Minimally invasive percutaneous screw fixation of traumatic spondylolisthesis of the axis

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OBJECT Most cases of traumatic spondylolisthesis of the axis (hangman’s fracture) can be treated nonoperatively with reduction and subsequent immobilization in a rigid cervical collar or halo. However, in some instances, operative management is necessary and can be accomplished by using either anterior or posterior fusion techniques. Because open posterior procedures can result in significant blood loss, pain, and limited cervical range of motion, other less invasive options for posterior fixation are needed. The authors describe a minimally invasive, navigation-guided technique for surgical treatment of Levine-Edwards (L-E) Type II hangman’s fractures.

METHODS For 5 patients with L-E Type II hangman’s fracture requiring operative reduction and internal fixation, percutaneous screw fixation directed through the fracture site was performed. This technique was facilitated by use of intraoperative 3D fluoroscopy and neuronavigation.

RESULTS Of the 5 patients, 2 were women, 3 were men, and age range was 46–67 years. No intraoperative or postoperative complications occurred. All patients wore a rigid cervical collar, and flexion-extension radiographs were obtained at 6 months. For all patients, dynamic imaging demonstrated a stable construct.

CONCLUSIONS L-E type II hangman’s fractures can be safely repaired by using percutaneous minimally invasive surgical techniques. This technique may be appropriate, depending on circumstances, for all L-E Type I and II hangman’s fractures; however, the degree of associated ligament injury and disc disruption must be accounted for. Percutaneous fixation is not appropriate for L-E Type III fractures because of significant displacement and ligament and disc disruption. This report is meant to serve as a feasibility study and is not meant to show superiority of this procedure over other surgical options.

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KEY WORDS hangman’s fracture; spondylolisthesis; trauma; percutaneous; minimally invasive; neuronavigation
Management decisions regarding the treatment of these fractures are based on estimates of stability. Stable fractures (L-E Type I) and certain adequately reduced L-E Type II fractures are generally treated with brace therapy involving a rigid cervical collar or halo immobilization. For unstable fractures, including some L-E Type II and most Type IIa and III fractures, or when external brace immobilization fails, surgical management is generally indicated. Surgical options are varied but have historically included posterior or anterior stabilization, including C1–2 and C1–3 posterior fusion with occasional occiput incorporation and, more recently, C2–3 anterior cervical disectomy and fusion. The use of C-2 direct transpedicular fixation has also been described. Bilateral transpedicular screw fixation is a motion-preserving and physiological operation; however, it may be technically difficult because of variable patient anatomy over an unstable fracture, potentially resulting in neurovascular injury.

We report a case series containing 5 patients with L-E Type II fractures. For all patients, conservative therapy failed and surgical stabilization was required. Using neuronavigation, we performed minimally invasive, percutaneous, direct screw fixation of the fracture in all patients. The results were excellent. This surgical treatment for hangman’s fractures represents a novel incremental improvement over existing techniques, and this study was meant to determine the feasibility of this procedure.

Methods
Patient Population
From 2009 through 2014, 5 patients (3 male, 2 female) underwent repair of hangman’s fractures by percutaneous screw fixation across the fracture site. The mean age of the patients was 55 years (range 46–67 years). All injuries were evaluated by thin-cut (< 2 mm) noncontrast CT imaging of the cervical spine. An intraoperatively reduced fracture can be seen in Fig. 1. Fracture classification was based on the L-E system. All patients had Type II fractures (and no other cervical spine injuries) resulting from motor vehicle collisions; at the time of the initial visit and throughout treatment, they remained neurologically intact (American Spinal Injury Association Grade E). For all patients, initial treatment was either a rigid cervical collar or halo immobilization, which then failed, and surgical intervention was required.

Radiological Assessment
Initial fracture assessment and L-E classification were based on axial and sagittal CT images of the cervical spine. The fracture deformity was described in terms of degree of angulation, amount of translation, and displacement. Angulation was measured by the angle subtended by lines drawn along the inferior endplate of C-2 and the inferior endplate of C-3. Anterior translation was measured by the distance between a line drawn parallel to the posterior margin to the body of C-3 and the posterior margin of the body of C-2 at the level of the disc space. Displacement was measured as the maximal distance between the 2 fracture segments. Premobilization and postmobilization radiographs of the cervical spine were compared to assess for degree of angulation and translation to determine adequate stabilization of the fracture segment. Patient follow-up consisted of routine anteroposterior and lateral cervical spine radiographs taken in inpatient and outpatient settings. Instability was determined as failure of the fracture site to remain well aligned, with increased angulation and fracture displacement of greater than 2 mm from that seen on prior images taken while the patient was in a rigid cervical collar or halo.

Surgical Technique
All patients underwent fiberoptic intubation, were placed in a Mayfield head clamp, and then were carefully positioned prone. Preflip and postflip neuromonitoring (of somatosensory evoked and motor evoked potentials) was performed and continued throughout the procedure. A BrainLAB registration star was fixed to the Mayfield clamp (Fig. 2A). The fracture was subsequently reduced under fluoroscopic guidance while changes in neuromonitoring were assessed. After fracture reduction, intraoperative CT scanning was performed using the Iso-C3D C-arm (Siremobil, Siemens, Medical Solutions) (Fig. 2B). The images were then uploaded into the BrainLAB navigation system (VectorVision compact plus BrainLAB image-guided surgery system 4.0). After the CT images were reviewed, appropriate trajectories were chosen to enable safe passage of a cannulated lag or fully threaded screw to reduce and/or stabilize the fracture fragments.
Depending on patient anatomy, the skin entry point was determined by using a virtual offset on the BrainLAB navigation program. The location was generally lateral and inferior to the C-2 lateral mass and was optimized by selected trajectories from the neuronavigation imaging. A small stab incision was made at each entry site (Fig. 2C), and a specially adapted drill probe/guide with navigation capability was advanced under computer-aided guidance to the pedicle of C-2 (Fig. 2D). For confirmation of the accuracy of the neuronavigation, fluoroscopic images were taken intermittently. After the pedicle was identified, a power driver (Stryker Cordless Power Driver) was used to advance a threaded K-wire across the fracture site and into the body of C-2. After proper alignment was verified by fluoroscopy, a cannulated drill was advanced over the K-wire and subsequently tapped across the fracture line. To avoid changes in fragment alignment that may result in false localization during navigation, this procedure was performed bilaterally before lagging the fracture fragments on either side (Fig. 3). If any concern arises, however, reimaging by using the Iso-C3D C-arm and navigation off the new images can be performed at any time. After placement of the K-wires and bilateral drilling and tapping, a 3.5-mm lag or fully threaded Universal Cannulated Screw (Medtronic Sofamor Danek) was advanced across the fracture line on each side, and the trajectory was confirmed by use of intermittent fluoroscopy. Average screw length was 30–35 mm. The stab incisions were subsequently sutured with a single 3-0 VICRYL inverted subcutaneous stitch followed by application of Derma- bond skin glue (both Ethicon).

Postoperatively, patients wore a rigid cervical collar. Postoperative CT images were used to confirm screw placement and fracture reduction (Fig. 4). Ambulation was encouraged during the immediate postoperative period. Radiographic and clinical evaluations were performed at 2, 6, 12, and 24 weeks postoperatively. Flexion-extension radiographs were obtained at 6 months postoperatively (Fig. 5).

**Results**

For all 5 patients, percutaneous screw fixation of L-E Type II hangman’s fracture was successful. The details of each case are shown in Table 1. The range of initial angulation was 10°–16° (average 13°) and that of initial displacement was 3–6 mm (average 4.6 mm). To assure adequate size for screw placement, pedicle size was measured on preoperative CT images; for all patients, the pedicle was large enough to accept a 3.5-mm screw.

Patient 1 was noncompliant with the cervical collar, and chronic alcohol abuse resulted in multiple falls. Surgical management was chosen for this patient because of the likelihood he would remove his collar after discharge and suffer a worse injury. Patient 2 initially was given a rigid cervical collar, but follow-up imaging at 2 weeks indicated fracture instability with motion, increased angulation, and displacement when compared with that seen on prior cervical spine plain radiographs. The patient was given the option of halo immobilization or surgery and chose surgery. Patient 3 also showed increased angulation...
after 4 weeks of initial rigid cervical spine immobilization and was subsequently placed in a halo, which again failed to adequately stabilize the fracture after an additional 2 weeks, resulting in the need for surgical management. Patient 4 had multiple neck lacerations, so long-term use of a collar entailed a significant risk for further skin breakdown and infection. He also had a large scalp laceration and avulsion, which precluded treatment with halo immobilization. Patient 5 initially underwent halo immobilization, but no signs of fusion were apparent by Week 12 because of an inability to adequately approximate and maintain alignment of the fracture site.

The average total duration of the procedure was 70 minutes (30 minutes for positioning, 10 minutes for the Iso-C3D C-arm spin with neuronavigation setup, and 30 minutes for screw fixation). Blood loss was negligible (5–15 ml). No neurovascular complications occurred. Postoperative CT images demonstrated all screws to be in proper alignment without breach of bony walls. Flexion-extension radiographs obtained at 6 months demonstrated ossification across the fracture site with no mobility of fracture seen during imaging.

Discussion

Although hangman’s fractures are easily identified, management remains controversial and the most effective treatment remains a topic of debate. Li et al. published a meta-analysis (32 papers, 357 patients) of nonoperative conservative management, according to L-E classification. The rates of fracture healing were 100%, 60%, 42%, and 38% for patients with L-E Type I, II, IIa, and III fractures, respectively.20 For reasons including concurrent injuries, compliance, and fracture severity, conservative treatment of hangman’s fractures will not always suffice.20,23 A recent paper by Shin et al. advocates for the early use of surgical fixation of hangman’s fractures because of high rates of nonunion and pseudarthrosis, along with patient dissatisfaction associated with long-term rigid cervical collar and halo use.27 Shin et al. suggested the use of posterior reduction and screw fixation as a primary treatment for hangman’s fractures of all grades. As such, surgical stabilization, including minimally invasive direct percutaneous fracture fixation, is a potentially useful adjunct in the proper management algorithm. Although we still favor conservative options as initial management strategies, a minimally invasive technique may further improve patient satisfaction and decrease associated surgical comorbidities.

The placement of direct C-2 pars or pedicle screw fixation hardware requires considerable technical ability because of potential variable anatomy, especially in the traumatized spine.3,5,6,9,15,21 Reliance on anatomical landmarks can be misleading and can result in neurovascular injury. Computer-assisted neuronavigation is a useful adjunct for improving the accuracy of complicated screw placement;16,25 however, its use in the fixation of unstable fractures can result in inaccuracy and screw misplacement because of pre- and intraoperative movement of the fractured spine. Real-time CT-based intraoperative
neuronavigation can diminish the possibility of such inaccuracies.\textsuperscript{13} Iso-C3D navigation has been well described for use in cervical spine surgery.\textsuperscript{13,16,24} Hott et al. demonstrated the intraoperative use of the Iso-C3D C-arm in a series of 30 patients with varied pathology of the cervical spine, including traumatic, degenerative, congenital, and neoplastic conditions. Of 96 screws placed, 2\% violated the cortex, but no neurovascular complications occurred.\textsuperscript{16} Rajasekaran et al. reported the successful intraoperative use of the Iso-C3D C-arm in an open repair of hangman’s fracture.\textsuperscript{24}

The use of C-2 pars and pedicle screw fixation has also been described for large posterior constructs and standalone fixation for hangman’s fractures.\textsuperscript{2,3,5,7,8,15} Borne et al. described the open repair of 12 hangman’s fractures with direct pars screws without neurovascular complications, pseudarthrosis, or postoperative instability.\textsuperscript{3} ElMiligui et al. reported the use of direct open transpedicular screw fixation in 15 patients with L-E Type II fractures. All patients had excellent anatomical and functional results and preservation of motion, but all patients underwent traditional open techniques.\textsuperscript{11} Hakalo and Wroński compared 8 cases of open direct pars screw fixation with 9 cases of C2–3 anterior plate fixation in patients with Effendi Type II hangman’s fractures. Although motion was preserved at C1–2 for patients in both groups, direct pars screw fixation was reported to be safer and more cost effective.\textsuperscript{15} These reports provide evidence for the utility of direct open C-2 pars screw fixation in patients with traumatic spondylolisthesis. The successful outcomes of this small series of patients that we have presented suggest that the percutaneous screw fixation may be just as effective, although further follow-up data and evaluation of additional cases are needed. Again, the utility of the direct pars screw fixation has been established, and our modification to this technique is not meant to show superiority but rather feasibility.

Wu et al.\textsuperscript{32} reported the use of percutaneous transpedicular screw fixation for hangman’s fractures; they performed preoperative imaging to ascertain entry points, angles, and distances for screw fixation without the use of neuronavigation. In place of intraoperative neuronavigation, they used measurements, angles, and trajectories established from the preoperative CT scans to plot their percutaneous screw course. Intraoperative fluoroscopy was used to verify anatomical locations and screw position. Postoperative CT scans demonstrated that 17 (85\%) of 20 screws were placed satisfactorily and that 3 screws (15\%) perforated the pedicle wall (< 2 mm). They otherwise reported proper alignment and solid fusion in all cases and that the patients with cortical breach were asymptomatic.

To the best of our knowledge, we have reported the first small series of minimally invasive, percutaneous, direct, CT-based, neuronavigation-assisted repair of hangman’s fractures. The percutaneous technique presented here seems to be equally safe and effective as the open procedures previously reported, without the pedicle wall perforation rate of 15\% associated with the percutaneous approach reported by Wu et al.\textsuperscript{32} We again highlight the value of intraoperative CT imaging and neuronavigation in this procedure. As mentioned, fracture alignment as seen on CT images may change due to differences in preoperative to intraoperative patient position. Having real-time CT imaging to plot neuronavigation trajectories intraoperatively is key for avoiding complications. In this region, even minor inaccuracies between what is seen on preoperative images to the actual location of fracture and bones seen in the operating room are unacceptable and can lead to severe neurovascular injury.\textsuperscript{24} As such, we strongly advocate the use of intraoperative neuronavigation to reduce this potential risk. Although our series contained only 5 patients, we were able to safely place all screws (10/10) by using the Iso-C3D C-arm for intraoperative visualization and verification. Precise intraoperative imaging is especially helpful for proper screw placement in a percutaneous approach because the surgeon is unable to visualize anatomical landmarks. Neuronavigation offers a clear benefit in terms of safety.

Additional benefits of the percutaneous approach may include shorter operative times, faster recovery, less blood loss, and less muscle disruption. Percutaneous minimally invasive surgery techniques have gained popularity among spine surgeons and offer several advantages, including shorter lengths of stay, decreased pain, shorter recovery times, less blood loss, lower infection rates, and preservation of surrounding anatomical structures.\textsuperscript{28–30} As demonstrated in this series of patients, the combination of minimally invasive techniques and intraoperative CT-based neuronavigation has enabled the safe and effective repair of hangman’s fracture by use of a percutaneous approach.

This series has several limitations, one of which is its relatively small size (only 5 patients). Few conclusions can be drawn from such a small sample size, but the goal of the study was not to show superiority but rather the feasibility of this technique. Thus far, our surgical and postopera-

\begin{table}
\centering
\caption{Summary of data of patients with L-E Type II hangman’s fracture*}
\begin{tabular}{llllll}
\hline
Patient No. & Age (yrs), Sex & Angulation ($^\circ$) & Displacement (mm) & Initial Treatment & Length of FU (mos) \\
\hline
1 & 67, M & 11 & 3 & Collar (patient noncompliant) & 17 \\
2 & 54, F & 10 initial, 14 collar & 4.5 & Collar (motion detected) & 16 \\
3 & 50, F & 16 initial, 22 halo & 4.5 & Halo (failed after 4 wks) & 18 \\
4 & 59, M & 12 & 5 & Collar (few days only due to infection risk) & 18 \\
5 & 46, M & 16 & 6 & Halo (failed at 12 wks) & 12 \\
\hline
\end{tabular}
\end{table}

\textsuperscript{*} For all 5 patients, the fusion was stable postoperatively.
tive outcomes have been successful, thereby encouraging future use and study of this technique. All patients in this series also underwent a trial of conservative management before surgical intervention. Although the timing of surgery for these fractures and fusion rates can be questioned, Apfelbaum et al. were able to demonstrate no difference in fusion rates of odontoid fractures when treated immediately and up to 6 months after injury. Some patients in the odontoid study were also treated conservatively for up to 6 months before a screw was placed, and fusion rates were equivalent to those for patients who underwent surgical intervention immediately. Our study is also limited by its generalizability. Surgeons must have access to the required equipment, including intraoperative CT and neuronavigation equipment. In addition, we have no images to confirm solid fusion at the fracture site. Although we do not routinely perform postoperative CT to assess fusion, clinical follow-up at 12–18 months revealed no symptoms suggestive of hardware failure or pseudarthrosis. The success of open transpedicular screw fixation has been well reported and suggests that a similar result would follow percutaneous screw fixation.

Conclusions

We have described the management of traumatic L-E Type II hangman's fractures by use of minimally invasive, percutaneous, navigation-assisted, direct screw fixation. For all 5 patients, conservative treatment had either failed or was not continued because the patients were poor candidates. Each patient underwent surgery without complications; screw placement was excellent and fusion was stable by 6 months postoperatively. Patients suitable for this method of treatment would include those with either L-E Type I fractures that fail to heal in rigid immobilization, unreliable patients with Type I and Type II fractures, and patients with Type II and Type Ila fractures with minimal disc disruption. Although we still recommend nonoperative management when possible, Shin et al. have advocated for the use of early surgical intervention. If patients are carefully selected and intraoperative neuronavigation is used, this technique seems to be a safe and effective method for the treatment of traumatic spondylolisthesis of the axis.

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References


Author Contributions

Conception and design: Frankel, Buchholz, Morgan. Acquisition of data: Frankel. Analysis and interpretation of data: Frankel. Drafting the article: Buchholz, Robinson. Critically revising the article: Frankel, Buchholz. Reviewed submitted version of manuscript: Buchholz. Administrative/technical/material support: Frankel.

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