the alternative trajectories. This finding is comparable to previous work which has shown that neurovascular compromise occurs in 4.2% of patients [17]. Additionally, not requiring replacement of the screw is important as Defino et al. found insertion, removal and reinsertion of a pedicle screw in the same hole compromised resistance to pullout. Our results support the use of robot-assisted navigation in the thoracic region and the non-inferiority of robot-assisted navigation to other screw-placement methods due to the superb accuracy and lack of neurological deficits.

Additionally, our study is unique as the cases occurred in an acute, traumatic setting. Acute, spine surgery provides unique challenges which are non-modifiable including increased likelihood of hypotension from shock, increased neurological complications, increased operative hemorrhages, polytraumas, and operating in non-ideal conditions despite operative methods [19]. Understanding the feasibility of robot-assisted spine surgery is important as research on spinal cord injuries suggests hyperacute (<8 hours post-injury) decompression should be performed. Jug et al. and Grassner et al. demonstrated improved neurological...
Conclusions

variability in surgeons as the accompanying resident-assistant varied between cases. However, there was some variability in surgeons as the accompanying resident-assistant varied between cases. However, the purpose of this paper was not to address affordability, and this issue has been previously discussed. This study does have caveats. This study had a low number of cases. Therefore, as with any technology, we cannot state that robotic-assisted spine surgery would be appropriate in all acute, spinal trauma cases and can only claim noninferiority versus other methods. However, given that each patient is a polytrauma, the hospitalization duration comparison to previous studies loses meaning as complicating injuries contributed to the duration of the hospitalization. For instance, one major critique of this paper may be the increased operative time associated with utilizing a robot. However, we do not discuss additional procedures being performed such as laminectomies which were included in our operative time. Furthermore, we demonstrated that operative times are continuing to improve as no plateau has been met (Figure 1). These findings are consistent with previous adoptions of 3D-navigated techniques in spine surgery [14-16]. Optimization will likely decrease operative times further. Interestingly, previous studies have suggested that robot-assisted surgery has a small learning curve [14]. Through robot-assisted surgery, more confidence may be placed on pre-planned trajectories allowing the surgeon to focus on the additional procedures such as corpectomies or laminectomies as well as provide further confidence in the navigation necessary for the thoracic spine.

The accuracy of our pedicle screw placement can be traced to our meticulous attention to merge scores and stabilization of instruments via the robotic arm so as not to deform the spine further. Specifically, we found the instability of the spine can lead to motion of the spinal column even during breathing if the fracture is severe. Spinal instability would lower the accuracy of our pre-operative and interoperative image merge. To help address a proper merge, we have found breath holds were crucial. For improved screw accuracy, we found apnea before initial drilling and screw placement, stabilization of instrumentation by a robotic arm, and minimizing pressure on unstable areas when drilling as methods to maximize accuracy. Using these steps, we have managed to have accurate screw placements in an acute, traumatic setting. Also, it is important to note the dual verification required the placement of a second array to maximize accuracy. Using these steps, we have managed to have accurate screw placements in an acute, traumatic setting.

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A second critique of this paper would be the blood loss. Previous work has demonstrated decreased blood loss for robot-assisted spinal surgery as opposed to freehand techniques [22]. However, our surgeries were performed in the acute phase and in the context of other injuries. Therefore, direct comparisons for blood loss, specifically, are less meaningful and misleading when compared to historical studies. While we agree that decreased blood loss is interesting, being a case series and lacking a control cohort, this study does not provide the correct framework to evaluate blood loss, and a future study would be needed to address this question. Furthermore, this study may be criticized for the hospitalization length of the patients. However, given that each patient is a polytrauma, the hospitalization duration comparison to previous studies loses meaning as complicating injuries contributed to the duration of the hospitalization. For instance, one patient was hospitalized over two months for non-spine-related injuries and complications.

A second caveat may be that spine robots are expensive and cost-prohibitive for a number of hospitals [25]. However, the purpose of this paper was not to address affordability, and this issue has been previously documented. Finally, this study was performed by a single surgeon at a single institution, and the argument could be made that these results are not applicable to multiple surgeons. However, there was some variability in surgeons as the accompanying resident-assistant varied between cases. This study does have caveats. This study had a low number of cases. Therefore, as with any technology, we cannot state that robotic-assisted spine surgery would be appropriate in all acute, spinal trauma cases and can only claim noninferiority versus other methods. However, given that our goal was proof of concept, we believe that despite our low number of cases, it provides valuable insight for thoracic spine surgery during the acute, traumatic setting.

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Conclusions

Conclusion:

Robot-assisted pedicle screw placement is a feasible alternative to other pedicle screw placement techniques in thoracic and lumbar spine fixation surgery during an acute, traumatic setting with many benefits. These
benefits include multiple redundancy checks for screw accuracy, improved stability of instruments, and less deformity of fractured vertebrae due to the rigid robot arm supporting the tools. Additionally, we demonstrated the operative times decrease as the surgeon gains experience. Furthermore, we demonstrate safe pedicle screw placement in both the lumbar and thoracic spine. We hope through the adoption of robot-assisted spine surgery in the thoracic and lumbar region during the acute, traumatic setting, patients will have the safest surgeries possible.

Additional Information

Disclosures

Human subjects: Consent was obtained or waived by all participants in this study. University of Oklahoma Health Sciences Center Institutional Review Board issued approval 2/2020/IRB #: 11641. Animal subjects: All authors have confirmed that this study did not involve animal subjects or tissue. Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: Payment/services info: All authors have declared that no financial support was received from any organization for the submitted work. Financial relationships: All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. Other relationships: All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Kraemer WL, Schenricht EH, Lever J, McInnis RJ, McKee MD, Waddell DP. Functional outcome of thoracolumbar burst fractures without neurological deficit. J Orthop Trauma. 1996, 10:541-4. 10.1097/00005131-199610000-00006
2. Chang V, Holly LT. Bracing for thoracolumbar fractures. Neurosurg Focus. 2014, 37:E3. 10.3171/2014.4.FO14S177
3. Bengtze U, Johnell O, Redlund-Johnell I: Changes in incidence and prevalence of vertebral fractures during 30 years. Calcif Tissue Int. 1982, 39:295-6. 10.1007/BF02256562
4. Frankel R, Krishna V, Vandergrift A, Bauer DC, Forrest B. Natural history and risk factors for adjacent vertebral fractures in the fracture intervention trial. Spine (Phila Pa 1976). 2013, 38:2201-7. 10.1097/BRS.0b013e31829002c5
5. Christiansen BA, Bouxsein ML. Biomechanics of vertebral fractures and the vertebral fracture cascade. Curr Osteoporos Rep. 2010, 8:198-204. 10.1007/s11914-010-0051-2
6. Tinetti ME, Speechley M: Prevention of falls among the elderly. N Engl J Med. 1989, 320:1055-9. 10.1056/NEJM198904203201606
7. Benzal EC. Impact None interfaces. Biomechanics of Spine Stabilization: Principles and Clinical Practice. Benzal EC (ed): McGraw-Hill, New York, NY; 1995. 127-34.
8. McCormack BM, Benzal EC, Adams MS, Baldwin NG, Rupp FW, Maher DI. Anatomy of the thoracic pedicle. Neurosurgery. 1991, 37:303-4. 10.1227/00006123-199506000-00016
9. Kerić N, Donezi C, Hui J, et al.: Evaluation of robot-guided minimally invasive implantation of 2067 pedicle screws. Neurosurg Focus. 2017, 42:E11. 10.3171/2017.2.FOCUS1652
10. Fan Y, Peng Du J, Liu J, Zhang N, Liu SC, Hao D: Radiological and clinical differences among three assisted technologies in pedicle screw fixation of adult degenerative scoliosis. Spine (Phila Pa 1976). 2018, 8:080. 10.1097/BRS.0000000000003717
11. Devito DP, Kaplan L, Dietr R, et al.: Clinical acceptance and accuracy assessment of spinal implants guided with SpineAssist surgical robot: retrospective study. Spine (Phila Pa 1976). 2016, 52:109-15. 10.1097/BRS.0000000000001828
12. Grauer L, Wutte C, Klein B, et al.: Early decompression (< 8 h) after traumatic cervical spinal cord injury improves functional outcome as assessed by spinal cord independence measure after one year. J Neurotrauma. 2016, 33:1658-66. 10.1089/neu.2015.4325
13. Jug M, Keijer N, Vesel M, Al Mawed S, Docevic M, Herman S, Bajovic FF. Neurological recovery after traumatic cervical spinal cord injury is superior if surgical decompression and instrumented fusion are performed within 8 hours versus 8 to 24 hours after injury: a single center experience. J Neurotrauma. 2015, 32:1385-92. 10.1089/neu.2014.3767
14. Hunstman RT, Ahrendt LA, Riggsblom R, Ledonio CC. Robotic-assisted navigated minimally invasive pedicle screw placement in the first 100 cases at a single institution. J Robotic Surg. 2020, 14:199-203. 10.1007/s11760-019-00959-6
15. Le X, Tian W, Shi Z, et al.: Robotic-assisted versus fluoroscopy-assisted cortical bone trajectory screw instrumentation in lumbar spinal surgery: a matched-cohort comparison. World Neurosurg. 2018, 120:745-51. 10.1016/j.wneu.2018.08.157
16. Mason A, Puslin R, Babuska JM, Rajpal S, Burneikiene S, Nelson EL, Villovecchio AT: The accuracy of pedicle screw placement using intraoperative image guidance systems. J Neurosurg Spine. 2014, 20:196-203. 10.3171/2013.11.SPNEU15413
17. Hicks JM, Singla A, Shen FH, Arlet V: Complications of pedicle screw fixation in scoliosis surgery: a systematic review. Spine (Phila Pa 1976). 2010, 35:646-70. 10.1097/BRS.0b013e3181d1021a
18. Defino HL, Rosa RC, Silva P, Shimbano AG, Albuquerque da Paula FF, Volpon JB: Mechanical performance of cylindrical and dual-core pedicle screws after repeated insertion. Spine (Phila Pa 1976). 2012, 37:1187-91. 10.1097/BRS.0b013e3182415e8a
19. Xing D, Chen X, Ma JX, et al.: A methodological systematic review of early versus late stabilization of thoracolumbar spine fractures. Eur Spine J. 2013, 22:2157-66. 10.1007/s00586-012-2624-1
20. Shi B, Jiang D, Hu Z, Zhang W, Hu L, Zhang L: Application of spinal robotic navigation technology to minimally invasive percutaneous treatment of spinal fractures: a clinical, non-randomized, controlled study. Orthop Surg. 2021, 13:1556-63. 10.1111/ots.12993
21. Shafi KA, Pompeu YA, Vahuvar AS, Ma E, Sivaganesan A, Shabi P, Qureshi SA: Does robot-assisted navigation influence pedicle screw selection and accuracy in minimally invasive spine surgery?; Neurosurg Focus. 2022, 52:E8. 10.3171/2021.11.FO12S1526
22. Naik A, Smith AD, Shaffer A, et al.: Evaluating robotic pedicle screw placement against conventional modalities: a systematic review and network meta-analysis. Neurosurg Focus. 2022, 52:E10. 10.3171/2021.10.FO12S1509
23. Bai YS, Zhang Y, Shen ZQ, et al.: Learning curve of computer-assisted navigation system in spine surgery. Chin Med J (Engl). 2010, 123:2899-94. 10.3760/cma.j.issn.0366-9999.2010.21.007
24. Sasso RC, Garrido BJ: Computer-assisted spinal navigation versus serial radiography and operative time for posterior spinal fusion at L5-S1. J Spinal Disord Tech. 2007, 20:118-22. 10.1097/BSD.0b013e32801f2a13
25. D’Souza M, Gendreau J, Feng A, Kim LH, Hu AL, Veenavagu A: Robotic-assisted spine surgery: history, efficacy, cost, and future trends. Robot Surg. 2019, 6:9-23. 10.2147/RSSR.S190720