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Upper Cervical Spine Injuries — A Secondary Publication

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Abstract: *Objectives:* Based on anatomical knowledge of the upper cervical spine, it is necessary to be familiar with the classification, diagnosis, and treatment strategies currently used clinically for upper cervical spine injuries. *Summary of literature review:* Upper cervical spine injuries are major injuries with potentially fatal consequences. The occipitocervical junction, which is composed of several structures, protects the brain and cranial nerves. We need to know the mechanism of each type of damage, and in particular, we must understand the anatomy of the occiput, atlas, and axis, as well as the definitions of landmarks of the positional relationships among all structures. *Materials and methods:* This study reviewed the latest literature on upper cervical spine injuries. *Results:* In occipital condyle fractures and atlanto-occipital injuries, we should understand how to evaluate instability and the treatment methods according to each classification. In atlas injuries, it should be evaluated whether the transverse atlantal ligament has been damaged. In axis fractures, it is necessary to understand the surgical method according to the shape of the odontoid fracture. *Conclusions:* Knowledge of soft tissue and bony structural relationships in the upper cervical spine is required for the diagnosis and treatment plan of upper cervical injuries.

Keywords: Upper cervical spine injury; Occipitocervical junction; Atlas; Axis; Odontoid

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1. Introduction

The occipitocervical junction is a complex structure between the skull and the upper cervical spine. It provides stability during complex movements at the occipitocervical junction. It protects the brain stem and cranial nerves and provides a stable cerebrovascular blood supply. It consists of the atlantooccipital joint, the atlantoaxial joint, and several intrinsic and extrinsic ligaments. It has a large range of motion, but fewer supportive structures compared to other parts of the body, and damage to the upper and lower extremities can lead to devastating complications such as paralysis [1]. 25% of all injuries are associated with head injuries and 40% with nerve injuries. In high-energy trauma patients, injury to the occipitocervical junction should always be suspected. In addition, in elderly patients and those with narrow spinal canals, even mild hyperextension injury can cause spinal cord injury [2]. Therefore, for proper diagnosis and treatment, it is necessary to classify, diagnose, and clinically treat injuries based on the anatomical features of the upper cervical spine.

2. Diagnosis and assessment

2.1. Understanding the anatomical structures

The occiput and atlas perform rotational movements through several joints. These are shallow condyloid joints, providing some bony stability to the occipitocervical junction. The dens of the axis form a synovial joint with the posterior part of the anterior arch of the atlas. Laterally, a pair of synovial joints create the bony articulation of C1–C2. Intrinsic ligaments are structured from anterior to posterior as follows: the anterior atlantooccipital membrane, apical and alar ligaments, the superior band of the longitudinal ligament, and the tectorial membrane. Behind these structures are the dura mater, spinal cord, and posterior atlantooccipital membrane. The tectorial membrane is the cranial extension of the posterior longitudinal ligament, connecting the posterior part of the axis to the foramen magnum. The cruciate ligament connects the posterior surface of the dens to the anterior arch of the atlas via the transverse atlantal ligament, and the vertical fibers extend from the foramen magnum to the axis. The alar ligaments connect the dens of the axis to the occipital condyles. Extrinsic ligaments also contribute to the stability of the occipitocervical junction, including the nuchal ligament, anterior longitudinal ligament, and the elastic fibers of the ligamentum flavum [3].

The sagittal plane movement of the upper cervical spine mainly occurs through the occipitocervical joint (15–20°), while rotational movement primarily occurs through the atlantoaxial joint (50° on each side) [4].

2.2. Initial assessment and diagnosis

Damage to the occipitocervical junction and subsequent structural instability can have devastating consequences, therefore, high-energy injuries should be assessed for instability. In addition, the initial examination for motor, sensory, and type of injury should be performed to determine the severity of neurological injury, and the American Spinal Injury Association's guidelines (ASIA) and the Advanced Trauma Life Support guidelines (ATLS) should be used to assess the severity of neurological injury and prognosis.

Despite the increased diagnostic sensitivity due to cervical spine CT, a single cross-table lateral radiograph remains the first radiographic examination to be performed. The evaluation involves assessing the basion, opisthion, occipital condyles, odontoid process, atlas, and axis for fractures and structural relationships, as well as evaluating changes in and consistency of the atlantooccipital and atlantoaxial joints [5]. In patients suspected of having severe ligament injuries, a supine radiograph taken immediately after the injury might result in false negatives due to gravity and muscle contraction. It is also necessary to assess for prevertebral soft tissue swelling. This can also be evaluated through a simple lateral radiograph, with normal ranges being considered as less than 10 mm at the nasopharyngeal space at C1, less than 5 mm at the retropharyngeal space at C3, and less than 22 mm at the retropharyngeal space at C6 (less than 14 mm in children) [6]. However, simple radiographic imaging alone may be limited in directly assessing the atlantooccipital and atlantoaxial joints. Therefore, for the alignment assessment of the occipitocervical junction, indirect evaluation can be performed through correlation assessment of the following anatomical indicators using CT as a reference. McRae's line is an imaginary line drawn from the anterior to the posterior point of the foramen magnum in the median sagittal plane of the skull. Normally, the odontoid process should be positioned less than 5 mm below this line. If it exceeds this line, basilar invagination can be diagnosed. McGregor's line is an imaginary line drawn from the posterior edge of the hard palate to the lowest point of the occipital bone's base curve. If the tip of the odontoid process invades this line by more than 4.5 mm, basilar invagination can be diagnosed [7]. The Wackenheim line is a downward line extending from the clivus to the upper cervical spine and should be located 1–2 mm from the tip of the odontoid process. If the odontoid process intersects the Wackenheim line, basilar invagination can be diagnosed. The atlanto-dens interval (ADI) is the distance from the anterior cortical bone of the odontoid process to the posterior cortical bone of the anterior arch of C1, with a normal range of within 3 mm. If it is 3–5 mm, transverse atlantal ligament injury and C1–2 instability should be suspected. Additionally, the posterior cortical bone of the atlas and the anterior cortical bone of the axis should form parallel lines, and if the space available for the cord (SAC) between the posterior cortical bone of the odontoid process and the anterior cortical bone of the posterior arch of the atlas is 13 mm or less, it is defined as a narrow spinal canal (**Figure 1**).

Through open mouth view (open mouth view) and coronal CT, if the lateral mass displacement on both sides is 7 mm or more based on the relationship of the odontoid process, lateral mass of C1, and the odontoid process, transverse ligament injury can be suspected (rule of Spence) (**Figure 2**). After these initial screening tests and evaluations, further assessments should be conducted. It is also important to note that the information obtained from flexion-extension radiographs in trauma patients is limited and may actually increase the risk of neurological damage, so it is not recommended [8].

Other imaging tests along with CT scans are the primary diagnostic test for cervical spine injuries along with plain radiographs. MRI may also be used to evaluate spinal cord injury and cervical spine anatomy. MRI is difficult to obtain if neurological deficits are present, a spinal cord contrast CT may be performed.

Figure 1. Cervical computed tomography and magnetic resonance imaging (midsagittal cut). Dotted line: Wackenheim line, red line: McRae line, blue line: McGregor line, yellow line: atlanto-dens interval (ADI), black arrow: space available for the cord (SAC).

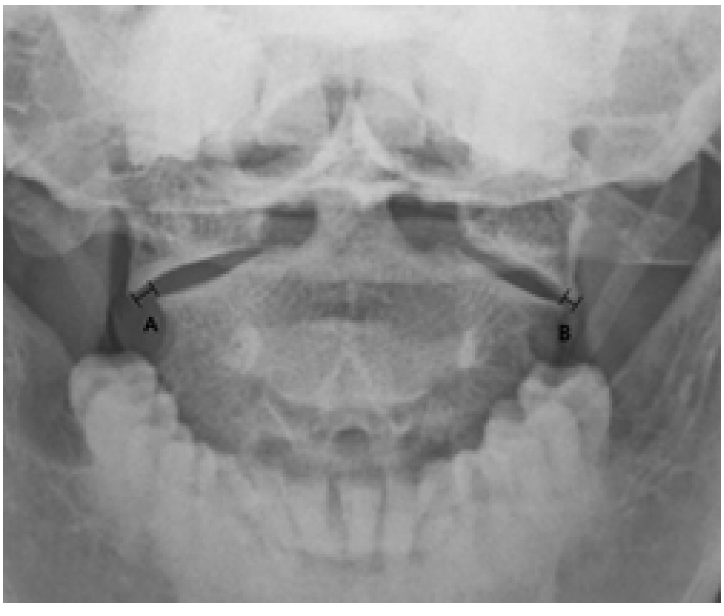

Figure 2. Cervical open-mouth view. The sum of A and B is the lateral mass displacement.

3. Diagnosis and treatment according to injury

3.1. Occipital condyle fracture

To diagnose an odontoid process fracture, cervical CT is used as the primary examination, and plain radiographs can also be referenced, although they are relatively less sensitive. Anderson and Montesano classified odontoid process fractures into the following three types (I: Impacted type; II: Fracture involving the base of the skull; III: Avulsion fracture of the alar ligament) [9]. Types I and II are generally stable and can be treated conservatively by wearing a rigid cervical brace for 6–8 weeks. For type III, it is necessary to confirm whether there is instability indicating cranio-cervical dissociation. If there is no cranio-cervical dissociation, a halo vest can be worn for 12 weeks. If dissociation is present, it is an indication for surgery, and occipitocervical fusion can be performed. Therefore, the presence of a type III fracture alone is not an indication for surgery; rather, the confirmation of associated dissociation should be considered for surgical intervention.

Meanwhile, in a study by Van der Burg *et al.*, the union rate, clinical outcomes (Neck Disability Index, NDI; Neck Pain and Disability Scale, NPAD), and range of motion were analyzed for 39 patients with fractures of the odontoid process (Type I: 4, Type II: 16, Type III: 19) [10]. Among the 39 patients, no significant differences were found in NDI (P = 0.34 & 0.98) and NPAD (P = 0.44 & 0.46) based on the classification and treatment. Additionally, there were no significant differences in the range of motion when comparing isolated odontoid fractures with those accompanied by cervical fractures. Except for one patient, all 25 patients who completed radiographic follow-up showed bone union at the final follow-up. Therefore, the study concluded that conservative treatment of odontoid process fractures, regardless of the fracture type, results in satisfactory bone union and clinical outcomes. The Anderson classification was reported to have little clinical relevance.

3.2. Atlantooccipital dislocation

Diagnosis of atlantooccipital dislocation can be made by measuring Power's ratio and the basion-axis interval (BAI) and basion-dens interval (BDI) on CT. The basion-dens interval, which is the distance between the basion and the tip of the odontoid process, is considered normal if it is 12 mm or less. Similarly, the basion-axis interval, which is the vertical distance from the basion to the anterior cortex of the axis, is also considered normal if it is 12 mm or less. If either the BAI or BDI exceeds 12 mm, dislocation should be suspected. Additionally, a Power's ratio of 0.9 or less on CT may indicate anterior dislocation of the atlantooccipital joint (**Figure 3**). In cases of severe occipitocervical joint dislocation with neurological deficits, reduction and the application of a halo vest may be performed, but this is only for temporary stabilization and surgical fixation will be required later. The halo vest should be applied carefully to avoid excessive traction. According to Traynelis' classification, type I is anterior displacement, type II is vertical displacement, and type III is posterior displacement.

Figure 3. (A) Basion-dens interval (BDI), Basion-axis interval (BAI). (B) Power's ratio: AB/CD (A: basion, B: posterior spinolaminar line of the atlas, C: opisthion, D: anterior arch of the atlas).

Harborview classification focuses more on the degree of instability rather than the direction of displacement and divides it into three categories with therapeutic implications. Type 1 involves minimal or no displacement and is typically unilateral; in such cases, it may be deemed sufficient to treat with orthoses, as ligamentous support to maintain occipitocervical alignment is considered adequate. Type 2 injuries show positive traction testing (partial or complete), indicating instability requiring surgical fixation. Type 3 injuries exhibit severe instability with malalignment of the occipitocervical junction (greater than 2 mm deviation from normal ranges in BAI and BDI). In these cases, there is a high mortality rate and often significant neurological deficits. Surgery requires posterior fixation from the occiput to at least C2 [11].

Furthermore, if a craniocervical dislocation is confirmed, vascular injury assessment is necessary. In a study by Kazemi *et al.*, among 28 patients with craniocervical dislocation, 14 had cerebrovascular injuries, with a total of 25 cerebrovascular injuries reported (12 carotid artery injuries and 13 vertebral artery injuries) [12]. Depending on the presence of cerebrovascular injuries, preoperative and postoperative management and surgical plans may change. Therefore, it is necessary to evaluate cerebrovascular injuries, such as through angiography, in patients suspected of having such injuries (**Figure 4**).

Figure 4. A 63-year-old man who had been in a motorcycle accident. The image shows the dislocation of the occipital condyle.

3.3. Atlas fracture

Degeneration of the zygapophyseal joints can cause a fracture of the articular process and may injure the transverse ligament, leading to transverse atlantal ligament (TAL) disruption. Falls are the most common cause, and spinal cord injury at C1 is rare due to the wider spinal canal at this level. It is associated with other cervical spine injuries in 50% of cases, with the hangman's fracture being the most frequent. Diagnosis involves open-mouth radiographs and CT scans of the facet joints, measuring the degree of lateral displacement of the C1 lateral masses relative to C2. A total lateral mass displacement (LMD) of more than 7 mm raises suspicion of TAL injury, while less than 5.7 mm suggests a lower likelihood of TAL injury (**Figure 2**). However, Woods *et al.* evaluated the accuracy of the "rule of Spence" through 11 cadaveric studies, finding that an average lateral mass displacement of 3.2 mm (± 1.2 mm) observed in experiments using high-resolution/high-speed cameras resulted in TAL injury, and analysis showed a significant likelihood of TAL injury when lateral mass displacement exceeded 3.8 mm ($P < 0.001$). Therefore, lateral mass displacement is not a reliable independent indicator of TAL injury, and diagnosis through MRI should take precedence over it, utilizing it as a supplementary measure [13].

When there is a single transverse process fracture and no damage to the transverse process ligament, stability can be assessed, so evaluation of the transverse process ligament is essential in determining the treatment plan. Evaluation of the transverse process ligament is necessary for determining the treatment plan because if there is no damage to the transverse process ligament in the case of a sole transverse process fracture, stability can be assessed. Evaluation of the ligament and confirmation of injuries such as avulsion fractures by MRI and CT are necessary. If the type of fracture is stable and the transverse process ligament is intact, conservative treatment with a rigid brace can be performed for 6–12 weeks. When a transverse process ligament tear is confirmed, surgical treatment is indicated, and fusion surgery can be performed. There have been reported cases of satisfactory results without fusion of the upper cervical spine through compression osteosynthesis using C1 lateral mass screws in cases of unstable Jefferson fractures, but a long-term follow-up analysis is required (**Figure 5**) [14].

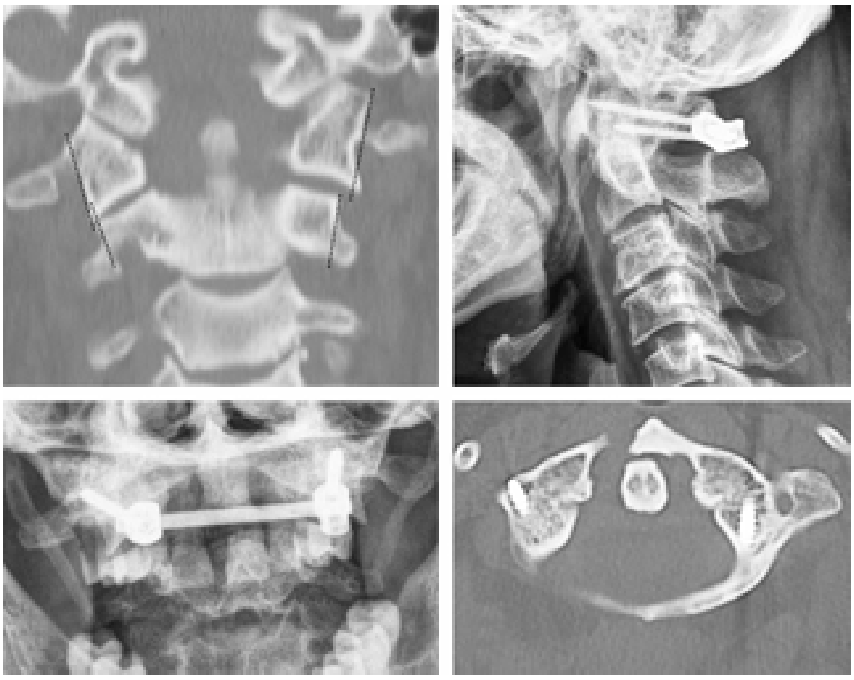

Figure 5. A 59-year-old woman who had been in a slip-down injury. The image shows rupture of the transverse atlantal ligament and lateral mass displacement. Compressive reduction and osteosynthesis using C1 lateral mass screw fixation were performed.

3.4. Transverse annulus ligament damage

Injuries and head trauma resulting from overestimation and falls primarily occur when the occiput hits the ground. In cervical spine curvature images, if the occipital-atlantal interval is between 5 to 10 mm, transverse atlantal ligament (TAL) injury is diagnosed, while if it is above 10 mm, TAL rupture is diagnosed and requires surgical intervention. According to the classification by Dickman using horizontal plane CT, type 1 involves a rupture of the TAL itself and requires surgical stabilization via C1–2 fusion, while type 2 involves a lateral mass fracture of C1 and can be treated conservatively with Halo vest application (**Figure 6**).

3.5. Atlantoaxial rotatory subluxation

Three types of instability in the subaxial cervical spine are recognized. Type A is characterized by rotational subluxation in the horizontal plane, type B involves translational instability due to lateral facet injury, and type

C involves bilateral facet dislocation with vertical instability. Each type may also exhibit overlapping features. Type A is predominantly non-traumatic and presents with rotational subluxation. Subaxial cervical spine rotational subluxation is classified into four categories by Fielding & Hawkins classification, characterized by symptoms such as dysphagia and limitation of cervical motion range (**Figure 7**). Subluxation is asymmetrically projected on simple radiographs, showing a typical "winking sign" which aids in diagnosis [15]. Treatment includes wearing a cervical collar for one week followed by one week of bed rest if onset is less than a week, hospitalization with halo traction and cervical collar for 4–6 weeks if it persists for 1–4 weeks, and possible fusion if it lasts for more than 4 weeks. If conservative management fails, surgical intervention through a posterior approach may be necessary (**Figure 8**).

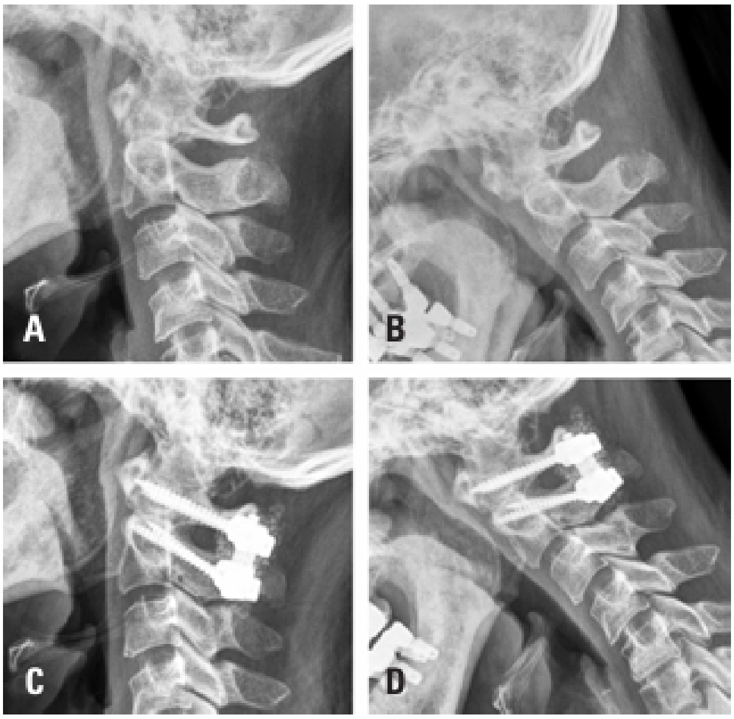

Figure 6. Plain radiographs of a 48-year-old woman after a pedestrian traffic accident. (A, B) Preoperative flexion and extension view. The atlas-dens interval was increased on the flexion view. (C, D) Postoperative flexion and extension view. Stabilized atlas-dens interval is noted.

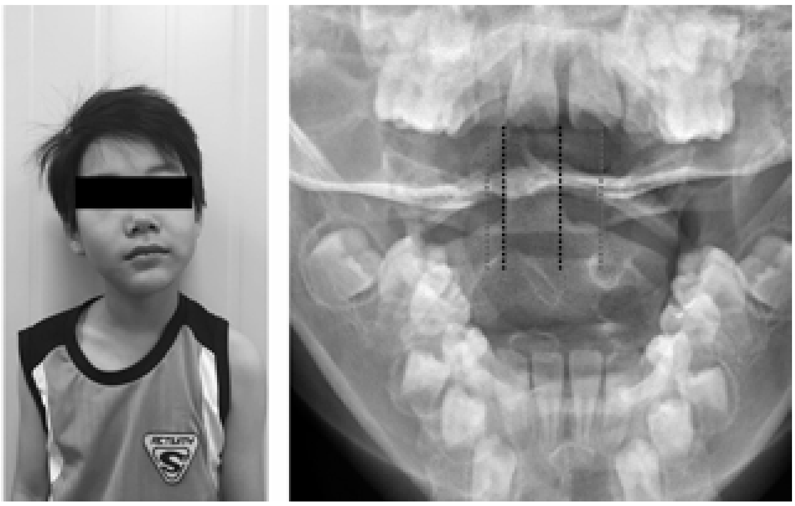

Figure 7. An 8-year-old boy with an asymmetric posture due to atlantoaxial rotatory subluxation.

Figure 8. Holter traction for atlantoaxial rotatory subluxation.

3.6. Odontoid fracture

Odontoid fractures account for 10–15% of all cervical spine injuries, and 75% of pediatric cervical spine injuries. Mechanistically, anterior displacement is observed in flexion injuries, while posterior displacement is observed in extension injuries. According to Anderson and D'Alonso, it can be classified into three types. Type 1 is an oblique fracture at the spinous process of the odontoid due to avulsion of the supraspinous ligament. Type 2 involves a fracture through the body of the odontoid with a high risk of nonunion due to vascular compromise. Especially when the displacement is more than 5 mm, angulation is more than 10 degrees, there is posterior displacement, or the patient is over 50 years old, the risk of nonunion is high. Type 2 fractures can be further classified according to the direction of the fracture line using the Grauer classification. Type 2A has no or minimal displacement and no comminution, 2B has a fracture line extending from anterior to posterior, and 2C has a fracture line extending from anterior to posterior. Anterior screw fixation is indicated for type 2B fractures, while posterior fusion is indicated for type 2C fractures (**Figure 9**). Contraindications for anterior screw fixation include type 2C fractures, concurrent unstable vertebral fractures, suspicion of pathological fractures, and nonunion of odontoid fractures. Type 3 involves an extension fracture to the C2 vertebral body, which can occur at various locations in the C1–2 joint complex, with a 90% union rate with conservative treatment.

On the other hand, in a study by Andre *et al.*, despite the conservative treatment using a halo vest, there is still a high rate of non-union in the elderly. Therefore, for the elderly, fixation surgery using two screws is also recommended to reduce the possibility of non-union. Additionally, after assessing the fracture status and vertebral artery, C1–2 fusion surgery may also be considered [16,17].

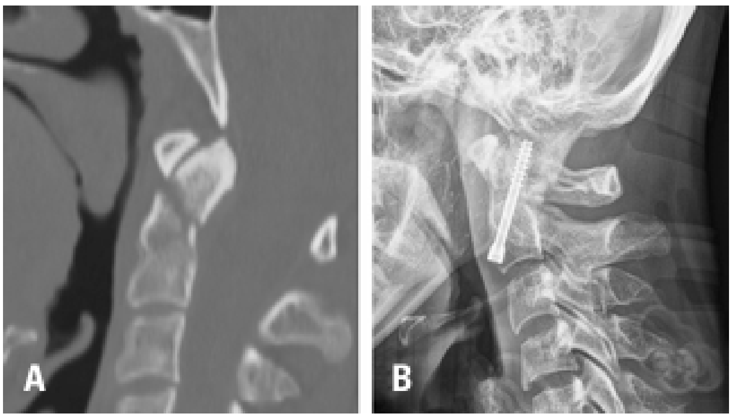

Figure 9. A 37-year-old woman who had been in a fall down injury. (A) Type IIB odontoid fracture. (B) Postoperative radiograph of anterior screw fixation.

3.7. Traumatic spondylolisthesis of the axis

Traumatic spondylolisthesis of the axis is the second most common axis fracture (38%) and generally occurs due to hyperextension and axial loading. It is also called Hangman's fracture and involves bilateral pedicle fractures of the axis with separation of the axis pedicle and body [18]. According to the classification by Levine and Edwards, Type 1 exhibits minimal displacement (< 3 mm) and typically requires rigid cervical collar immobilization for 12 weeks. Type 2 involves horizontal displacement of 3 mm or more accompanied by angulation, resembling Type 1 on lateral views but showing more than 3 mm of displacement on upright radiographs after collar application, necessitating treatment with a halo vest for 12 weeks. Type 2A is a flexion-distraction injury without horizontal displacement but with a horizontal fracture line, potentially with more posterior displacement and possible C2–3 disc and posterior longitudinal ligament injuries. Treatment involves conservative management with a halo vest for 12 weeks. Type 3 involves C2–3 facet dislocation, often requiring surgical intervention as closed reduction is not achievable. Surgery involves posterior approach reduction of the dislocated facet followed by fusion of C1–3 or C2–3. Preoperative MRI evaluates disc injury, and if present, anterior discectomy and fusion followed by posterior reduction can be performed [19-21].

4. Conclusion

To diagnose and treat various upper cervical injuries effectively, understanding the correlation between adjacent soft tissues and osseous structures is necessary. Based on this understanding, establishing a treatment direction is essential. Additionally, anticipating fatal outcomes through early appropriate screening tests is crucial.

Disclosure statement

The authors declare no conflict of interest.

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