# Motion Preserving Surgery Using O-Arm for Unstable Hangman Fracture

Satish Kumar Verma[1] Pankaj Kumar Singh[1] Dattaraj Parmanand Sawarkar[1] Amandeep Kumar[1]
Deepak Agarwal[1] P. Sarat Chandra[1] Shashank Sharad Kale[1]

[1]Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi, India

**Address for correspondence** Pankaj Kumar Singh, MCh, Department of Neurosurgery, All India Institute of Medical Sciences, New Delhi 110029, India (e-mail: drpankajsingh11@gmail.com).

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## Abstract

**Aim** To evaluate clinical outcomes, radiological findings (displacement and angulation), and bony fusion in cases of unstable hangman's fracture.

**Introduction** Hangman fracture, also known as traumatic spondylolisthesis of axis vertebra, is classically defined as bilateral pars interarticularis fracture of axis vertebra. Opinions vary regarding optimal treatment of unstable hangman's fractures. Some authors have recommended use of rigid orthosis, whereas others have recommended internal fixation. The peculiar anatomy of the upper cervical spine is highly variable, and presence of surrounding neurovascular structures makes axis pedicle screw fixation even more technically challenging. The advent of intraoperative three-dimensional navigation systems facilitates safe and accurate instrumentation.

**Materials and Methods** This article analyzes patients operated for type II and IIa hangman's fractures during the period from September 2011 to August 2018 by two neurosurgeons. The patients' age, sex, mechanism of injury, associated injuries, and neurologic status were noted. The authors retrospectively assessed the clinical outcome, radiological findings (displacement and angulation), and bony fusion.

**Result** Eighteen patients with age ranging from 17 to 81 years, were operated using computed tomography-based (O-arm) navigation. Accuracy of screw insertion, preoperative and postoperative displacement, and angulation of C2 over C3 were evaluated. Bony fusion was assessed in all patients. A total of 92 screws were inserted: 36 screws in C2 pedicle, 34 in C3 lateral mass, 20 in C4 lateral mass, and 2 in C5 lateral mass. Of these 92 screws, 36 C2 pedicle screws were inserted under O-arm guidance. The mean preoperative C2–C3 displacement was 4.5 ± 2.1 mm, and the mean postoperative displacement was 1.8 ± 1.1 mm with a mean reduction of 2.7 ± 1.4 mm. The mean preoperative C2–C3 angulation was 10.2 ± 7.6 degrees and the postoperative angulation was 2.52 ± 4.62 degrees with a mean reduction of 8.2 ± 11.6 degrees. Screw malplacement was seen in two C2 pedicle screws (2/36, 5.5%). All C2 pedicle screw breaches were of grade 2. Excellent anatomical reduction in all cases could be achieved as established by the improvement in morphological parameters of fracture.

**Conclusion** This series using O-arm in unstable hangman fracture demonstrates that intraoperative O-arm-based navigation is a safe, accurate, and effective tool for screw placement in patients with unstable hangman fracture.

**Keywords**
- axis vertebra
- hangman fracture
- instrumentation
- intraoperative navigation
- pedicle screw

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## Introduction

Traumatic spondylolisthesis of the second cervical vertebra is considered as hangman's fracture and it is accompanied by variable disruption of C2–C3 intervertebral disc, ligamentous complex resulting in a spectrum of deformity in the cervical spine. It contributes nearly 4 to 7% of all cervical spine fractures.[1,2] Hangman's fracture involves complex biomechanics due to cervical hyperextension with axial loading which forces the skull, atlas vertebra, and the body of C2 moving as one unit, while the posterior elements of C2 along with the posterior elements of third cervical vertebra moving as another unit.[3] The opinions regarding management of unstable hangman's fracture are divided. Occipito cervical fusion is usually performed with attendant loss of motion.[4] C1–C2 fixation may also be performed but also results in loss of significant mobility at the C1–C2 joint.[5] Reconstitution of the C2 pedicle with C2 pedicle screws with additional fixation of C3 is the most direct method to reduce and fix these fractures. Putting C2 pedicle screws especially in this setting is a challenge and three-dimensional (3D) computed tomography (CT)-based intraoperative navigation (O-arm) provides precise information for accurate screw placement.

## Material and Methods

In the present study, we included 18 patients who were operated by two surgeons where C2 pedicle screw insertion with variable extent of subaxial cervical lateral mass fixation was performed from September 2011 to August 2018. Patients' demographic profile, mechanism of injury, associated injuries, preoperative and postoperative neurologic status, radiological parameters of fracture morphology, intraoperative events, postoperative complications, bony fusion, and any progressive cervical spine deformity were assessed. Preoperative and postoperative neurologic assessments were done by the operating surgeon and each patient was assigned American Spine Injury Association (ASIA) score. Preoperative and postoperative C2–C3 displacement and angulation were measured using the picture archiving and communication system (Centricity, GE Healthcare).

Radiological diagnosis was done with 3D CT scans and fracture morphology was assessed to measure two morphological parameters—C2–C3 displacement and C2–C3 angulation in all cases. C2–C3 displacement was measured as the distance between parallel lines drawn through the midpoints of C2 and C3 at the level of the intervertebral disc in the mid-sagittal section. C2–C3 angulation was defined as the angle formed by lines drawn along the inferior endplate of C2 and the inferior endplate of C3.

Magnetic resonance imaging (MRI) was performed in all patients to assess the integrity of intervertebral discs, ligamentous complex, extradural thecal sac compression, spinal cord signal changes/contusions, etc. Any intrinsic spinal cord injury detected on MRI is particularly important for prognosticating neurologic recovery after the surgery.

Surgical procedure involved two essential aspects—(1) placement of C2 pedicle screws and C3 lateral mass screws on both the sides and (2) exclusion of C1 from the construct. Additional involvement of lower cervical vertebrae in the implants construct was done in cases with prominent C2–C3 angulation resulting in subaxial cervical kyphosis.

ASIA scores were reassessed by the operating surgeon in the immediate postoperative period to check for any new neurologic deficits. Postoperative CT scan was obtained in follow-up before the patient is discharged. Postoperative scans were assessed for (1) accuracy of screw placement, (2) reduction of the fracture displacement, (3) C2–C3 angulation, and (4) C2–C3 displacement. Accuracy of the screw insertion was assessed on 3D CT scan images and were categorized as per modified classification of Gertzbein and Robbins: grade 1 (screw completely within the pedicle), grade 2 (< 50% of the screw diameter outside the pedicle), and grade 3 (> 50% of the screw diameter outside the pedicle). The criteria used for the successful fusion included formation of callus across the fracture. All patients were followed up clinically and radiologically in the postoperative period at regular intervals on outpatient basis or telephonically.

## Surgical Procedure

Informed and written consent for the surgical procedure was taken. All patients were operated in prone position on Allen spine table (Allen Medical Systems, A Hill-Rom Company). Skull traction was applied after induction of the patient 1 cm anterior to the tragus just below the superior temporal line and a weight of 3 to 4 kg was used for traction. Iliac crest was prepared in all cases. O-arm intraoperative imaging system (Medtronic, Inc.) with intraoperative CT scan and 3D navigation system was used in all the patients. Vertical midline incision from C1 to C5 spinous process was made, keeping in mind not to expose the facet capsules of the levels not planned for fusion. A dynamic reference array was applied on the C1 posterior arch, and an intraoperative CT scan using O-arm with center at C2 level was performed. The gantry of O-arm rotates by 360 degrees, and the scanning and transfer of the images takes only few seconds. The fracture site was defined by dissecting around the upper border of the C2 pedicle. After registration with the help of 3D navigation, the entry point and trajectory of C2 pedicle screws on both sides were defined. Kirschner wire (K-wire) was then gradually drilled under guidance. When the K-wire tip reached the fracture site, an intraoperative CT scan was repeated to confirm the position and the direction of K-wire, and once the correct position was confirmed, the C2 lamina was compressed, the K-wire was advanced, and its position was confirmed again with CT scan. The pedicle was then tapped on both the sides, and before inserting the pedicle screws on both sides, C2 lamina was compressed anteriorly so that there was no or minimal space between the two fractured fragments and the C2 pedicle screws were then inserted. After this, lateral mass screws were inserted in C3 and/or C4 and/or C5, depending upon the severity of the disco-ligamentous injury, listhesis, lateral mass fracture, and the need to correct the angulation. C5 lateral mass was only used when there was fracture of C4. After screw placement, rods were inserted on both sides, the skull traction weight removed, and the screws were tightened completing the screw-rod construct. Bone graft harvested from iliac crest was placed after decortication. Patients were advised to wear hard cervical collar for 12 weeks postoperatively.

## Results

In total, 18 patients with unstable hangman's fracture (Levine and Edwards classification) underwent posterior cervical fixation where C2 pedicle screws were inserted as a part of implant construct. C1 vertebra (atlas) was excluded in all the cases. There were 16 male and 2 female patients (►**Table 1**). Sixteen patients presented early after injury, whereas two patients presented after a long period after injury with persisting neck pain after trauma. Road traffic accident was the most common mode of injury and was the cause in 11, followed by fall from height in 6 patients, and fall of heavy object on the neck in 1 patient. Associated vertebral fractures were seen in eight patients, five of these patients had an associated C1 fracture only, two patients had associated C1 arch and C3 lamina fracture, and one patient had an associated C6–C7 anterolisthesis. Associated right upper trunk brachial plexus injury was present in one patient. The patient underwent spinal accessory to suprascapular neurotization and Oberlin's transfer (ulnar nerve fascicle to musculocutaneous nerve) after few months of the spine surgery.

All the patients complained of neck pain with restriction of neck movement. Thirteen patients were ASIA E. The other five patients had neurologic deficits: of these, one patient was ASIA A, two patients were ASIA B, and one patient each were ASIA C and ASIA D. Injury to the C2–C3 disc along with disco-ligamentous complex injury was seen on MRI in all the patients. All patients were operated as soon as possible, once they presented to our center. One patient had preoperative respiratory arrest but was resuscitated immediately and was operated after hemodynamic stabilization. Intraoperative period was uneventful in all the patients.

A total of 92 screws were inserted: 36 screws in C2 pedicle, 34 in C3 lateral mass, 20 in C4 lateral mass, and 2 in C5 lateral mass. Of these 92 screws, 36 C2 pedicle screws were inserted under O-arm guidance. The mean preoperative C2–C3 displacement was 4.5 ± 2.1 mm, and the mean postoperative displacement was 1.8 ± 1.1 mm with a mean reduction of 2.7 ± 1.4 mm. The mean preoperative C2–C3 angulation was 10.2 ± 7.6 degrees and the postoperative angulation was 2.52 ± 4.62 degrees with a mean reduction of 8.2 ± 11.6 degrees. Screw malplacement was seen in two C2 pedicle screws (2/36, 5.5%). All C2 pedicle screw breaches were grade 2.

One patient with associated with C6–C7 anterolisthesis underwent C6 corpectomy and iliac bone tricortical graft placement with anterior cervical plate. In the postoperative period, there was no new-onset neurologic deficit in any of the patients. All patients who had preoperative neurologic deficits (5/18) improved after surgery. The patient with ASIA A improved to ASIA D. Of the two patients with ASIA B, one improved to ASIA C and the other one to ASIA D. Two patients with ASIA C and D improved to ASIA E. Postoperative CT scan revealed good reduction in 17 cases and satisfactory reduction in 1 case.

The mean follow-up period was 41.5 + 16.8 months. The average duration of hospital stay was 13.6 ± 2.8 days (►**Table 2**). Bony fusion was achieved in all cases after surgery, as demonstrated on CT scans done at 4 to 6 months' follow-up. Rotation was preserved at C1–C2 joint in all cases as C1 was excluded in all of them. No complications related to the implant construct were noted.

One case operated (patient number 4, ►**Table 1**) in this series is presented for illustration.

This patient sustained injury to the neck due to fall of object on his neck. He came to us few days after injury with ASIA score B. MRI revealed cord signal change at C2 with anterolisthesis and retroangulation of C2 body (►**Fig. 1**). His CT scan revealed type II hangman's fracture with 3-point fracture of C1 ring, anteriorly on the left side (►**Fig. 2A**) and bilateral posteriorly (►**Fig. 2B**). He was operated under intraoperative CT guidance (O-arm), bilateral K-wires were put in C2 pedicles under image guidance, CT scan was done to confirm trajectory (►**Fig. 3A**, **B**), and tapping was done. After tapping, bilateral pedicle screws were put. Lateral mass screws were put in both C3 and C4. As retrolisthesis is not corrected by traction, slight distraction was done between C2 and C3 after putting rods on both sides. Patient improved to ASIA C and follow-up CT revealed good healing of fractures of both C1 (►**Fig. 4A**, **B**) and C2.

## Discussion

Schneider et al[6] in 1965 coined the term hangman's fracture due to its similarity to the fracture described in the autopsy report of a judicial hanging by Wood Jones and is the most frequent upper cervical fracture after the fracture of odontoid process of C2. To standardize the management of hangman's fractures, Levine and Edwards proposed a classification system modifying the one described by Effendi et al.[7,8] Presently, there is no consensus on the best management of hangman's fracture and it remains controversial. It includes both nonoperative and operative protocols.[9-11]

Type I fractures are considered as stable and are usually managed nonsurgically with cervical hard collar immobilization/rigid orthosis/prolonged traction for 8 to 14 weeks. There are higher rates of pseudoarthrosis that may cause persistent cervical pain, anterior dislocation, kyphosis, and pin-related problems, such as skull fracture, scalp hematoma, and pin site infection.

Fusion rates after conservative management have been reported to be 60% in type II, 45% in type IIA, and 35% in type III.[12] In regions with hot and humid climate, as in tropical countries, halo immobilization and prolonged traction are not tolerated well by patients. In many cases, hangman fracture is associated with other injuries, which may conflict with rigid immobilization. Considering the disco-ligamentous injury, the dislocation and angulations of fracture, the desire to shorten recovery, and the high nonunion rates, many authors prefer surgery for unstable hangman fracture.[12-18] We

**Table 1** Clinical, radiological, neurologic, operative, and follow-up details of the patients included in this series

| Serial no. | Age/Sex | Mode of injury | CT findings | Displacement (mm), angulation (degrees) preoperative | Displacement (mm), Angulation (degrees) postoperative | Breach | ASIA (preop) | ASIA (post-op) | Procedure done | Operative time (min) | Intraoperative blood loss (mL) | Follow-up duration | Follow-up CT fusion |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 25/M | RTA | II | 6 mm, 11.5 | 2.64 mm,–5 | No | E | E | C2 P, C3–4 LMS | 435 | 600 | 42 | Yes |
| 2 | 60/M | FFH | II | 6.3 mm, 20 | 4.57 mm,14 | No | E | E | C2 P, C3 LMS | 195 | 300 | 50 | Yes |
| 3 | 17/M | RTA | II | 3.5 mm, 7 | 1 mm, 3 | Rt C2P, grade 2 medial | E | E | C2 P, C3 P | 260 | 300 | 55 | Yes |
| 4 | 50/M | Others | II | 3.5 mm,–30 | 2.6 mm, 3 | No | B | C | C2 P, C3–4 LMS | 315 | 400 | 21 | Yes |
| 5 | 81/M | FFH | II | 4.1 mm, 13 | 1 mm, 3 | No | E | E | C2 P, C3–4 LMS | 300 | 250 | 36 | Yes |
| 6 | 22/M | RTA | II | 3.2 mm, 6 | 0 mm, 2 | No | E | E | C2 P, C3–4 LMS | 360 | 1,500 | 48 | Yes |
| 7 | 36/M | RTA | IIa | 2 mm, 13 | 2 mm,3.5 | No | E | E | C2 P, C3–4 LMS | 280 | 400 | 49 | Yes |
| 8 | 22/M | RTA | IIa | 2.8 mm, 12 | 2 mm, 4.0 | No | D | E | C2 P, C3 LMS + C6 corpectomy, iliac bone tricortical graft, and plating | 225 + 150 | 600 | 58 | Yes |
| 9 | 25/F | RTA | IIa | 2.9 mm, 24 | 2 mm, 3.5 | No | A | D | C2 P, C3–4 LMS | 345 | 400 | 56 | Yes |
| 10 | 28/M | RTA | II | 9 mm, 3 | 3 mm,–8.5 | No | E | E | C2P, C3 LMS | 225 | 300 | 36 | Yes |
| 11 | 19/M | RTA | II | 4.6 mm, 6 | 2 mm, 2.5 | No | E | E | C2 P, C3 LMS | 195 | 300 | 80 | Yes |
| 12 | 32/M | FFH | II | 3 mm, 10 | 1 mm, 3.8 | No | E | E | C2 P | 180 | 500 | 62 | Yes |
| 13 | 36/F | FFH | II | 3.5 mm, 2 | 0.5 mm, 1 | Rt C2P, grade 1 medial | E | E | C2P,C3–4 LMS | 240 | 500 | 24 | Yes |
| 14 | 25/M | FFH | II | 4 mm, 7 | 1 mm, 3 | No | E | E | C2P, C3 LMS | 195 | 250 | 32 | Yes |
| 15 | 37/M | FFH | II | 3 mm, 4 | 2 mm, 2 | No | C | E | C2P,C3–4-5 LMS | 360 | 1000 | 31 | Yes |
| 16 | 28/M | RTA | II | 4 mm, 5 | 2 mm, 3 | No | E | E | C2P, C3LMS | 255 | 350 | 18 | Yes |
| 17 | 31/M | RTA | II | 9 mm, 6 | 2 mm, 3 | No | E | E | C2, 3, 4P | 260 | 400 | 14 | Yes |
| 18 | 42/M | RTA | II | 6 mm, 5 | 2.5 mm, 2 | No | E | E | C2P-3–4 LMS | 310 | 400 | 11 | Yes |

Abbreviations: ASIA, American Spine Injury Association; CT, computed tomography; F, female; FFH, fall from height; LMS, lateral mass screw; M, male; RTA, road traffic accident.

operated on all type II, IIA, and III fractures directly with no trial of conservative treatment.

Type II, IIA, and III fractures are classified as unstable. Treatment goal in unstable hangman fracture is to achieve anatomical reduction, maintain alignment, and maintain the patients' ability to live an active life without pain or disability and these objectives can be achieved by internal fixation. In these cases having significant displacement/angulation and instability, surgical reduction and stabilization by screw-rod constructs are performed, usually by posterior fusion of the upper cervical vertebrae or anterior fusion of C2–C3. There are many surgical stabilization techniques described in the literature through the anterior, posterior, and combined anteroposterior (360-degree fixation) approaches.[16,19-21]

Several anterior approaches, such as the classical anterior cervical discectomy and fusion, and transoral or extraoral approaches were applied with C2–C3 discectomy and segmental fixation with bony fusion. Anterior cervical discectomy and fusion addresses C2–C3 disc herniation and C2–C3 stabilization.[17,19,20] This approach may be suitable for hangman's fractures with intervertebral disc injury with posterior disc herniation and subsequent spinal cord compression or spinal instability. Anterior approach, however, does not address the posterior fractured part of the C2. In addition, it may have the disadvantages of approach-related problems; a high anterior approach risks injury to vital structures,

**Table 2** Details of included patients and perioperative parameters

| Serial no. | Characteristic | Value |
|---|---|---|
| 1 | Mean age (y) | 34.3 ± 16.8 |
| 2 | Sex ratio (female/male) | 1:8 |
| 3 | Fracture type | |
| | II | 15 |
| | IIa | 03 |
| | III | Nil |
| 4 | Mean operative time (min) | 280.7 ± 70.4 |
| 5 | Mean operative blood loss (mL) | 488.1 ± 309 |
| 6 | Mean hospitalization (d) | 13.6 ± 2.8 |
| 7 | Mean follow-up period (mo) | 41.5 + 16.8 |

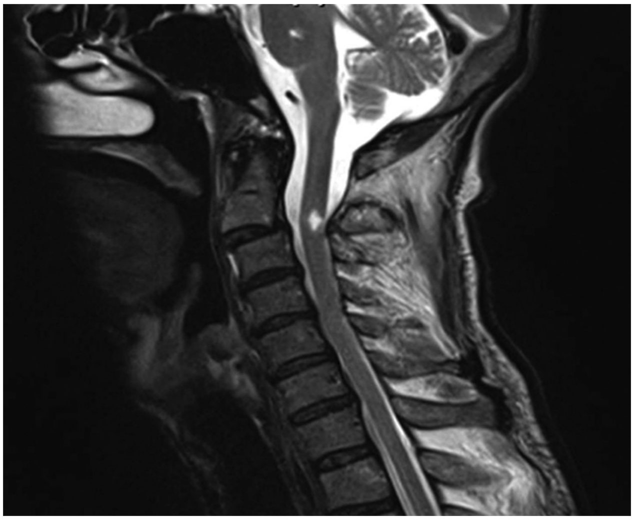

**Fig. 1** Magnetic resonance imaging of the illustrative case showing cord signal change at C2–C3 disc space level with anterolisthesis and retroangulation of C2 body.

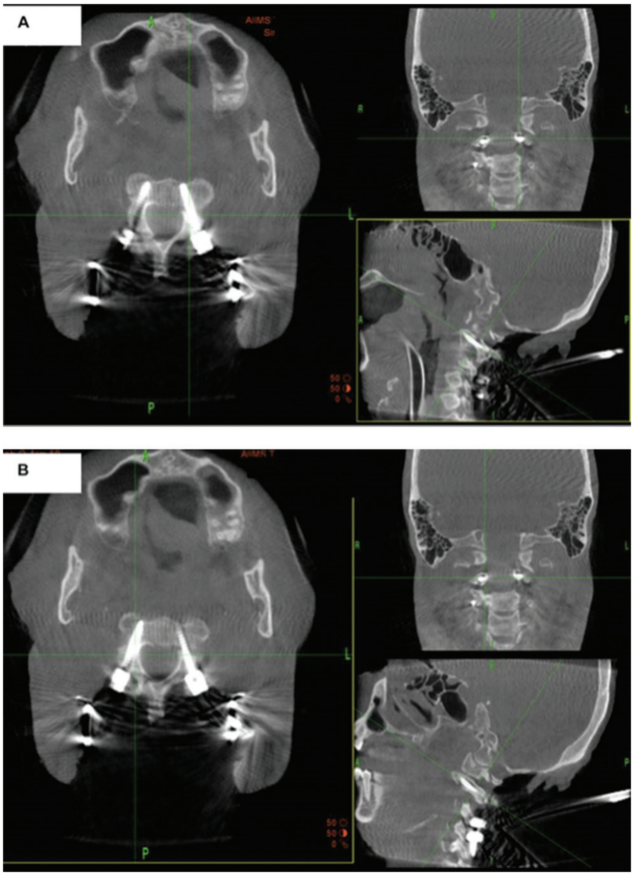

**Fig. 3** Intraoperative computed tomography scans show (**A**) right-sided C2 pedicle screw in the axial, coronal, and sagittal planes, and (**B**) left-sided C2 pedicle screw in the axial, coronal, and sagittal planes.

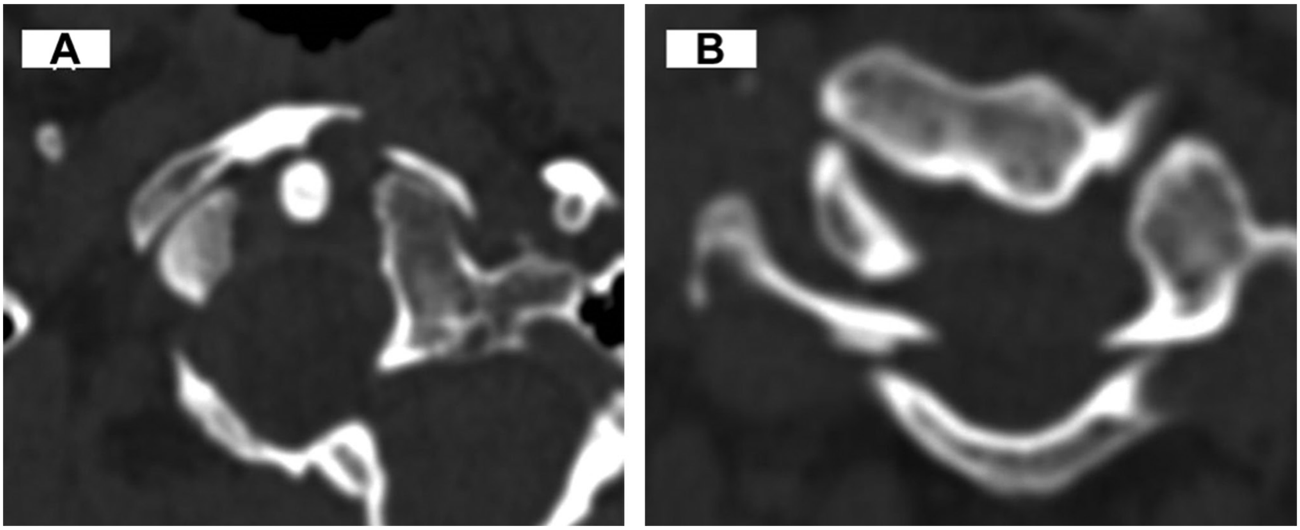

**Fig. 2** Preoperative computed tomography scan show (**A**) 3-point fracture of C1 ring, anteriorly on the left side and (**B**) bilateral posteriorly and fracture of bilateral C2 pars.

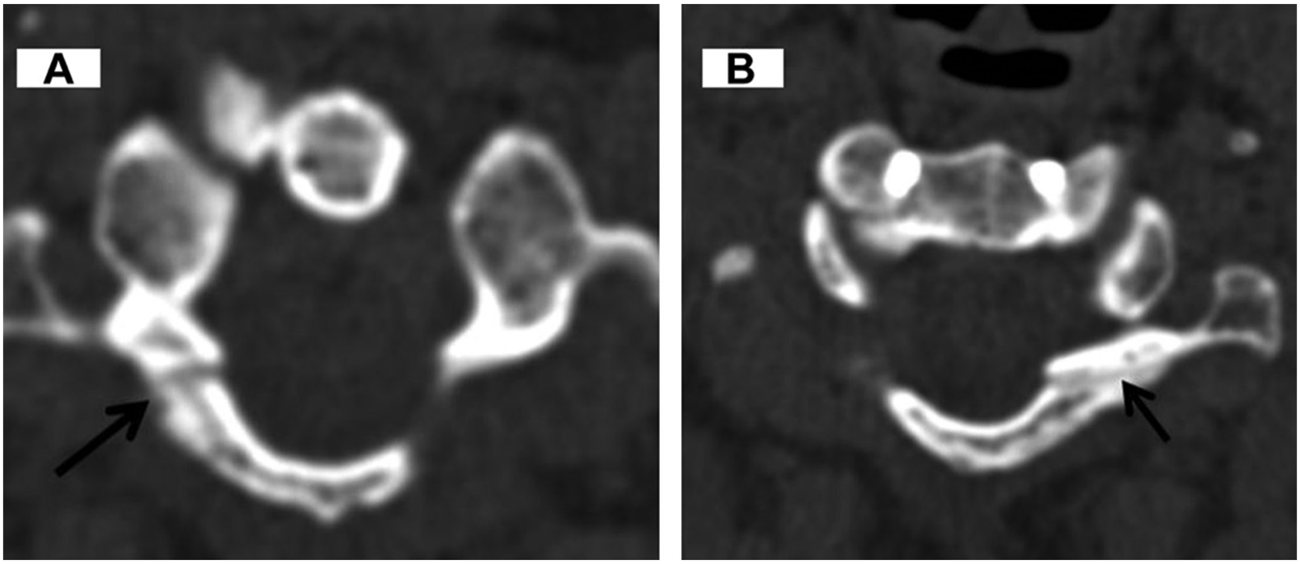

**Fig. 4** Follow-up computed tomography scan revealed good healing (arrows) of fractures of both (**A**) C1 and (**B**) C2.

specially the facial and hypoglossal nerves, branches of the external carotid artery, contents of the carotid sheath, and the superior laryngeal nerve.

Posterior surgery was previously performed using C1–C3 wire fixation, this technique requires adjunctive postoperative halo-vest immobilization. But this procedure has several drawbacks. It carries the risk of intraoperative complications involved in placing sublaminar wires like dural tears, cord injury, and neurologic deficits. It also restricts motion at the atlanto-axial joint.[22] Also, it carries the complications associated with halo-vest immobilization as mentioned earlier.

Direct osteosynthesis by putting pars screws, bridging the fracture line was described by Leconte[23] and Bristol et al[24] with the advantage of retaining motion at the atlanto-axial joint. However, this approach does not take care of the C2–C3 disc disruption,[13,25] and this may result in repeated dislocations at the fracture site.[26,27] It also fails to correct displacement, kyphosis, and loss of disc height.[25]

Several studies reported C2 pars/pedicle screw fixation combined with C3 lateral mass screw fixation, or C1 lateral mass screws combined with C-3 lateral mass screw fixation.[28] Involvement of C1 in the implants construct is not justified as the pathology lies at the level of C2–C3 disc, ligaments, and C2 pars interarticularis and it should be avoided as it will cause loss of rotation at the C1–C2 joint.

Authors highlight the importance and versatility of the C2–C3 posterior fixation using the C2 pedicle along with variable extent of subaxial lateral mass screw fixation. This type of fixation provides the maximum biomechanical strength as it is known that pedicle screws engage all the three spinal columns and thus have maximum pull-out strength among any possible screw in a particular vertebra. In the biomechanical study by Duggal et al,[12] posterior C2–C3 screw technique was more effective in the stabilization of the hangman fracture than anterior cervical plating and C2 pars screw placement. Posterior treatment is more effective because the construct acts as a tension band against flexion, lateral bending, and axial rotation.[12,29] Compared with the anterior approach, this approach results in better stabilization with multilevel fixation in unstable hangman's fractures involving associated cervical fractures. It provides a stabilizing 3-column spinal fixation.[16,29] It also avoids the need for external orthosis such as a halo-vest. The fracture deformity objectively assessed by the morphological parameters of C2–C3 displacement and angulation was also corrected, restoring the normal anatomical relations. Any kyphotic deformity due to fracture at subaxial levels is also corrected by this construct. Good anatomical reduction along with rigid construct resulted in solid bony fusion after few months of surgery in all patients.

Putting a screw in the pedicle of axis is particularly challenging in view of its complex anatomical relations with the vertebral artery with accompanying paravertebral venous plexus, C2 nerve root, and thecal sac. Conventional techniques described in the literature are performed under biplanar fluoroscopy and they are based on the external anatomic landmarks to guide screw insertion but the rate of screw malplacements are high. Yukawa et al[30] reported a grade 2 and grade 3 screw malplacement rate of 13.1% in 620 cervical pedicle screw fixations using a fluoroscopy-assisted technique, whereas the malplacement rate in C2 and C3 was even higher (21.6%).

With the use of continuous fluoroscopy with a two-dimensional (2D) view, potential for screw malplacement of C2 is still present even in the experienced hands.[16] CT-based navigation may be very useful in avoiding these malplacements and consequent neurovascular violations. CT-based navigation provide real-time navigation with the option of planning the most appropriate screw trajectory based on intraoperative CT-based registration of the exposed bony landmarks. Also, it provides the option of intraoperative CT after inserting the K-wires and correcting any significant breach/malplacements in the same surgery. Richter et al[31] reported excellent results of cervical screw placement using CT-based navigation in a cadaveric study. Tian et al[32] showed good accuracy with grade 2 misplacement of 7.84% and no grade 3 misplacement with intraoperative 3D fluoroscopy-based navigation; however, this was a C-arm-based study, with a rotation of 190 degrees as compared with our study in which we have used O-arm (360-degree rotation). Ito et al[33] reported a misplacement rate of no more than 2 mm in 2.8% of 176 cervical pedicle screws using Iso-C 3D navigation. In our cases, there were only two grade 2 misplacements (5.5%) of C2 pedicle screw. In one of these cases, there was some technical issue with navigation during surgery after the placement of pedicle screw on one side. In other case, complete alignment was not achieved in intraoperative period.

Intraoperative 3D navigation offers several advantages.[34] With this technique, motion artifacts are avoided as the images are obtained within the operative room under general anesthesia, with the patient in the desired position. This is especially important in unstable fractures where preoperative CT scanning may not reflect the actual intraoperative anatomical relationships. The registration is automatic and avoids the inaccuracies inherent to the manual registration, which uses paired-points or surface-matching algorithm. Also, all the scanned vertebral levels are autoregistered and there is no need to re-register at each vertebral level individually. It offers superior quality higher-resolution intraoperative 3D images than those of other intraoperative 3D fluoroscopy systems. The 3D images obtained using the O-arm have nearly the same quality as those of recent multidetector helical CT scans. Also, the option of movements allows 2D fluoroscopy views and multiplanar 3D images in any direction (anteroposterior, lateral, and oblique) without much effort.

Preoperatively, once the O-arm is draped in a sterile plastic drape, all moving parts in the gantry are enclosed, and this system can easily obtain 2D and 3D images as often as required, while keeping the surgical field sterile. In this regard, the O-arm has an advantage over existing 3D fluoroscopy, which obtains 3D images by movement of the C-arm throughout the 190-degree scan over a surgical site. The preparation time for O-arm-based navigation is shorter than that for existing 3D fluoroscopy-based navigation systems.[34] The per capita cost, of using O-arm navigation does not change as compared with other methods of spinal navigation. Nevertheless, the initial cost of the O-arm is much higher.

In the present series of 18 cases of type II and IIA hangman's fracture, two neurosurgeons have operated on all the cases. C2 pedicle and C3 lateral mass screw fixation and sometimes C2 pedicle and C3–C4 and rarely C5 lateral mass screw fixation were used. C5 lateral mass screws were inserted when C4 lateral mass was fractured. This technique comprehensively addresses the detached posterior arch of C2 by reducing the fractured pedicles or pars and also stabilizes the disco-ligamentous injury of C2 relative to C3.[14] A rigid orthosis is also avoided after surgery, and rotation at C1–C2 is fully preserved. C1–C2 rotation preservation is the main advantage of this procedure. The strength of CT navigation for C2 pedicle screw placement in this setting is that it allows for safe osteosynthesis of the C2 fracture and avoidance of fusion of the C1–C2 articulation, which significantly impacts patients' postoperative neck rotation and quality of life.

The present series has few limitations. It is a small-sized retrospective study. Also, there is no control group for comparison, such as patients undergoing an anterior cervical discectomy and fusion or traditional free-hand technique of posterior polyaxial cervical pedicle screw placement. Another limitation is that the patients were exposed to significant amount of radiation over a short time period, with each patient undergoing CT four times from diagnosis to follow-up.

## Conclusion

Hangman fracture is bilateral pars interarticularis fracture of axis and involves significant impact. Posterior cervical fixation including C2 pedicle screws in the construct is very efficient in reducing the fracture/dislocation. Pedicle screw insertion in C2 is challenging due to the presence of surrounding neurovascular structures but it can be put with precision under O-arm-guided navigation, and position of screws can be confirmed by intraoperative CT scan. Patients can be operated and mobilized early with preservation of motion at the C1–C2 joint. Excellent anatomical reduction in all cases could be achieved as established by the improvement in morphological parameters of fracture. This series using O-arm in unstable hangman fracture demonstrates that intraoperative O-arm-based navigation is a safe, accurate, and effective tool for screw placement in patients with unstable hangman fracture.

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**Conflicts of Interest**
None.

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