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Minimally Invasive Unilateral Percutaneous Transfracture Fixation of a Hangman's Fracture Using Neuronavigation and Intraoperative Fluoroscopy

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Key words
- Cervical fracture
- Hangman's fracture
- Image guidance
- Minimally invasive
- Neuronavigation
- Unilateral

Abbreviations and Acronyms
3D: 3-Dimensional
CT: Computed tomography
K-wire: Kirschner wire

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BACKGROUND: **Traumatic spondylolisthesis or hangman's fracture is a common cervical spine fracture. Most cases of traumatic spondylolisthesis are treated nonoperatively with external immobilization. The indications for surgery have generally included fracture instability or failed nonoperative management. Operative stabilization can be performed through either anterior or posterior approaches and has generally required instrumentation using open methods. We propose a technique for surgical repair of hangman's fracture that is minimally invasive and motion preserving using recent advances in 3-dimensional image-guidance technology. We believe this method represents another option in the treatment of hangman's fractures, because it allows for immediate stabilization, prompt recovery, and quick mobilization.**

CASE DESCRIPTION: **We present the case of 2 patients with hangman's fractures who had undergone surgical unilateral transfixation with minimally invasive percutaneous screw placement. In both cases, we used 3-dimensional neuronavigation and bidirectional intraoperative fluoroscopy. The operative time from incision to closure was <30 minutes. Preparation and positioning after intubation varied from 40 to 150 minutes. No intraoperative complications occurred. Both patients were discharged within 48 hours postoperatively. The follow-up examinations at 3 months, 12 months, and 5 years revealed healthy bony fusion on computed tomography imaging and an excellent clinical recovery.**

CONCLUSION: **We have provided 2 examples in which minimally invasive unilateral fixation of hangman's fractures proved to be safe and effective. In both cases, the patients were immediately relieved of their pain, quickly mobilized, and promptly discharged. The achievement of successful fusion confirmed at the follow-up examinations.**

INTRODUCTION

Traumatic spondylolisthesis of the axis or hangman's fracture represents ~4% of all cervical spine traumas.[1] Numerous treatments have been proposed; however, for most cases external immobilization has remained the mainstay of treatment.[1-3] Rigid halo immobilization has been reported to achieve high fusion rates >90%.[2,4-6] Cervical collars have also been used to successfully treat hangman's fractures.[1,3] Surgery could potentially improve the fusion rate[1,4,5,7] but the patient must accept the additional risk. Consequently, most clinicians have resorted to surgery as a secondary option, when traditional management has failed.[1,3]

In some circumstances, surgery could be indicated as a primary treatment. Halo vests are known to compromise pulmonary volumes and can compromise respiratory capacity, which can be dangerous and lead to respiratory failure in patients with pre-existing or acquired pulmonary conditions.[8,9] Certain unstable fractures, such as Effendi type III, which involve locked and dislocated C2-C3 facets, or Levine-Edwards type IIa/III, which involve fracture displacement and angulation, have also been recognized to be insufficiently treated by external fixation, and experts have generally recommended surgery.[1-3,5,10] Halo fixation can also fail and has its own series of complications, including infection, nerve injury, scalp laceration, pain, and visible scarring.[1,11]

Although, in general, the surgical fusion rates have tended to be greater than nonoperative procedures, they can be associated with significant morbidity and/or mortality.[1] Traditional surgical techniques have tended to be open, requiring extensive dissection and lengthy procedural times. The complications have included possible blood loss requiring transfusion, infection, lengthy recovery, and nontrivial medical risks for elderly individuals with comorbidities.[12] Minimally invasive surgery, however, avoids many of these issues by exposing patients to less tissue invasion.[13] These techniques have been increasingly used in spinal surgery to achieve improved outcomes by exploiting careful preoperative planning and recent innovations in neuronavigation technology.[14-16]

With these advantages, minimally invasive internal fixation of a hangman's fracture using pedicle screw insertion with neuronavigation could be another option

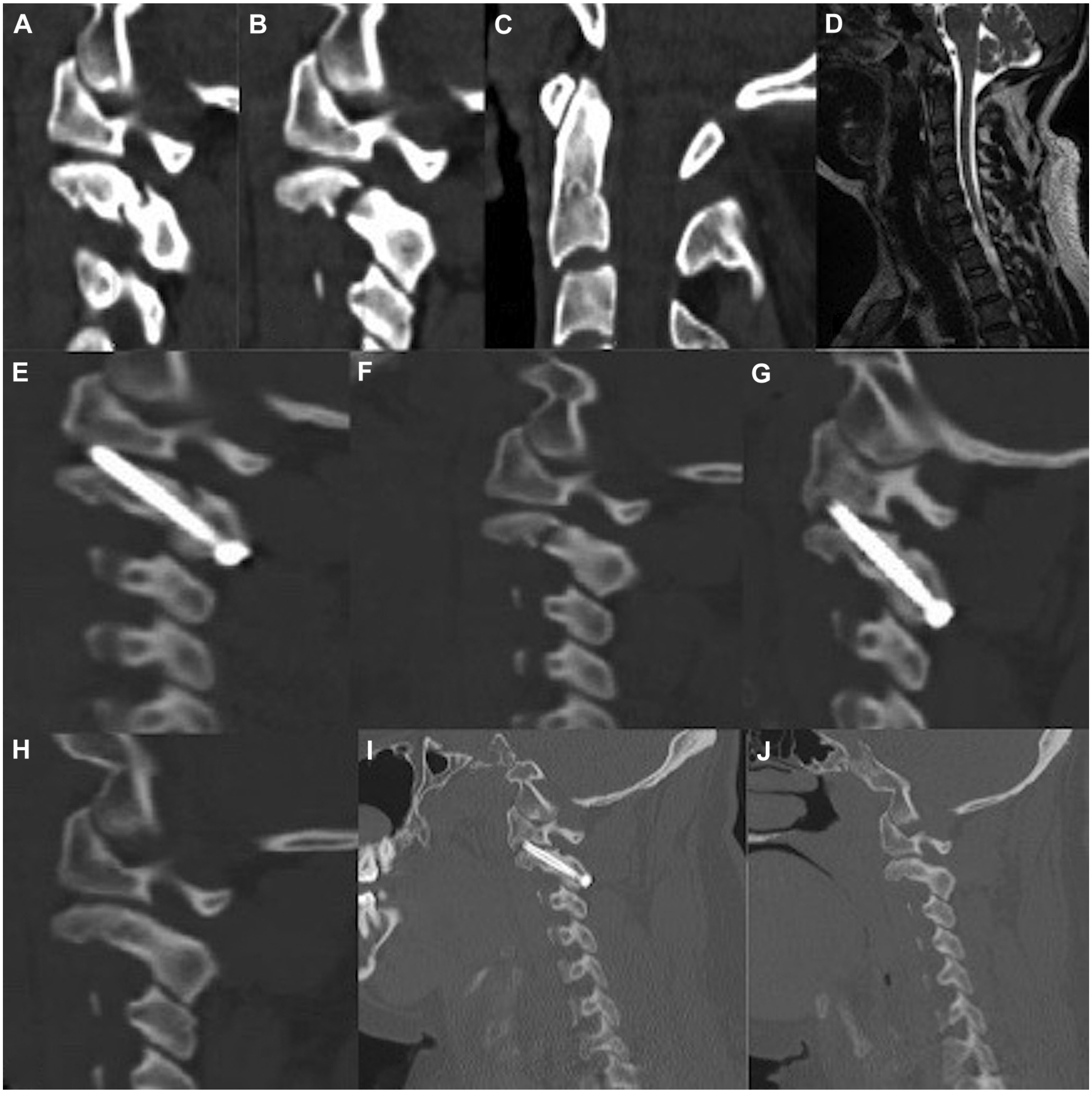


Figure 1. (**A–C**) Sagittal computed tomography (CT) scans of the cervical spine showing hangman's fracture with angulation of C2-C3 over C3. (**D**) Sagittal T2-weighted magnetic resonance imaging scan of the cervical spine showing the ligamentous injury. (**E,F**) Sagittal CT scans of the cervical spine showing the fixated fracture immediately postoperatively. (**G,H**) Sagittal CT scans of the cervical spine showing the fixated fracture at the 3-month follow-up visit. Sagittal CT scans of the cervical spine showing the (**I**) right and (**J**) left sides of the fixated fracture at the 5-year follow-up visit.

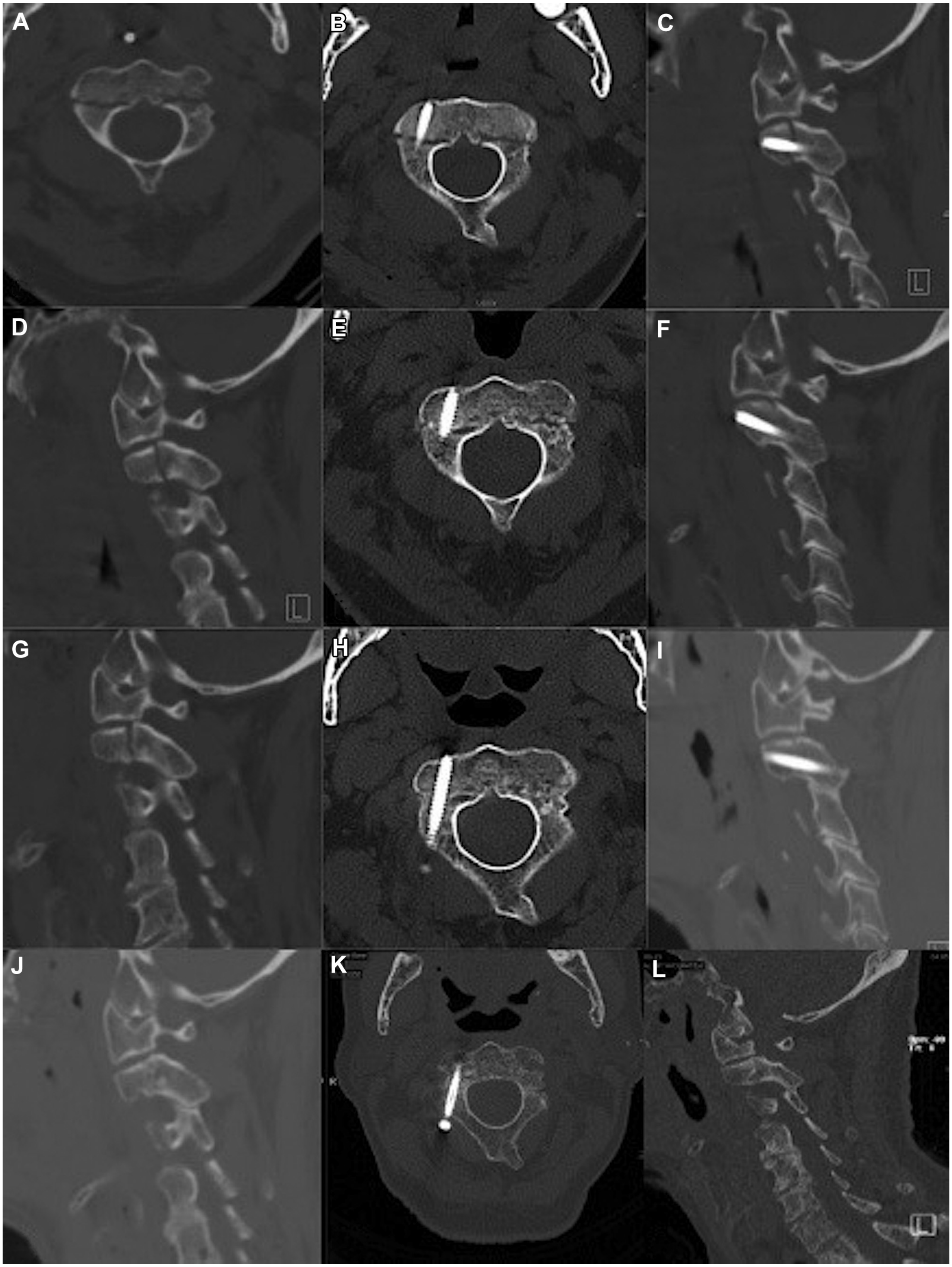
in the management of nonangulated hangman's fractures in stable patients.

CASE DESCRIPTION

We present the cases of 2 patients with hangman's fractures.

Patient 1

A 35-year-old man experienced a traumatic hyperextension injury from a fall down 4 stairs. He presented with neck pain and no neurological deficits. Computed tomography (CT) imaging revealed fractures through both parts of C2, consistent with a hangman's fracture, type IIa (Levine classification; Figure 1A–C). A magnetic resonance imaging scan of the cervical spine showed edema in the area of the C2-C3 interspinous ligaments, suggesting additional ligamentous injury (Figure 1D). The patient was offered the option of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minimally invasive surgery, including transfracture fixation with the intention to stabilize the fractured segment. The patient elected for surgery.

The patient was brought to the operating room 4 days after injury. After fiberoptic intubation, he was placed in Mayfield head fixation and turned to the prone position. During the next 47 minutes, the patient was positioned to achieve perfect orthogonal views with perpendicularly placed C-arms. The anteroposterior and lateral images of the axis were then used to calibrate our neuronavigation system (BrainLAB, Munich, Germany) using CT fluoroscopic guidance (Figure 1C). After calibration, the potential trajectories were then determined on each side through each fracture. The entry point was through the posterolateral portion of each facet, directed anteromedially through the pedicle and then the fracture. For patient 1, the right side was thought to be the ideal trajectory, and the distance from the skin to the facet was 15 cm.

A 1.5-cm skin incision was made in the posterolateral neck. A precalibrated trocar was passed down to the facet—laminar junction with repeated fluoroscopic imaging for guidance. Trajectories for the Kirschner wire (K-wire) were then estimated again and confirmed. The K-wire was inserted through the facet, pedicle, and fracture and placed as close as possible to the anterior cortical border without breaching this bone. A cannulated drill was used to widen this trajectory with careful attention aimed toward preventing K-wire advancement. For patient 1, a 30-mm-long, 4-mm-diameter threaded screw successfully captured the fractured segment and reduced the fracture (Figure 1E). The wound was closed within 20 minutes of the incision.

Postoperative CT imaging confirmed excellent screw positioning and transfixation of the fractured segment. However, a breach of the C1-C2 joint had occurred, which could be avoided in future patients by performing 3D imaging studies after screw insertion. The patient had experienced immediate resolution of his pain on examination in the recovery room and was discharged 2 days later.

Follow-up CT imaging at 3 months postoperatively confirmed early fusion on the fixated right side of C2 and evidence of fusion on the nonfixated left side (Figure 1G,H). At the 12-month and 5-year follow-up imaging studies (Figure 1I,J), fusion had occurred on both sides, with no evidence of instability.

Patient 2

After an all-terrain vehicle injury, a 76-year-old man (a farmer) experienced fractures of C1, C2, and C3. The C2 fracture was a hangman's fracture type I (Levine classification) and was through both pars. The C1 fracture was a bilateral posterior laminar fracture, and at C3, the fracture was through the spinous process. He also had coexisting pulmonary injuries but had no neurological deficits. The patient was offered the option of minimally invasive surgery, including transfracture fixation, with the intention to stabilize the fractured segment. The patient elected for surgery.

The same operative method for our first patient was used for patient 2. The preparation time before surgery, but after intubation, was 150 minutes. The trajectory from the skin to the facet was 50 mm. The threaded screw length was 34 mm and the diameter was 4 mm. The total surgical cut time was 25 minutes. Postoperative CT imaging of the cervical spine showed excellent screw positioning (Figure 2C).

The patient had experienced almost complete relief of pain postoperatively. The patient was quickly mobilized and discharged home 2 days later. Follow-up CT imaging of the cervical spine scan at 3 months postoperatively showed substantial healing (Figure 2E). The right side of the C2 vertebra where the transarticular screw was inserted showed further union. At the 12 month follow-up study, CT imaging showed partial union of the fracture and good apposition of the bony structures (Figure 2I). No evidence of instability was seen.

DISCUSSION

We have reported 2 patients who had developed hangman's fractures that were successfully managed with minimally invasive neuronavigation-assisted instrumented fixation. The technique allowed for anatomical joint preservation, minimal tissue disruption, and relatively short operative times. We believe that with the recent advances in accuracy and reliability in neuronavigation technology,[16-18] it is now safer than previously to be able to percutaneously fixate fractures throughout the entire spine, without the need to perform extensive and potentially dangerous dissection. Under certain circumstances, in appropriate patients, and with adequate training, we believe that the indications for surgical management of hangman's fractures can be widened.

Hangman's fractures are frequently managed with conservative treatment using a rigid cervical collar or halo immobilization device for 12 weeks, because it results in high fusion rates and, in general, has a low rate of complications.[1-3,11] However, external immobilization will not be appropriate for all cases, in particular, those with unstable C2 fractures, halo intolerance, and/or coexisting trauma and many elderly individuals.[1,2,8,11,19] Complications resulting from external immobilization have been reported in previous studies and have described cases of pin site infection, pressure sores, and aspiration pneumonia.[8,11] Hangman's fractures are also painful, with many patients requiring opioids to manage their pain. Such treatment can be necessary for many weeks when patients are managed

Figure 2. (**A**) Axial computed tomography (CT) scan of the cervical spine showing the hangman's fracture. (**B**) Axial CT scan of the cervical spine showing the fixated fracture immediately postoperatively. Sagittal CT scans of the cervical spine showing the (**C**) fixated fracture (right side) and (**D**) fixated fracture (left side) immediately postoperatively. (**E**) Axial CT scan of the cervical spine showing the fixated fracture at the 3-month follow-up visit. Sagittal CT scans of the cervical spine showing the (**F**) right and (**G**) left sides of the fixated fracture at the 3-month follow-up visit. (**H**) Axial CT scan of the cervical spine showing the fixated fracture at the 12-month follow-up visit. Sagittal CT scans of the cervical spine showing the (**I**) right and (**J**) left sides of the fixated fracture at the 12-month follow-up visit. (**K**) Axial CT scan of the cervical spine showing the fixated fracture at the 5-year follow-up visit. (**L**) Sagittal CT scan of the cervical spine of the fixated fracture (left side) at the 5-year follow-up visit.

nonoperatively. Our 2 patients were able to be weaned off opioids rapidly. They experienced immediate pain control within hours after surgery. Cervical collars were not necessary.

Traditional open surgical techniques in the management of hangman's fractures can be fairly invasive and associated with small, but significant, risks of injury to the vertebral artery, spinal cord, and nearby neural structures.[1,12] Commonly used surgical methods have included anterior fusion of C2 and C3 with interpositional bone grafts and cervical plating, which has risks such as injury to the facial nerve or external carotid artery branches and loss of range of motion.[10,15,20] Posterior segmental fusion has also been proposed as a treatment of hangman's fracture with almost perfect fusion rates.[15,21] However, posterior segmental fusion results in significant reduction in rotational movement.[15] Furthermore, the extensive dissection results in a more difficult recovery than with anterior procedures.[16]

Judet et al.[22] in 1970 proposed transpedicular osteosynthesis, which is a "physiological" operation, because it leads to direct fixation of the fracture and preservation of the range of motion, does not lead to segmental fusion, and allows for anatomic healing.[14] However, their method of pedicle screw fixation does have important risks such as trauma to the vertebral artery and/or spinal cord.[23] Minimally invasive versions of their method have since been proposed to help limit the risks of trauma to neurovascular structures by allowing for preoperative assessment of the fracture path using neuronavigation. The use of neuronavigation includes the ability to select the best screw trajectory, screw placement point, and screw length.[14,15,20] Intraoperative assessment can also be obtained through C-arm fluoroscopy, allowing for live imaging of the screw insertion.[14,15,20]

In the past, neuronavigation had major inaccuracies, with numerous examples of misplaced screws.[16,24,25] However, the technology has continued to advance and has matured to a level of clinical acceptability.[16] Recent advances in neuronavigation have increased the accuracy substantially, and the present technologies are capable of use to cannulate small pedicles.[13,26] A review by Tjardes et al.[27] on neuronavigation for spinal surgery highlighted the use of CT-guided, 2-dimensional and 3D fluoroscopy usage during surgery throughout the cervical spine, including odontoid fractures, atlantoaxial instability, C6-C7 subluxation, and hangman's fractures. Image-guided variants of the approach reported by Judet et al.[22] are becoming more common and have been described using both intraoperative CT guidance by Taller et al.[14] and isocentric mobile C-arm 3D navigation navigation by Rajasekaran et al.[15,20]

We have proposed the use of 2 C-arms to take both anteroposterior and lateral radiographs with neuronavigation for unilateral minimally invasive percutaneous transarticular screw fixation of a hangman's fracture.[15] This surgical operation does have important risks, including vertebral artery injury, cervical nerve injury, spinal cord injury, and pedicle compromise during insertion. Excessive advancement of K-wires and misadvancement of K-wires must be monitored constantly.[18] Although in our 2 patients, the position of the vertebral artery was inferred by the location of the foramen transversarium, angiographic studies such as CT angiography or magnetic resonance angiography could aid surgical planning and decrease the risk by choosing to fixate the side with the nondominant vertebral artery. Complications will be minimized, however, using the percutaneous approach, which helps to limit blood loss and injuries to the vertebral artery.

This technique might also be more cost effective than nonoperative care because the discharge for our patients was prompt. Another novel aspect of our approach was the decision to perform only unilateral screw fixation. We believe that unilateral fixation is sufficient to achieve fusion because both of our patients had experienced immediate pain relief after surgery, suggesting that the fractured segment had been stabilized. Under such circumstances, bony fusion should occur, given the appropriate passage of time. Unilateral fixation has the obvious advantage of reducing risk by $\geq$50%. Should failure occur, the contralateral pedicle will remain for repeated surgery.[28] In addition, this technique offers another treatment option for nonangulated hangman's fractures in stable patients and reducible angulated fractures in the absence of C2-C3 disc herniation. The use of preoperative CT angiography or magnetic resonance angiography in future cases to select the nondominant vertebral artery could further decrease the risk of vertebral artery injury.

CONCLUSION

Although external immobilization remains an important treatment modality, it is not without complications or impairment.[1-3,8,9] We have proposed a novel method of fixation of nonangulated hangman's fracture in stable patients and in patients with reducible unstable fractures in the absence of C2-C3 disc herniation. Our method is minimally invasive, with a short operative time, allows for quick mobilization, preserves the range of motion, and offers a short recovery time.[14,15,20,28] We believe that with adequate training and experience, this method can be safely used to improve outcomes and achieve high rates of fusion. As advancements in intraoperative imaging and navigation continue, these methods will be increasingly used to treat spinal injuries.[16,29] However, our study was small. We encourage further evaluation with larger patient series and thoughtful analysis before general recommendations are made.

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