CT analysis of anatomical variation and injury affecting posterior pedicle screw fixation for unstable Hangman fractures

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Abstract
The aim of this study was to evaluate the anatomical variations and injuries in patients with unstable Hangman fractures that affected the posterior pedicle screw placement of C2 to C3 and retrospectively review our experience with management of these fractures. Clinical data were reviewed in 72 patients with unstable Hangman fractures, especially using 3-dimensional computed tomography (3D-CT) scan to identify the presence of anatomical variations or injuries and analyzing the treatment strategies we used. Twenty-two patients (22/72, 30.6%) with 39 (C2 or C3) risk factors were not fit for safe C2 to C3 pedicle screw placement, due to factors such as small pedicle size of C2 or C3, high-riding vertebral arteries, fractured fragments encased into vertebral canal, or transverse process foramens of C2, sclerotic pedicles and pedicle fractures of C3. One or more than one of these risk factors could pose more risks of arterial or neural structures damages to pedicle screw fixation for unstable Hangman fractures. Individualized treatment plans were made to minimize the risks of surgery for the 22 patients. There is a high incidence of anatomical variations and injuries in the C2 to C3 region in patients with unstable Hangman fractures that affect the pedicle screw placement. Preoperative evaluation of these conditions using 3D-CT scans is of paramount importance to avoid and decrease operative complications and to choose appropriate surgical techniques.

Abbreviations: 3D-CT = 3-dimensional computed tomography, ASIA = American Spinal Injury Association scale.

Keywords: anatomical variations, Hangman fractures, injuries, pedicle screw, screw trajectory

1. Introduction
Traumatic spondylolisthesis of the axis, the so-called Hangman fracture, was first discovered by Haughton in 1866 in dead criminals from judicial hanging, and Schneider et al. in 1965 officially named this kind of fracture. It is characterized by bilateral C2 pars interarticularis fracture with a variable degree of translation or angulation of the C2 on the C3 vertebrae. Most of Hangman fractures can be treated conservatively. However, it is controversial with the treatment of types II, IIa, and III lesions (Levine=Edward Classification) which usually are unstable and better be treated with rigid immobilization.

Various managements for unstable Hangman fractures are available, including traction and external immobilization, anterior surgery, posterior surgery, and both anterior and posterior approach. Although the ideal strategies for those lesions are still controversial, the posterior fixation has been advocated by some authors for its relatively simple procedure and a low rate of complications. Posterior procedures include C2 isthmic or transpedicular screw fixation only, C2 to C3 pedicle screw fixation, and extensive arthrodesis from C1 to C3. In recent decades, C2 to C3 pedicle screw fixation is used widely. However, before operation, it is worthy of considerable because the C2 to C3 pedicle screw fixation technique is technically demanding and individual variations and injuries of these segment may add more risks. However, no study focusing on these anatomical variations and injuries and their impacts on C2 to C3 pedicle screw placement for unstable Hangman fractures in English literatures published until now.

In this report, we reviewed clinical data of 72 patients with unstable Hangman fractures in our hospital between May 2004 and December 2013, to evaluate the anatomical constraints that affected the placement of C2 to C3 screw and retrospectively reviewed our experience with management of these fractures.

2. Materials and methods
Clinical data were collected on 72 consecutive patients with unstable Hangman fractures (56 males and 16 females). The average age was 38 years (range, 17–73 years). The causes of injury were motor vehicle accidents (35 cases), falls (30 cases), and others (7 cases). Combined organ injuries included head injury (7 cases), multiple rib fractures (5 cases), subaxial cervical spine injuries (4 cases), thoracolumbar spine fractures (3 cases),
and fracture of the extremities (2 cases). Axial pain and restricted motion of the cervical spine were found in all cases. According to American Spinal Injury Association scale (ASIA), 3 cases were graded as ASIA C, 8 cases were D, and grade E for other cases. According to Levine–Edward Classification, 30 patients were types II, 15 Ila, and 7 III.[17] Forty-two of 72 injuries were atypical Hangman fractures as described by Starr and Eismont.[17] The patients with unsatisfactory imaging, or with congenital deformities (basilar impression, atlantooccipital fusion, C2 to C3 block vertebra, etc.), infection, tumor at the C1 to C3 level, were excluded from the study.

The C2 to C3 pedicle screw trajectories were specifically assessed, using 3-dimensional computed tomography (CT) scan, to identify the presence of any anatomical variations or injuries that would preclude safe screw placement in these segments. The C2 screw trajectory was considered to the way of screw placement through the pars interarticularis, the true pedicle, and the vertebral screw trajectory was considered the way of screw placement would preclude safe screw placement in these segments. The C2 screws placement, risk factors, such as small pedicle size, sclerotic pedicle, and pedicle fracture, were evaluated, and a small pedicle size was considered when the largest pedicle width was 4.0 mm or less.

In this study, the presence of anatomical variations and injuries at C2 to C3 was determined for each side in all patients. Two authors (GL and QW) evaluated images independently and reached a consensus on interpretation, and this procedure was repeated again 1 month later. This study was undertaken in West China Hospital of Sichuan University and Affiliated Hospital of Southwest Medical University, and it was approved by the Ethics Committees of both institutions.

3. Results

Fifty patients (50/72, 69.4%) with 200 (C2 and C3) pedicles fulfilled the safe criteria for C2 to C3 screw placement fixation, and 22 patients (22/72, 30.6%) with 39 risk factors were found not to fit for safe screw placement. For these cases, single-factor, double-factor, even multifactor of the risks were present in the C2 to C3 region, including narrow pedicle of C2 (7.6\%, 11/144), high-riding vertebral arteries (4.2\%), fractured fragments encasing into vertebral canal (2.1\%) or transverse process foramen (1.4\%) of C3, an unilateral congenital defect in pars interarticularis of C2 (0.7\%), and narrow pedicle of C3 (3.5\%), sclerotic pedicles (4.9\%), and pedicle fractures (2.8\%) of C3 (Table 1). The vast majority of cases (20/22) had anatomical variations and/or injuries which affected either C2 or C3 screw placement, respectively, whereas only 2 cases had a concurrent influence on both C2 and C3 screws placement (cases Nos. 6 and 7). Variety of anatomical variations and injuries affecting the safe screw placement at C2 to C3 were shown in Figs. 1–8 and Table 1.

| No. | A (11) | B (6) | C (23) | D (3) | E (2) | C2 (16) | F (5) | G (7) | H (4) |
|-----|--------|-------|--------|-------|-------|---------|-------|-------|-------|
| 1   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | Type  |
| 2   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 3   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 4   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 5   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 6   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 7   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 8   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 9   | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 10  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 11  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 12  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 13  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 14  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 15  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 16  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 17  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 18  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 19  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 20  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 21  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |
| 22  | Left   | Right | Left   | Right | Left  | Right  | Left  | Right | A2,3  |

*See Table 1 for abbreviations and explanations.*
Figure 1. Axial computed tomography showing narrowing of bilateral pars interarticularis of C2.

Figure 2. Three-dimensional computed tomography showing high-riding of vertebral artery in left side of C2 transverse process.

Figure 3. Axial computed tomography showing bony fragment encasing into right foramen of transverse process of C2.

Figure 4. Axial computed tomography scan showing bony fragment encasing into the right side of spinal canal of C2.
Figure 5. Three-dimensional computed tomography showing congenital defect in pars interarticular of C2 (right side).

Figure 6. Axial computed tomography showing narrowing of bilateral C3 pedicles.

Figure 7. Axial computed tomography showing sclerosis and small size of bilateral C3 pedicles.

Figure 8. Axial computed tomography showing fractures of bilateral C3 pedicles with a sclerosis pedicle in left side.
As shown in Table 1, there were 17 patients with 23 risk factors that affected C2 pedicle screw fixation, including 10 patients with 11 narrow pedicles (1 bilateral sides and 9 unilateral side), 6 patients with 6 high-riding vertebral arteries (all unilateral side), 2 patients with 2 fractured fragments encasing into transverse process foramen for more than 50% (both unilateral side), 3 patients with 3 fractured fragments encasing into vertebral canal (all unilateral side), and 1 patient with unilateral congenital defect in pars interarticularis among the 144 C2 pedicle screw insertion sites. There were 7 patients with 16 risk factors that affected C3 screw fixation, including 3 patients with 5 narrow pedicles (2 bilateral sides and 1 unilateral side), 4 patients with 7 sclerotic pedicles (3 bilateral sides and 1 unilateral side), and 2 patients with 4 pedicle fractures (both bilateral sides) among the 144 possible C3 pedicle screw insertion sites.

Eleven patients underwent anterior approach, including 10 cases with anterior cervical discectomy and fusion at C2 to C3 level, and 1 patient with anterior cervical corpectomy and fusion (C3 corpectomy and C2–4 fixation).

Eleven cases underwent posterior approach, including 1 case (case No. 19 with right C3 narrow pedicle but without significant disruption of the discoligamentous complex) using direct repair of the pars fracture with C2 lag screws; 4 cases with C2 to C3 pedicle screw fixation: case No. 8 with small pedicle size (3.8 mm) in right side of C2 using 3.5 mm (diameter) lag screws to completely reduce the anterior translation; case No. 14 with bilateral C3 pedicles fractures using lag screws in this level; case No. 17 with fractures of bilateral C3 pedicles and a sclerosis C3 pedicle in left side and using lag screws in right C3 pedicle and targeting drill with bur and then inserting C3 pedicle screw for the left C3 pedicle; and case No. 21 with severe discoligamentous instability and bilateral sclerotic pedicles of C3 using targeting drill with bur and then inserting C3 pedicle screw. Five cases were treated with C1 screw and C3 screw fixation (case No. 3 with short neck and obesity, cases Nos. 10 and 13 with high-riding vertebral arteries, case No. 15 with a high-riding of vertebral artery in left side of C2 transverse process, and case No. 22 with a high-riding of vertebral artery in left side and congenital defect in pars interarticularis in right side of C2). One case (case No. 20 with bilateral narrow and sclerotic pedicles of C3) was treated with C2 screw and C4 screw fixation.

Two cases with posterior approach experienced severe bleeding when the C2 screw placement was prepared intraoperatively on 1 side, and the screws were placed to tamponade bleeding. Postoperative CT scans demonstrated 2 screws with lateral cortical breaches in C2 and 1 screw with lateral cortical breaches in C3 in the 11 cases with posterior approach, all without significant clinical consequences.

The mean follow-up time was 22 months (range, 6–36 months). No patient complained severe neck pain at final follow-up. After operation, all patients were relieved from preoperative pain. For the 11 patients with neurologic deficits, neurologic status improved from C to E in 1 case, from D to E in 8 cases, and from C to D in 2 cases, and no changes for other cases with grade E preoperatively. Imaging evaluation confirmed fusion and healing of fractures well at the final follow-up.

4. Discussion

In previous literature, the incidence of C2 pedicle screw placement with injuries of neurologic and vascular structures was between 11% and 66%.10,15,16,23,24] And when transpedicled screw fixation was used for Hangman fractures, a higher rate of intraoperative neurologic or vascular injury might be expected, taking into account of risk factors caused by these lesions, which would make C2 screw fixation more difficult and complex. Thus, for unstable Hangman fractures, more factors could inevitably affect the C2 to C3 pedicle screw fixation and pose more risks to critical structures. To the best of our knowledge, no reports have been published until now to specially analyze anatomical variations and injuries of C2 to C3 region in unstable Hangman fractures and assess their subsequent impact on the pedicle screw placement.

In the present study, 69.4% patients with both C2 and C3 pedicles fulfilled the safe criteria for C2 to C3 pedicle screw fixation. For these patients, various surgery procedures are available, such as an anterior surgery, posterior surgery, and both anterior and posterior approach, depending on the surgeon familiarity and preference. In our experience, we preferred C2 to C3 pedicle screw fixation technique for these patients. However, 30.6% patients were affected to some degree with C2 or C3 pedicle screw fixation, which meant there was a high incidence of anatomical variations and injuries in C2 to C3 region in patients with unstable Hangman fractures. In this situation, choosing an individual screw placement and individual strategy based on a thorough evaluation of these conditions is very important for such patients with minimal complication.

Our study has some limitations that should be mentioned. First, in addition to factors the present study focused on, other risk factors, including comminution and/or rotation of bony fragments of C2, interlocking of posterior facets of C2 to C3, asymmetrical fracture lines, also affect the C2 to C3 pedicle screw fixation and pose risks to the procedure, sometimes even with disastrous consequences. That is to say, variety of anatomical variations and injuries needed to be further investigated to avoid and decrease the operation risks in the C2 to C3 pedicle screw technique. Second, the present study is a retrospective, small sample size, and nonmulticenter 1. We expect prospective, large sample size, and multicenter studies to be conducted to investigate more risk factors and optimize the C2 to C3 pedicle screw fixation technique.

5. Conclusion

There is a high incidence of anatomical variations and injuries in the C2 to C3 region in patients with unstable Hangman fractures that preclude the safe placement of pedicle screw, and it requires considerable care and caution to assess the anatomical variations and injuries preoperatively. For the surgical management of unstable Hangman fractures, individualized treatment plans should be made based on preoperative radiographic findings to minimize the risks of surgery.

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